2018.1

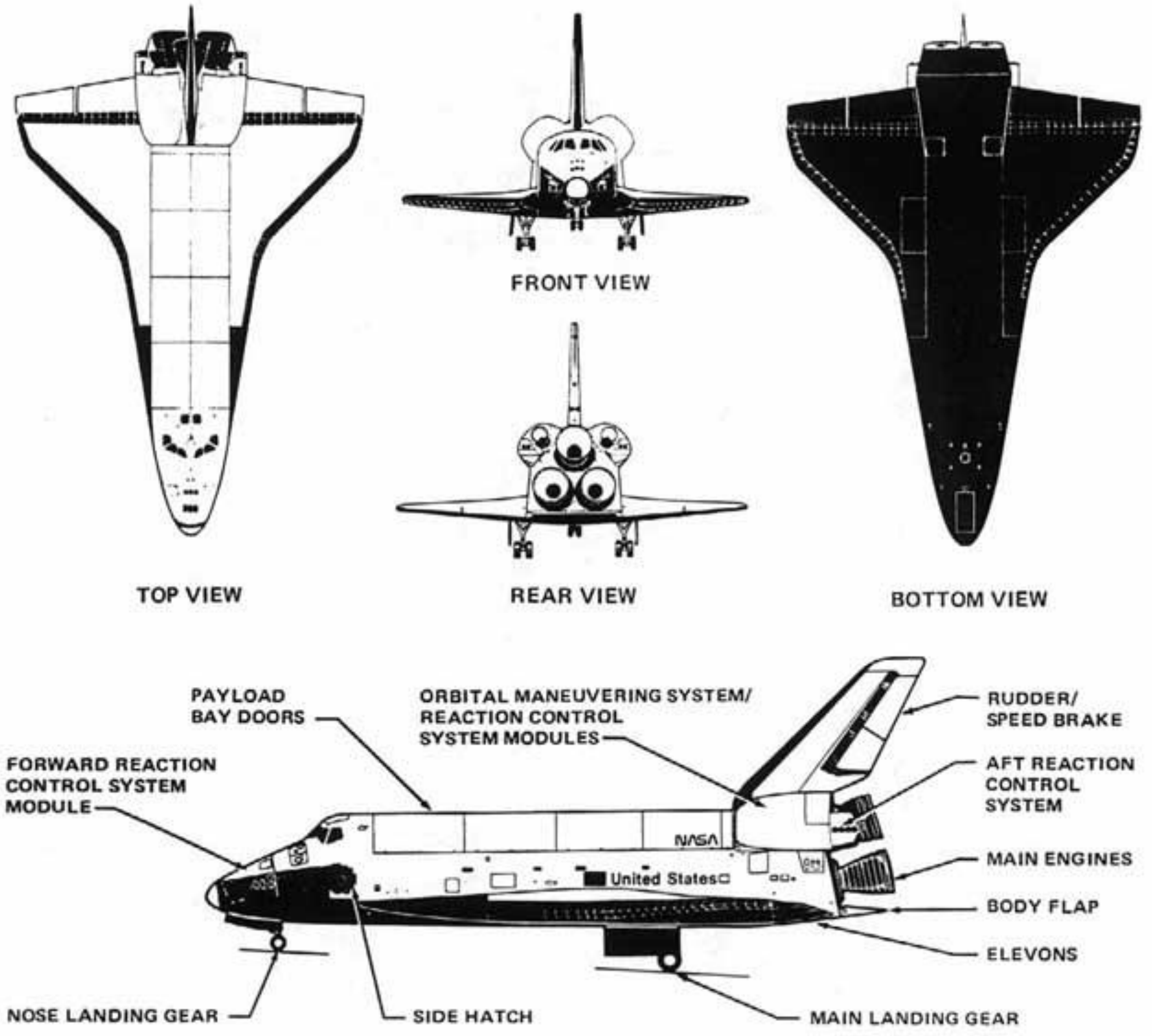
STUDENT
ASTRONAUT
CHALLENGE

2018 Student Manual

Directory

CHAPTER 1

The Space Shuttle



DIMENSIONS AND WEIGHT

WING SPAN	23.79 m	(78.06 FT)
LENGTH	37.24 m	(122.17 FT)
HEIGHT	17.25 m	(56.58 FT)
TREAD WIDTH	6.91 m	(22.67 FT)
GROSS TAKEOFF WEIGHT		VARIABLE
GROSS LANDING WEIGHT		VARIABLE
INERT WEIGHT (APPROX)	74 844 kg	(165 000 LB)

MINIMUM GROUND CLEARANCES

BODY FLAP (AFT END)	3.68 m	(12.07 FT)
MAIN GEAR (DOOR)	0.87 m	(2.85 FT)
NOSE GEAR (DOOR)	0.90 m	(2.95 FT)
WINGTIP	3.63 m	(11.92 FT)

Introduction

The space shuttle was the world's first reusable spacecraft and the first spacecraft in history that could carry large satellites both to and from orbit. The shuttle launches like a rocket, maneuvers in Earth orbit like a spacecraft and lands like an airplane.

Because of these requirements the Shuttle was shaped to look like an aircraft but to operate as a spacecraft. The structure of the Shuttle Orbiter comprises nine separate sections, or elements: the forward fuselage, the forward reaction control system module, the mid-fuselage, the payload bay doors, the aft fuselage, the vertical tail, the two orbital maneuvering system/reaction control modules and the wing.

The demands are greater than is usually the case with a conventional aircraft because the stresses imposed upon the structure are unique to the Shuttle. Because of this, the design team at North American Aviation had no precedents on which to base their prototype. It was the first of its kind, without the advantage of any previous learning curve, and one of a kind without parallel.

Columbia was the first space shuttle orbiter to be delivered to NASA's Kennedy Space Center, Fla., in March 1979. Columbia and the STS-107 crew were lost Feb. 1, 2003, during re-entry. The orbiter Challenger was delivered to KSC in July 1982 and was destroyed in an explosion during ascent in January 1986. Discovery was delivered in November 1983. Atlantis was delivered in April 1985. The Endeavor was built as a replacement following the Challenger accident and was delivered to Florida in May 1991. An early space shuttle orbiter, the Enterprise, never flew in space but was used for approach and landing tests at the Dryden Flight Research Center and several launch pad studies in the late 1970s.

A typical shuttle mission lasts seven to eight days but can extend to as much as 14 days depending upon the objectives of the mission.

Launching the Space Shuttle

To lift the 4.5 million-pound (2.05 million kg) shuttle from the pad to orbit (115 to 400 miles/185 to 643 km) above the Earth, the shuttle uses the following components:

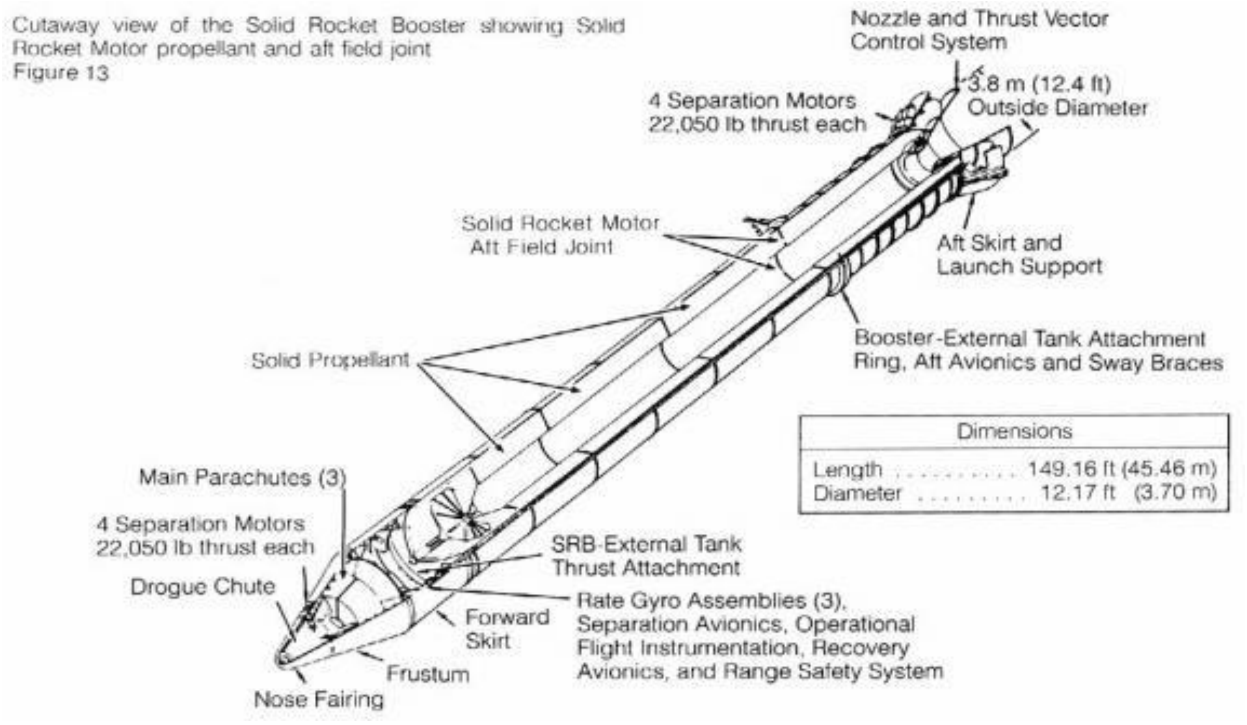
- two solid rocket boosters (SRB)
- three main engines of the orbiter
- the external fuel tank (ET)
- orbital maneuvering system (OMS) on the orbiter

Solid Rocket Boosters

The SRBs are solid rockets that provide most of the main force or thrust (71 percent) needed to lift the space shuttle off the launch pad. In addition, the SRBs support the entire weight of the space shuttle orbiter and fuel tank on the launch pad. Each SRB has the following parts:

- •solid rocket motor - case, propellant, igniter, nozzle
- •solid propellant fuel - atomized aluminum (16 percent) oxidizers - ammonium perchlorate (70 percent) catalyst - iron oxide powder (0.2 percent) binder - polybutadiene acrylic acid acrylonite (12 percent) curing agent - epoxy resin (2 percent)
- •jointed structure
- •synthetic rubber O-rings between joints
- •flight instruments
- •recovery systems parachutes (drogue, main) floatation devices signaling devices
- •explosive charges for separating from the external tank
- •thrust control systems
- •self-destruct mechanism

Because the SRBs are solid rocket engines, once they are ignited, they cannot be shut down. Therefore, they are the last component to light at launch.

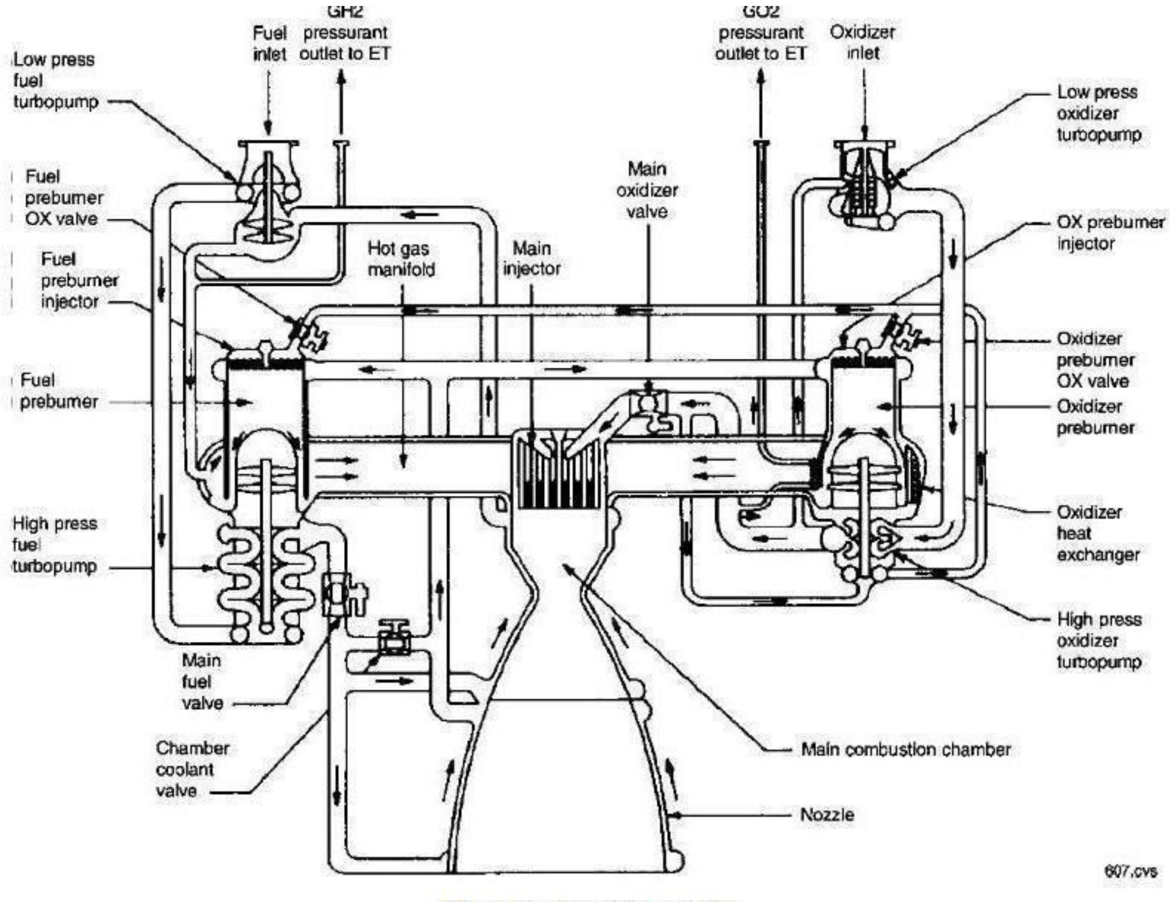


Cutaway view of the Solid Rocket Booster showing Solid Rocket Motor propellant and aft field joint
Figure 13

Main Engines

The orbiter has three main engines located in the aft (back) fuselage (body of the spacecraft). Each engine is 14 feet (4.3 m) long, 7.5 feet (2. 3 m) in diameter at its widest point (the nozzle) and weighs about 6,700 lb (3039 kg).

The main engines provide the remainder of the thrust (29 percent) to lift the shuttle off the pad and into orbit. The main engines burn liquid hydrogen and liquid oxygen as fuel which is stored in the external fuel tank (ET), at a ratio of 6:1. They draw liquid hydrogen and oxygen from the ET at an amazing rate, equivalent to emptying a family swimming pool every 10 seconds! The fuel is partially burned in a pre-chamber to produce high pressure, hot gases that drive the turbo-pumps (fuel pumps). The fuel is then fully burned in the main combustion chamber, and the exhaust gases (water vapor) leave the nozzle at approximately 6,000 mph (10,000 km/h). Each engine can generate between 375,000 and 470,000 lb (1,668,083 to 2,090,664 N) of thrust; the rate of thrust can be controlled from 65 percent to 109 percent maximum thrust. The engines are mounted on gimbals (round bearings) that control the direction of the exhaust, which controls the forward direction of the rocket



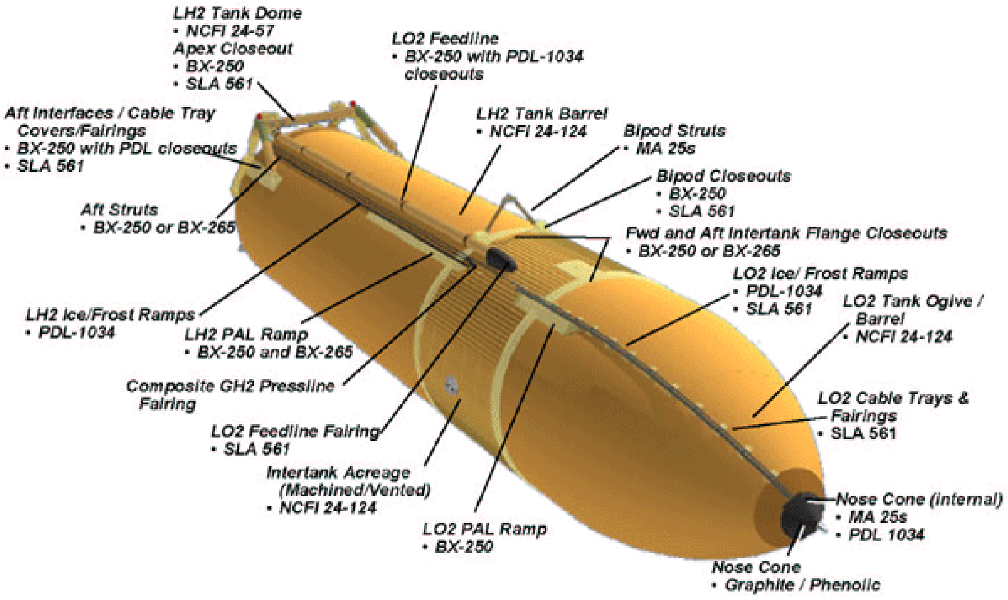
Main Engine Schematic

External Fuel Tank

As mentioned above, the fuel for the main engines is stored in the ET. The ET is 158 ft (48 m) long and has a diameter of 27.6 ft (8.4 m). When empty, the ET weighs 78,000 lb (35,455 kg). It holds about 1.6 million lb (719,000 kg) of propellant with a total volume of about 526,000 gallons (2 million liters).

The ET is made of aluminum and aluminum composite materials. It has two separate tanks inside, the forward tank for oxygen and the aft tank for hydrogen, separated by an inter-tank region. Each tank has baffles to dampen the motion of fluid inside. Fluid flows from each tank through a 17-inch (43 cm) diameter feed line out of the ET through an umbilical line into the shuttle's main engines. Through these lines, oxygen can flow at a maximum rate of 17,600 gallons/min (66,600 l/min) and hydrogen can flow at a maximum rate of 47,400 gallons/min (179,000 l/min).

The ET is covered with a 1-inch (2.5 cm) thick layer of spray-on, polyisocyanurate foam insulation. The insulation keeps the fuels cold, protects the fuel from the heat that builds upon the ET skin in flight, and minimizes ice formation. When Columbia launched in 2003, pieces of the insulating foam broke off the ET and damaged the left wing of the orbiter, which ultimately caused Columbia to break up upon re-entry.

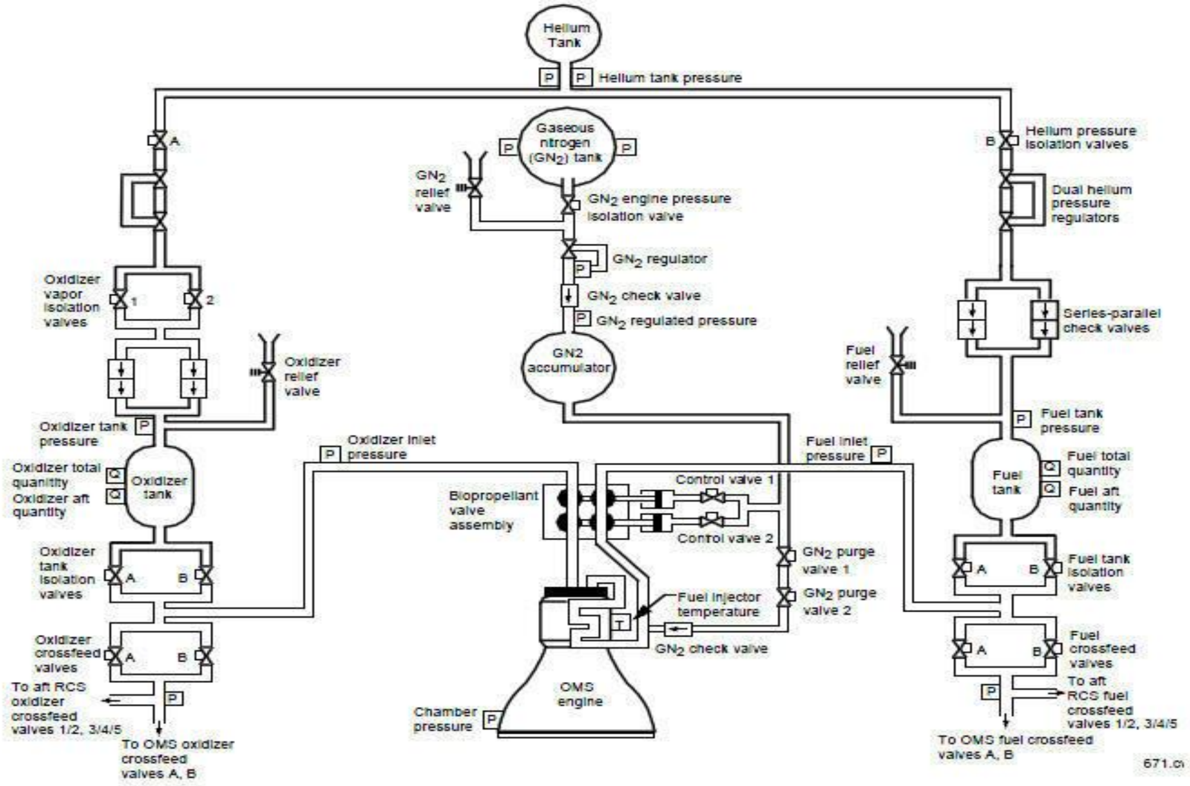


Space Shuttle Liftoff

The two orbital maneuvering systems' (OMS) engines are located in pods on the aft section of the orbiter, one on either side of the tail. These engines place the shuttle into final orbit, change the shuttle's position from one orbit to another, and slow the shuttle down for re-entry.

The OMS engines burn monomethyl hydrazine fuel (CH_3NHNH_2) and nitrogen tetroxide oxidizer (N_2O_4). Interestingly, when these two substances come in contact, they ignite and burn automatically (i.e., no spark required) in the absence of oxygen. The fuel and oxidizer are kept in separate tanks, each pressurized by helium. The helium pushes the fluids through the fuel lines (i.e., no mechanical pump required). In each fuel line, there are two spring-loaded solenoid valves that close the lines. Pressurized nitrogen gas, from a small tank located near the engine, opens the valves and allows the fuel and oxidizer to flow into the combustion chamber of the engine. When the engines shut off, the nitrogen goes from the valves into the fuel lines momentarily to flush the lines of any remaining fuel and oxidizer; this purge of the line prevents any unwanted explosions. During a single flight, there is enough nitrogen to open the valves and purge the lines 10 times!

Either one or both of the OMS engines can fire, depending upon the orbital maneuver. Each OMS engine can produce 6,000 lb (26,400 N) of thrust. The OMS engines together can accelerate the shuttle by 2 ft/s^2 (0.6 m/s^2). This acceleration can change the shuttle's velocity by as much as 1,000 ft/s (305 m/s). To place into orbit or to de-orbit takes about 100-500 ft/s (31-153 m/s) change in velocity. Orbital adjustments take about 2 ft/s (0.61 m/s) change in velocity. The engines can start and stop 1,000 times and have a total of 15 hours of burn time.



Orbital Maneuvering System Pressurization and Propellant Feed System for One Engine (other Engine Identical)

Profile of shuttle launch and ascent into orbit

As the shuttle rests on the pad fully fueled, it weighs about 4.5 million pounds or 2 million kg. The shuttle rests on the SRBs as pre-launch and final launch preparations are going on through T minus 31 seconds:

1. T minus 31 s - the onboard computers take over the launch sequence.

2. T minus 6.6 s - the shuttle's main engines ignite one at a time (0.12 s apart). The engines build up to more than 90 percent of their maximum thrust.

3. T minus 3 s - shuttle main engines are in lift-off position.

4. T minus 0 s -the SRBs are ignited, and the shuttle lifts off the pad.

5. T plus 20 s - the shuttle rolls right (180-degree roll, 78-degree pitch).

6. T plus 60 s - shuttle engines are at maximum throttle.

7. T plus 2 min - SRBs separate from the orbiter and fuel tank at an altitude of 28 miles (45 km). Main engines continue firing. Parachutes deploy from the SRBs. SRBs will land in the ocean about 140 miles (225 km) off the coast of Florida. Ships will recover the SRBs and tow them back to Cape Canaveral for processing and re-use.

8. T plus 7.7 min - main engines throttled down to keep acceleration below 3g's so that the shuttle does not break apart.

9. T plus 8.5 min - main engine shut down.

10. T plus 9 min - ET separates from the orbiter. The ET will burn up upon re-entry.

11. T plus 10.5 min - OMS engines fire to place the shuttle in a low orbit.

12. T plus 45 min - OMS engines fire again to place the shuttle in a higher, circular orbit (about 250 miles/400 km).

Orbiter in Space

Once in space, the shuttle orbiter can be the home for astronauts for seven to 14 days. The orbiter can be oriented so that the cargo bay doors face toward the Earth or away from the Earth depending upon the mission objectives; in fact, the orientation can be changed throughout the mission. One of the first things that the commander will do is to open the cargo bay doors to cool the orbiter.

The orbiter consists of the following parts:

- crew compartment - where astronauts live and work
- forward fuselage (upper, lower parts) - contains support equipment (fuel cells, gas tanks) for the crew compartment
- forward reaction control system (RCS) module - contains forward rocket jets for turning the orbiter in various directions
- movable airlock - used for spacewalks and can be placed inside the crew compartment or inside the cargo bay

- mid-fuselage: contains essential parts (gas tanks, wiring, etc.) to connect the crew compartment with the aft engines; forms the floor of the cargo bay
- cargo bay doors - the roof of the cargo bay and essential for cooling the orbiter
- remote manipulator arm - located in the cargo bay: moves large pieces of equipment in and out of the cargo bay; a platform for spacewalking astronauts
- aft fuselage - contains the main engines
- OMS/RCS pods (2) - contain the orbital maneuvering engines and the aft RCS module; turn the orbiter and change orbits
- airplane parts of the orbiter - fly the shuttle upon landing (wings, tail, body flap)

The crew compartment is located in the forward fuselage. The crew compartment has 2,325 cu.ft. of space with the airlock inside or 2,625 cu.ft with the airlock outside. The crew compartment has three decks:

<u>Flight deck - uppermost deck</u>

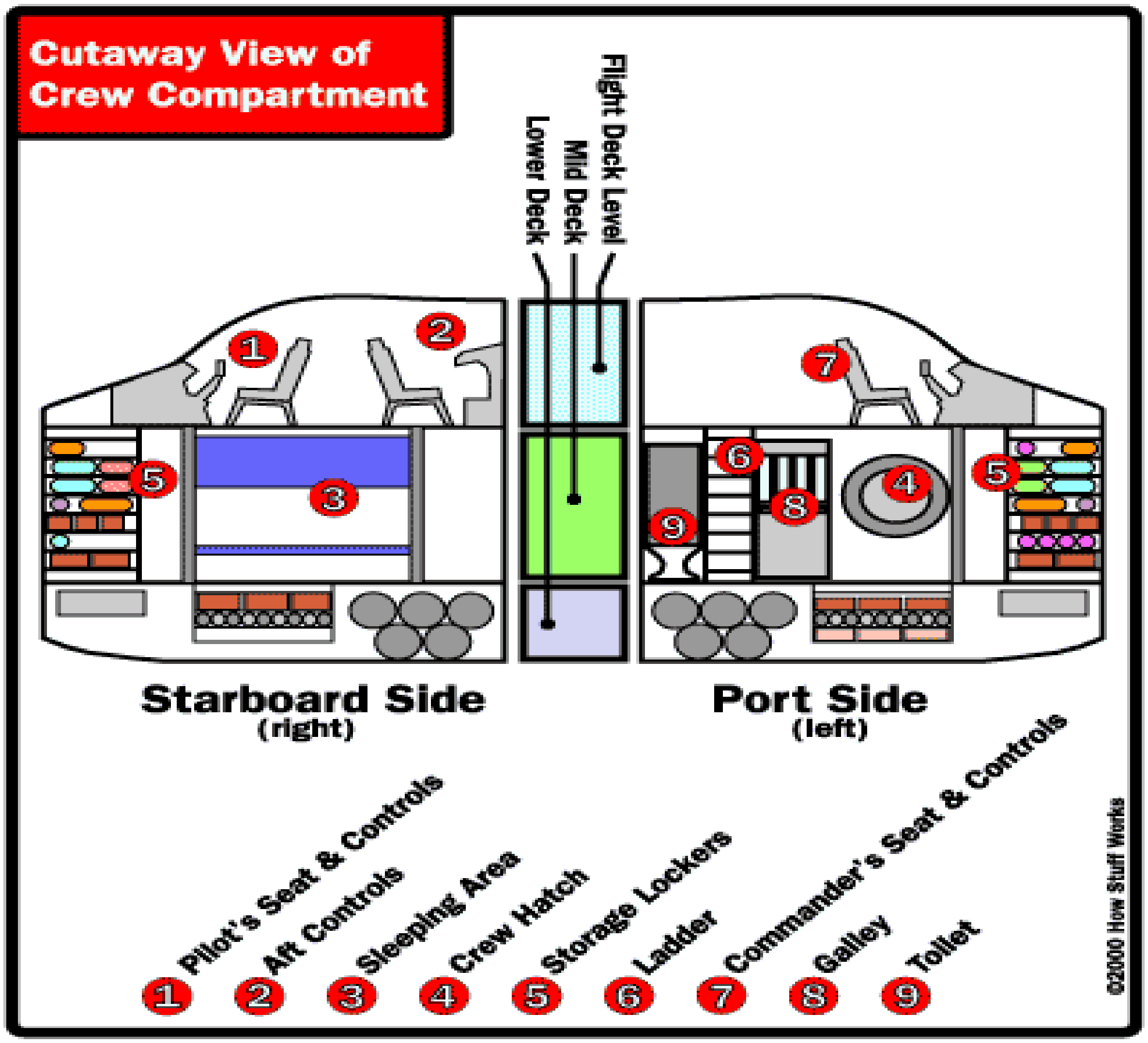
- forward deck - contains all of the controls and warning systems for the space shuttle (also known as the cockpit)
- seats - commander, pilot, specialist seats (two)
- aft deck - contains controls for orbital operations: maneuvering the orbiter while in orbit (rendezvous, docking, deploying a payload, and working the remote manipulator arm)

<u>Mid-deck</u>

- living quarters (galley, sleeping bunks, toilet)
- stowage compartments (personal gear, mission-essential equipment, experiments)
- exercise equipment
- airlock - on some flights
- entry hatch

<u>lower deck</u> (equipment bay)

- contains life support equipment, electrical systems, etc..



Living Environment

The shuttle orbiter provides an environment where astronauts can live and work in space. The shuttle provides the following:

- life support - atmosphere control, supply, and recycling; water; temperature control; light; food supply; waste removal; fire protection
- ability to change position and change orbits
- capability to talk with ground-based flight controllers (communications and tracking)
- stellar navigation to find its way around in orbit
- make its own electrical power
- coordinate and handle information (computers)

- base from which to launch/retrieve satellites; construction - such as building the International Space Station and conduct experiments

The orbiter must provide astronauts with an environment similar to Earth. The shuttle must have air, food, water, and a comfortable temperature. The orbiter must also take away the wastes products produced by the astronauts (carbon dioxide, urine, feces) and protect them from fire

Our atmosphere is a mixture of gases (78 percent nitrogen, 21 percent oxygen, 1 percent other gases) at a pressure of 14 lbs/in^2 (1 atm) that we breathe in and out. The space shuttle must provide a similar atmosphere. To do this, the orbiter carries liquid oxygen and liquid nitrogen in two systems of pressurized tanks, which are located in the mid-fuselage (each system has two tanks for a total of four tanks). The cabin pressurization system combines the gases in the correct mixture at normal atmospheric pressure. While in orbit, only one oxygen-nitrogen system is used to pressurize the orbiter. During launch and landing, both systems of each gas are used.

- Five loops of fans circulate the atmosphere. The circulated air picks up carbon dioxide, heat, and moisture:
- Chemical carbon dioxide canisters remove carbon dioxide by reacting it with lithium hydroxide. These canisters are located in the lower deck of the crew compartment and are changed every 11 hours.
- Filters and charcoal canisters remove trace odors, dust and volatile chemicals from leaks, spills, and outgassing.
- A cabin heat exchanger in the lower deck cools the air and condenses the moisture, which collects in a slurper. Water from the slurper is moved with air to a fan separator, which uses centrifugal force to separate water from the air. The air is re-circulated, and the water goes to a wastewater tank.

Besides air, water is the most important quantity aboard the orbiter. Water is made from liquid oxygen and hydrogen in the space shuttle's fuel cells (the fuel cells can make 25 lb (11 kg) of water per hour). The water passes through a hydrogen separator to eliminate any trapped hydrogen gas (excess hydrogen gas is dumped overboard). The water is then stored in four water storage tanks located in the lower deck. Each tank can hold 165 lb (75 kg).

The water tanks are pressurized by nitrogen so that water can flow to the mid-deck for use by the crew. Drinkable water is then filtered to remove microbes and can be warmed or chilled through various heat exchangers depending upon the use (food preparation, consumption, personal hygiene). Excess water produced by the fuel cells gets routed to a wastewater tank and subsequently dumped overboard.

Outer space is an extremely cold environment, and temperatures will vary drastically in different parts of the orbiter. You might think that heating the orbiter would be a problem. However, the electronic equipment generates more than enough heat for the ship. The problem is getting rid of the excess heat. So the temperature control system has to carry out two major functions:

> •Distribute heat where it is needed on the orbiter (mid-fuselage and aft sections) so that vital systems do not freeze in the cold of space.
>
> •Get rid of the excess heat.

The shuttle has two methods to handle temperature control:

> Passive methods - generally simple methods that handle small heat loads and require little maintenance; insulating materials (blankets), surface coatings, paints, all reduce heat loss through the walls of the various components just like home insulation. Electrical heaters - use electrically-heated wires like a toaster to heat various areas.
>
> Active methods – generally more complex, these systems use fluid to handle large heat loads and require maintenance. Cold plates are metal plates that collect heat by direct contact with equipment or conduction. Heat exchangers are used to collecting heat from equipment using fluid. The equipment radiates heat to a fluid (water, ammonia) which in turn passes heat on to Freon. Both fluids are pumped and re-circulated to remove heat. Pumps, lines, and valves transport the collected heat from one area to another.

- Radiators - located on the inside surfaces of the cargo bay doors that radiate the collected heat to outer space Flash evaporator/ammonia boilers - these devices are located in the aft fuselage and transfer heat from Freon coolant loops overboard when cargo bay doors are closed or when cargo bay radiators are overloaded.
- Flash evaporator Freon coolant loops wrap around an inner core. The evaporator sprays water on the heater core. The water evaporates removing heat. The water vapor is vented overboard. Ammonia boiler Freon coolant loops pass through a tank of pressurized ammonia. Heat released from the Freon causes the ammonia to boil. Ammonia vapor is dumped overboard.

The cabin heat exchanger also controls the cabin temperature. It circulates cool water to remove excess heat (cabin air is also used to cool electronic equipment) and transfers this heat to a Freon exchanger. The Freon then transfers the heat to other orbiter systems (e.g., cryogenic gas tanks, hydraulic systems) and radiates excess heat to outer space.

The orbiter has internal fluorescent floodlights that illuminate the crew compartment. The orbiter has external floodlights to illuminate the cargo bay. Finally, the control panels are lighted internally for easy viewing.

Food is stored on the mid-deck of the crew compartment. Food comes in several forms (dehydrated, low moisture, heat-stabilized, irradiated, natural and fresh). The orbiter has a galley-style kitchen module along the wall next to the entry hatch, which is equipped with the following:

- food storage compartments
- food warmers
- a food preparation area with warm and cold water outlets
- metal trays so the food packages and utensils do not float away

Like any home, the orbiter must be kept clean, especially in space when floating dirt and debris could present a hazard. Wastes are made from cleaning, eating, work and personal hygiene. To maintain general housecleaning, the astronauts use various wipes (wet, dry, fabric, detergent and disinfectant), detergents, and wet/dry vacuum cleaners are used to clean surfaces, filters and the astronauts themselves. Trash is separated into wet trash bags and dry trash bags, and the wet trash is placed in an evaporator that will remove the water. All trash bags are stowed in the lower deck to be returned to Earth for disposal. Solid waste from the toilet is compacted, dried and stored in bags where it is returned to Earth for disposal (burning). Liquid waste from the toilet goes to the wastewater tank where it is dumped overboard.

Fire is one of the most dangerous hazards in space. The orbiter has a Fire Detection and Suppression Subsystem that consists of the following:

- area smoke detectors on each deck
- smoke detectors in each rack of electrical equipment
- alarms and warning lights in each module
- non-toxic portable fire extinguishers (carbon dioxide-based)
- personal breathing apparatus - mask and oxygen bottle for each crew member

After a fire is extinguished, the atmosphere control system will filter the air to remove particulates and toxic substances.

Work aboard the Shuttle

The shuttle was designed to deploy and retrieve satellites as well as deliver payloads to Earth orbit. The shuttle uses the Remote Manipulator System (RMS). The RMS was built by Canada and is a long arm with an elbow and wrist joint. The RMS can be controlled from the aft flight deck. The RMS can grab payloads (satellites) from the cargo bay and deploy them or grab on to payloads and place them into the bay.

In the past, the shuttle was used for delivering satellites and conducting experiments in space. Within the mid-deck, there are racks of experiments to be conducted during each mission. When more space was needed, the mission used the Spacelab module, which was built by the European Space Agency (ESA). It fit into the cargo bay and was accessed by a tunnel from the mid-deck of the crew compartment. It provided a "shirt-sleeve" environment in which you could work. The Spacelab was lost along with Columbia in 2003. Now, most experiments are conducted aboard the International Space Station.

The shuttle's major role was to build and re-supply the International Space Station. The shuttle delivers components built on Earth. Astronauts use the RMS to remove components from the cargo bay and to help attach them to existing modules in the space station.

Space Shuttle Positioning, Communication, and Navigation

To change the direction that the orbiter is pointed (attitude), the reaction control system (RCS) located on the nose and OMS pods of the aft fuselage is used.

The RCS has 14 jets that can move the orbiter along each axis of rotation (pitch, roll, yaw). The RCS thruster’s burn monomethyl hydrazine fuel and nitrogen tetroxide oxidizer just like the OMS engines described previously. Attitude changes are required for deploying satellites or for pointing (mapping instruments, telescopes) at the Earth or stars. To change orbits (e.g., rendezvous, docking maneuvers), you must fire the OMS engines. As described above, these engines change the velocity of the orbiter to place it in a higher or lower orbit.

Tracking and Communication

The astronauts talk with flight controllers on the ground daily for the routine operation of the mission. In addition, they must be able to communicate with each other inside the orbiter or its payload modules and when conducting spacewalks outside.

NASA's Mission Control in Houston will send signals to a 60 ft. radio antenna at White Sands Test Facility in New Mexico. White Sands will relay the signals to a pair of Tracking and Data Relay satellites in orbit 22,300 miles above the Earth. The satellites will relay the signals to the space shuttle. The system works in reverse as well.

The orbiter has two systems for communicating with the ground:

- S-band - voice, commands, telemetry and data files
- Ku-band (high bandwidth) - video and transferring two-way data files

The orbiter has several intercom plug-in audio terminal units located throughout the crew compartment. Each astronaut wears a personal communications control with a headset. The communications control is battery-powered and can be switched from intercom to transmit functions. They can either push to talk and release to listen or have a continuously open communication line. To talk with spacewalkers, the system uses a UHF frequency, which is picked up in the astronaut's space suit. The orbiter also has a series of internal and external video cameras to see inside and outside.

Navigation, Power, and Computers

The orbiter must be able to know precisely where it is in space, where other objects are and how to change orbit. To know where it is and how fast it is moving, the orbiter uses global positioning systems (GPS). To know which way it is pointing (attitude), the orbiter has several gyroscopes. All of this information is fed into the flight computers for rendezvous and docking maneuvers, which are controlled in the aft station of the flight deck.

All of the onboard systems of the orbiter require electrical power. Three fuel cells make electricity; they are located in the mid-fuselage under the payload bay. These fuel cells combine oxygen and hydrogen from pressurized tanks in the mid-fuselage to make electricity and water. Like a power grid on Earth, the orbiter has a distribution system to supply electrical power to various instrument bays and areas of the ship. The water is used by the crew and for cooling.

The orbiter has five onboard computers that handle data processing and control critical flight systems. The computers monitor equipment and talk to each other and vote to settle arguments. Computers control critical adjustments especially during launch and landing:

- operations of the orbiter (housekeeping functions, payload operations, rendezvous/docking)
- interface with the crew
- caution and warning systems
- data acquisition and processing from experiments
- flight maneuvers

Pilots essentially fly the computers, which fly the shuttle. The shuttles have a Multifunctional Electronic Display Subsystem (MEDS), which is a full color, flat, 11-panel display system. The MEDS, also known as the "glass cockpit," provides graphic portrayals of key light indicators (attitude, altitude, speed). The MEDS panels are easy to read and make it easier for shuttle pilots to interact with the orbiter.

The Shuttle's Return to Earth

For a successful return to Earth and landing, dozens of things have to go just right. First, the orbiter must be maneuvered into the proper position. This is crucial to a safe landing. When a mission is finished, and the shuttle is halfway around the world from the landing site (Kennedy Space Center, Edwards Air Force Base), mission control gives the command to come home, which prompts the crew to:

1. Close the cargo bay doors. In most cases, they have been flying nose-first and upside down, so they then fire the RCS thrusters to turn the orbiter tail first.

2. Once the orbiter is tail first, the crew fires the OMS engines to slow the orbiter down and fall back to Earth; it will take about 25 minutes before the shuttle reaches the upper atmosphere.

3. During that time, the crew fires the RCS thrusters to pitch the orbiter over so that the bottom of the orbiter faces the atmosphere (about 40 degrees) and they are moving nose first again.

4. Finally, they burn leftover fuel from the forward RCS as a safety precaution because this area encounters the highest heat of re-entry.

Because it is moving at about 17,000 mph (28,000 km/h), the orbiter hits air molecules and builds up heat from friction (approximately 3000 degrees F, or 1650 degrees C). The orbiter is covered with ceramic insulating materials designed to protect it from this heat. The materials include:

- Reinforced carbon-carbon (RCC) on the wing surfaces and underside

- High-temperature black surface insulation tiles on the upper forward fuselage and around the windows

- White Nomex blankets on the upper payload bay doors, portions of the upper wing and mid/aft fuselage

- Low-temperature white surface tiles on the remaining areas

Maneuvering of the orbiter for re-entry

These materials are designed to absorb large quantities of heat without increasing their temperature very much. In other words, they have a high heat capacity. During re-entry, the aft steering jets help to keep the orbiter at its 40-degree attitude. The hot ionized gases of the atmosphere that surround the orbiter prevent radio communication with the ground for about 12 minutes (i.e., ionization blackout).

When re-entry is successful, the orbiter encounters the main air of the atmosphere and is able to fly like an airplane. The orbiter is designed from a lifting body design with swept back "delta" wings. With this design, the orbiter can generate lift with a small wing area. At this point, flight computers fly the orbiter. The orbiter makes a series of S-shaped, banking turns to slow its descent speed as it begins its final approach to the runway. The commander picks up a radio beacon from the runway (Tactical Air Navigation System) when the orbiter is about 140 miles (225 km) away from the landing site and 150,000 feet (45,700 m) high. At 25 miles (40 km) out, the shuttle's landing computers give up control to the commander. The commander flies the shuttle around an imaginary cylinder (18,000 feet or 5,500 m in diameter) to line the orbiter up with the runway and drop the altitude. During the final approach, the commander steepens the angle of descent to minus 20 degrees (almost seven times steeper than the descent of a commercial airliner).

Shuttle flight path for landing

When the orbiter is 2,000 ft. (610 m) above the ground, the commander pulls up the nose to slow the rate of descent. The pilot deploys the landing gear, and the orbiter touches down. As the commander applies the wheel brakes, the speed brake on the vertical tail is opened to help slow down the shuttle. A parachute is deployed from the back to help stop the orbiter. The parachute and the speed brake on the tail increase the drag on the orbiter. The orbiter stops about midway to three-quarters of the way down the runway.

After landing, the crew goes through the shutdown procedures to power down the spacecraft. This process takes about 20 minutes. During this time, the orbiter is cooling and noxious gases, which were made during the heat of re-entry, blow away. Once the orbiter is powered down, the crew exits the vehicle. Ground crews are on-hand to begin servicing the orbiter.

Space Shuttle Emergency Management

When an emergency occurs, it is Mission Controls responsibility to evaluate the event, triage the process, and evaluate the most important jobs that need to be accomplished. The safety of the flight crew is the primary focus of an emergency as Mission Control takes on a new series of responsibilities.

Understandably the flight crew gets very engaged after an anomaly. They want to help ensure the mission is a success and failure is a big concern. They need to be provided with frequent updates on findings and progress and participate in the evaluation of the emergency and its mitigation. This mission is very important to the flight crew but reason and balance needed to prevail.

The first concern is to “stop the bleeding”; questions naturally begin to surface about why the anomaly occurred. These queries, while important to understanding your continuing risk, should not distract the team from focusing their attention on continuing the mission and managing the problem.

Watch for Things Getting Complicated

After the anomaly, Mission Control needs to work through the data, consider responses, and to solve the problem. Teams have a tendency to create complex, multilayer solutions to mitigate the problem. Sometimes discussions work their way from one incremental fix to another, arriving at complex fixes and patches that would move the team far from its operations training and might not address the real problem. This complexity growth actually grows risk that the system will become so sophisticated it will be prone to operator error or create unforeseen interactions. In the heat of battle, there needs to be someone who keeps an eye on the risk of the solution. This is the responsibility of Mission Control; someone needs to ask, “Do we need to go that far, or can we live with just the first corrective measure?” Sometimes you need to agree that you can accept residual risk after addressing the principal problem. Missions have been lost because smart people did well-intended things that made problems worse.

Meeting the Challenge of the Emergency

The triage process must be a mix of urgency and focus, which comes from many, many operational rehearsals where the team trains for what is supposed to happen and even what is not supposed to happen. You need to focus not just on the specifics of what could go wrong, but on your behavior and process when something goes wrong.

Mission Control has many responsibilities when an emergency happens. You will have to depend on individual and team capabilities, training, and roles in ways that are hard to describe. You know that you must trust the team’s abilities and judgment, but also watch for signs, both within the team and outside, of good intentions yielding problematic results. You must be reasonable and even-handed, understanding that you cannot eliminate risk. The emergency is a time when a mission team shows what it is really made of.

Space Shuttle Abort Modes

The worst possible outcome of an Emergency is the “Mission Abort.” To meet this need, NASA developed multiple procedures to mitigate this specific possibility. A Space Shuttle abort procedure is an emergency procedure that is needed due to equipment failure on NASA's Space Shuttle, most commonly during ascent. The main engine failure was a typical abort scenario. There were fewer abort options during reentry and descent. For example, the Columbia disaster happened during reentry, and there were no alternatives in that portion of the flight.

Later in descent, certain failures were survivable, although not usually classified as an abort. For example, a flight control system problem or multiple auxiliary power unit failure would make reaching a landing site impossible, thus requiring the astronauts to bail out.

There were five abort modes available during ascent, in addition to pad (RSLS) aborts. These were divided into the categories of intact aborts and contingency aborts. The choice of abort mode depended on how urgent the situation was, and what emergency landing site could be reached. The abort modes covered a wide range of potential problems, but the most commonly expected problem was Space Shuttle Main Engine (SSME) failure, causing inability either to cross the Atlantic or to achieve orbit, depending on timing and number of failed engines. Other possible non-engine failures necessitating an abort included multiple auxiliary power unit (APU) failure, cabin leak, and external tank leak (ullage leak).

Redundant Set Launch Sequencer (RSLS) Abort

The main engines were ignited roughly 6.6 seconds before liftoff. From that point to ignition of the Solid Rocket Boosters at T - 0 seconds, the main engines could be shut down. This was called a "Redundant Set Launch Sequencer Abort," and happened five times, on STS-41-D, STS-51-F, STS-51, STS-55, and STS-68. It always happened under computer (not human) control, caused by computers sensing a problem with the main engines after starting but before the SRBs ignited. The SRBs could not be turned off once ignited, and afterward, the shuttle was committed to taking off. If an event such as an SSME failure requiring an abort happened after SRB ignition, acting on the abort would have to wait until SRB burnout 123 seconds after launch. No abort options existed if that wait was not possible.

Intact abort modes

There were four intact abort modes for the Space Shuttle. Intact aborts were designed to provide a safe return of the orbiter to a planned landing site or to a lower orbit than planned for the mission.

Return To Launch Site (RTLS)

In a Return To Launch Site (RTLS) abort, the Shuttle would have continued downrange until the solid rocket boosters were jettisoned. It would then pitch around, so the SSMEs fired retrograde. This maneuver would have occurred in a near-vacuum above the appreciable atmosphere and was conceptually no different from the OMS engines firing retrograde to de-orbit. The main engines continued burning until downrange velocity was killed and the vehicle began heading back toward the launch site at sufficient velocity to reach a runway. Afterward, the SSMEs were stopped, the external tank was jettisoned, and the orbiter made a normal gliding landing on the runway at Kennedy Space Center about 25 minutes after lift-off. The CAPCOM would call out the point in the ascent at which an RTLS was no longer possible as "negative return," approximately four minutes after lift-off.

Should all three SSMEs have failed, the shuttle would not have been able to make it back to the runway at KSC, forcing the crew to bail out. While this would have resulted in the loss of the Shuttle, the crew could escape safely and then be recovered by the SRB recovery ships.

This abort mode was never needed in the history of the Shuttle program. Astronaut Mike Mullane referred to the RTLS abort as an "unnatural act of physics," and many pilot astronauts hoped that they would not have to perform such an abort due to its difficulty.

Transoceanic Abort Landing (TAL)

A Transoceanic Abort Landing (TAL) involved landing at a predetermined location in Africa or western Europe about 25 to 30 minutes after lift-off. It was used when velocity, altitude, and distance downrange did not allow a return to the launch point via RTLS. It was also used when a less time-critical failure did not require the faster but possibly more stressful RTLS abort.

A TAL abort would be declared between roughly T+2:30 minutes (2 minutes and 30 seconds after liftoff) and Main Engine Cutoff (MECO), about T+8:30 minutes. The Shuttle would then land at a pre-designated friendly airstrip in Europe. The last four TAL sites until the Shuttle's retirement were Istres Air Base in France, Zaragoza and Morón air bases in Spain, and RAF Fairford in England. Prior to a Shuttle launch, two of them were selected depending on the flight plan, and staffed with standby personnel in case they were used. The list of TAL sites changed over time; most recently Ben Guerir Air Base in Morocco (TAL site from July 1988–June 2002) was eliminated due to terrorist attack concerns. Other previous TAL sites included Lajes Air Base, Terceira, Azores, Mallam Aminu Kano International Airport, Kano, Nigeria; Mataveri International Airport, Easter Island, Chile (for Vandenberg launches); Rota, Spain; Casablanca, Morocco; Banjul, Gambia; and Dakar, Senegal.

Preparations of TAL sites took 4 to 5 days and began a week before launch with the majority of personnel from NASA, the Department of Defense, and contractors arriving 48 hours before launch. Additionally, two C-130 aircraft from the Manned Space Flight support office from the adjacent Patrick Air Force Base including eight crew members, nine para-rescuemen, two flight surgeons, a nurse and medical technician, along with 2,500 pounds of medical equipment were deployed to either Zaragoza, Istres, or both. One or more C-21 or a C-12 aircraft were also deployed to provide weather reconnaissance in the event of an abort with a TALCOM, or astronaut flight controller aboard for communications with the shuttle pilot and commander. This abort mode was never needed during the entire history of the space shuttle program.

Abort Once Around (AOA)

An Abort Once Around (AOA) was available when the shuttle could not reach a stable orbit but had sufficient velocity to circle the earth once and land, about 90 minutes after lift-off. The time window for using the AOA abort was very short – just a few seconds between the TAL and ATO abort opportunities. Therefore, taking this option was very unlikely. This abort mode was never needed during the entire history of the space shuttle program.

Abort to Orbit (ATO)

An Abort to Orbit (ATO) was available when the intended orbit could not be reached, but a lower stable orbit was possible. This occurred on mission STS-51-F, which continued despite the abort to a lower orbit. The Mission Control Center in Houston (located at Lyndon B. Johnson Space Center) observed an SSME failure and called "Challenger--Houston, Abort ATO. Abort ATO".

The moment at which an ATO became possible was referred to as the "press to ATO" moment. In an ATO situation, the spacecraft commander rotated the cockpit abort mode switch to the ATO position and depressed the abort push button. This initiated the flight control software routines which handled the abort. In the event of lost communications, the spacecraft commander could have made the abort decision and taken action independently.

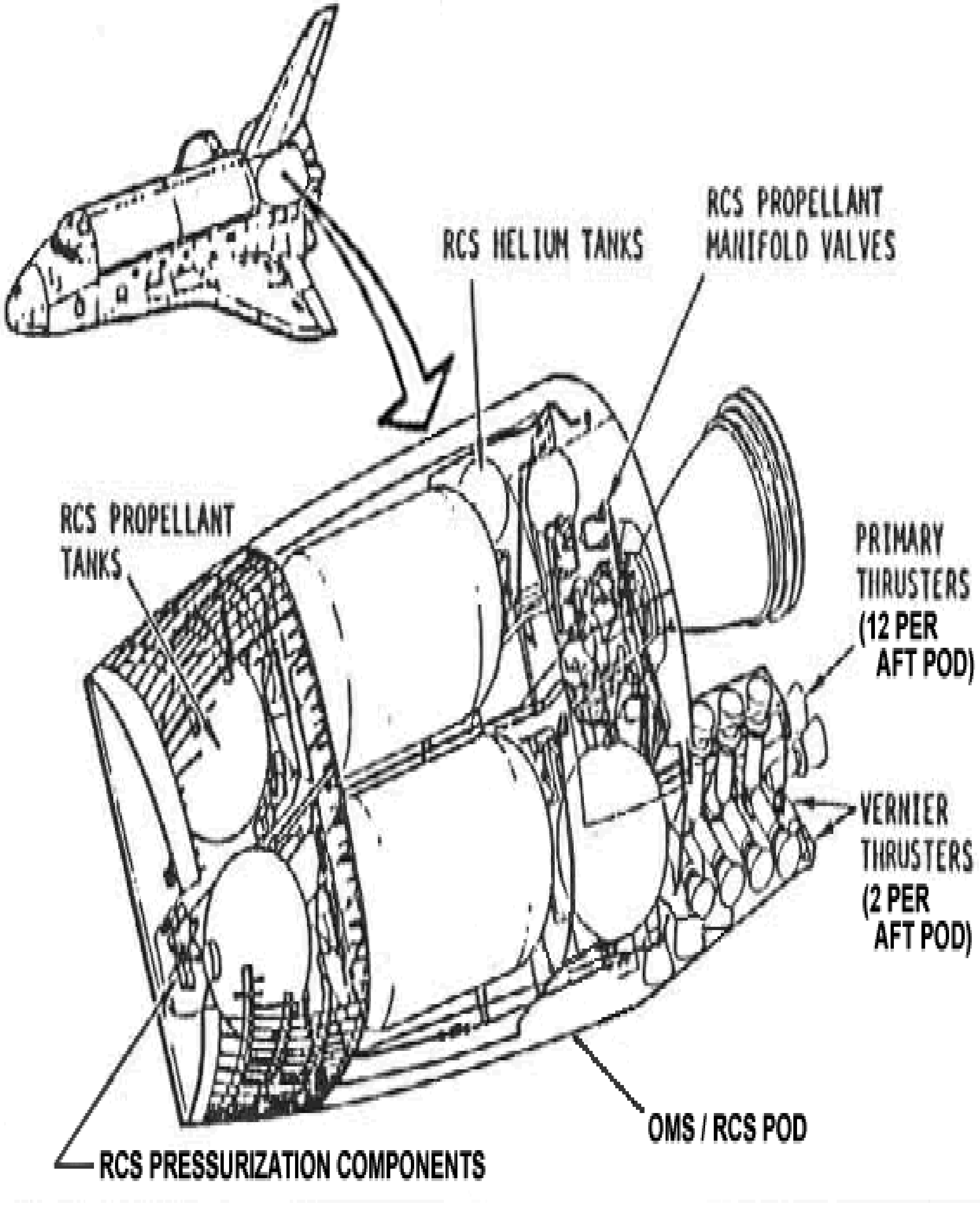
A hydrogen fuel leak in one of the SSMEs on STS-93 resulted in a slightly lower orbit than anticipated but was not an ATO; if the leak had been more severe, it might have necessitated an ATO, RTLS, or TAL abort.

Emergency landing sites

Pre-determined emergency landing sites for the Orbiter were determined on a mission-by-mission basis according to the mission profile, weather, and regional political situations.

Chapter 2

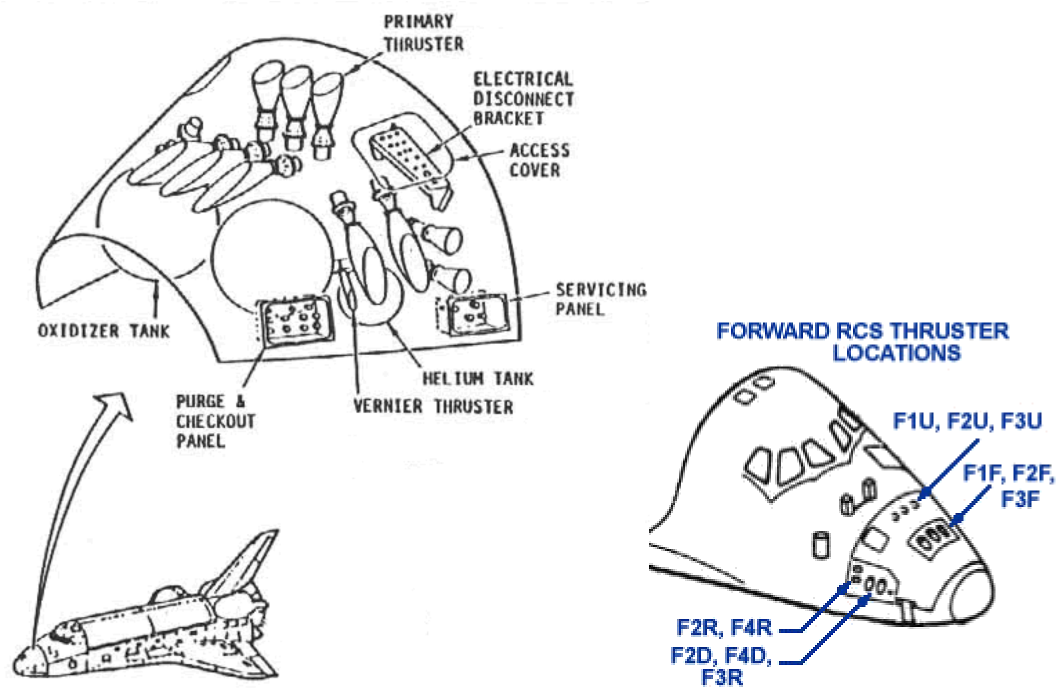
Reaction Control System



Introduction

The Reaction Control System (RCS) is a set of maneuvering thrusters used primarily to make attitude adjustments to the space shuttle orbiter. Key tasks include the separation of the shuttle from the external fuel tank after launch and repositioning the shuttle for re-entry. It also can serve as a replacement for one of the main engines in the event of main engine failure and can serve as a fuel dump under emergency conditions. Valves in an RCS module are controlled from a panel of switches that can be set to OPEN, CLOSE, or GPC for computer control. Talkbacks on the panel provide sensory feedback on the position of the valves

Forward RCS structures and components:



Construction

The RCS is composed of three subsystems which are the forward, left, and right RCS located in the nose and aft sections of the shuttle. Each subsystem consists of a fuel tank, an oxidizer tank, and a set of 14 jets (16 jets for the Forward RCS).

Jet usage and firing can be monitored and controlled from the ground, by the onboard computers, or by manually reading gauges and operating valves. Normally, jet firing is controlled by a computer that makes decisions on what jets to fire based on the type of attitude adjustment and the jets currently available.

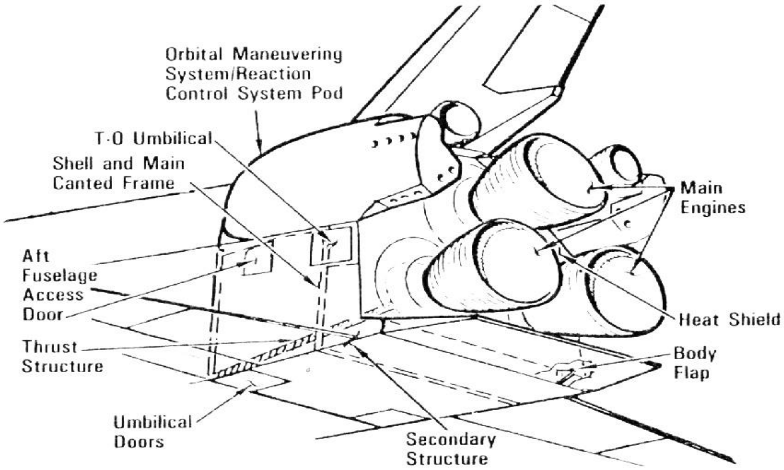
All three subsystems have a similar structure. A subsystem is composed of two pressurization and propellant feed systems one for oxidizer and one for fuel. These two systems are independent and connect at the thruster chambers at the ends of each manifold. Each feed system consists of a helium tank (which pressurizes the propellant), a propellant tank, a set of manifolds and thrusters, and a set of regulators and valves that distribute the propellant and deliver it to one or more of the manifolds.

Additionally, the left and right subsystems can be cross-connected so that they can share the same fuel and/or oxidizer tanks. They may also be connected to the main engine fuel and/or oxidizer tanks as well. Each pressurization system contains sensors used to monitor the RCS and assist in fault isolation as well as to calculate the quantity of propellant remaining.

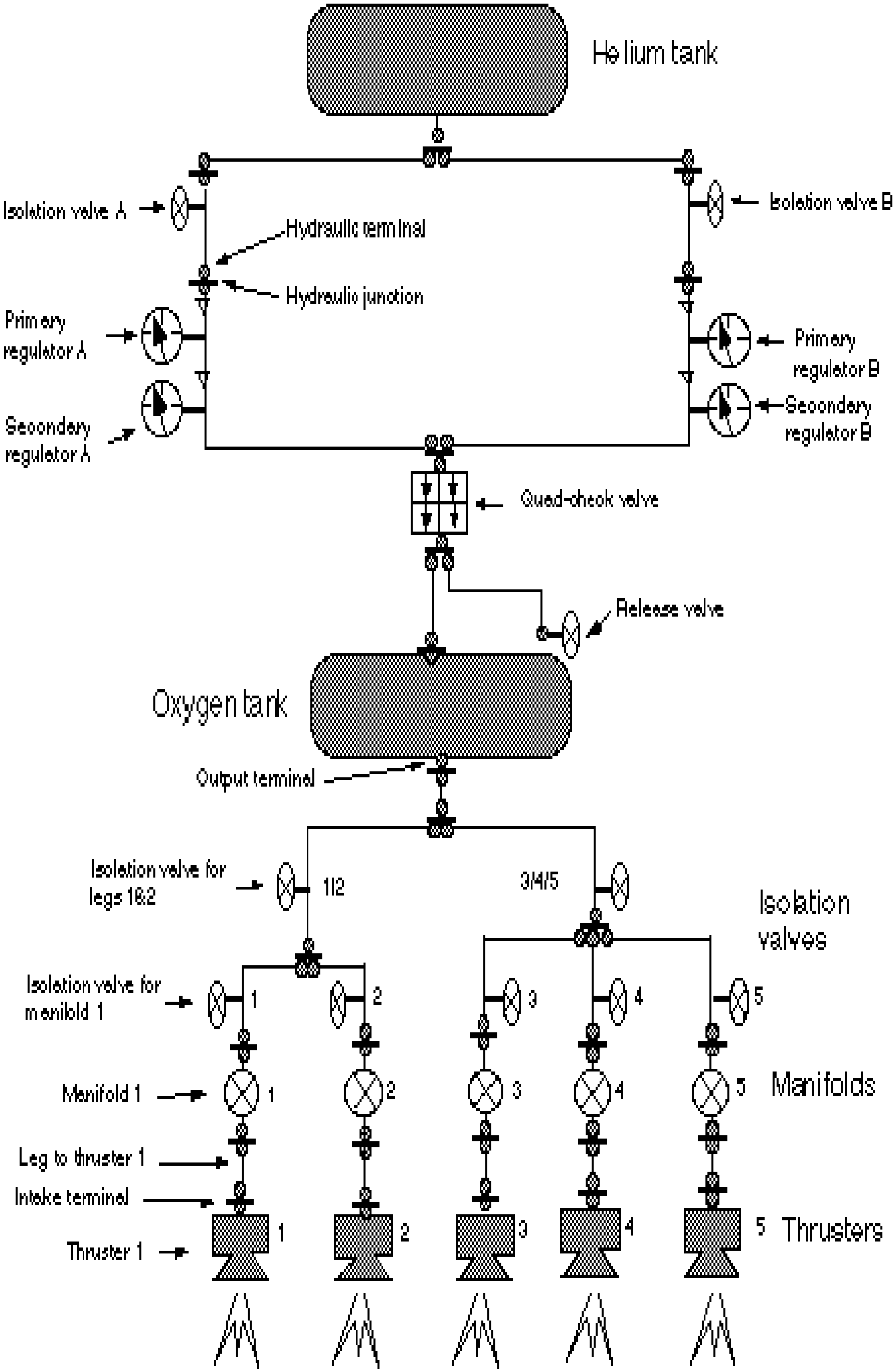
The helium tank passes through a series of regulators that reduce the pressure to the desired working pressure (242 to 248 psig). This pressure is transferred to the propellant tank which in turn forces the propellant into the tank lines, past any open isolation valves, and into any open manifolds. Finally, if the jet corresponding to a manifold is on, the fuel and oxidizer from the pair of feed systems are pushed into the thrust chamber where they explode on contact and produce thrust.

The system is designed for maximum reconfigurability, normally only one of the paths from the helium tank to the propellant tank is open with the second one kept as a spare. Each of these paths has two pressure regulators in series to guard against a single regulator failure. The isolation and manifold valves below the propellant tanks are used to reconfigure around a variety of leaks. Finally, the crossfeed valves permit operation of the system even when there is a catastrophic failure above the tank isolation valves.

To prevent under and overpressures in the propellant tank, a check valve (which prevents backflow into the helium tank) and a relief valve (which prevents the propellant tank pressure from becoming too high) are placed between the regulators and the propellant tank.



Aft Fuselage Structure


Helium tank
Isolation valve A
Hydraulic terminal
Hydraulic junction
Isolation valve B
Primary regulator A
Primary regulator B
Secondary regulator A
Secondary regulator B
Quad-check valve
Release valve
Oxygen tank
Output terminal
Isolation valve for legs 1&2
1/2
3/4/5
Isolation valves
Isolation valve for manifold 1
1
2
3
4
5
Manifold 1
Manifolds
Leg to thruster 1
Intake terminal
Thruster 1
Thrusters

System failures

Jets may be unavailable due to failures of the RCS. The following are possible conditions which would cause RCS failure.

Leaks - The locations of leaks are determined by the location of flow inhibition valves. Important leak locations are at:

1. The helium tank. A leak here will force the check valve to close. This cause a situation called “blowdown" to occur where the amount of usable propellant in the propellant tank is determined by the remaining pressure in the propellant tank (called “ullage"). If ullage pressure is low, then a potentially large amount of propellant will be trapped in the tank, unable to flow to the thrusters because there will not be enough pressure to push it out.

2. The helium line. A leak here has similar consequences to a helium tank leak. If the leak is in one of the helium legs (between the primary regulator and the helium tank isolation valve), then that leg can be isolated, and helium flow will pass through the other helium leg. If the leak cannot be isolated, then both helium isolation valves can be closed to maintain helium tank pressure. This places the system in a blowdown situation.

3. The propellant tank. A leak here requires closing the tank isolation valves. Cross-feed from the other RCS is needed to operate the jets within the subsystem.

4. The tank leg. This failure can be configured around, with the loss of fuel to some jets.

5. The manifolds. A leak here can be isolated with the loss of only the affected manifold.

6. The cross-feed line. A leak here reduces the reconfigurability of the system as cross-feeds cannot be performed.

Regulator failures - Regulators, can fail open or closed. Because of the series design of the helium line regulators and the fact that the regulators regulate at different pressures, there are three possible series regulator failures: failed closed (either regulator), primary failed open but secondary working, and both primary and secondary failed open.

The thrusters require a minimum pressure differential across them to function. When the manifold pressure is too low (below 180 psig), the jets will no longer operate, even if the manifold is re-pressurized. This failure is known as “jet starvation.” Once the jet has “starved,” it is unusable for the remainder of the mission.

Other failures - These include electrical and computer failures as well as individual valve failures.

Managing System Failures

Monitoring and diagnosing problems can be broken down into three phases typically described by the acronym “DIR.”

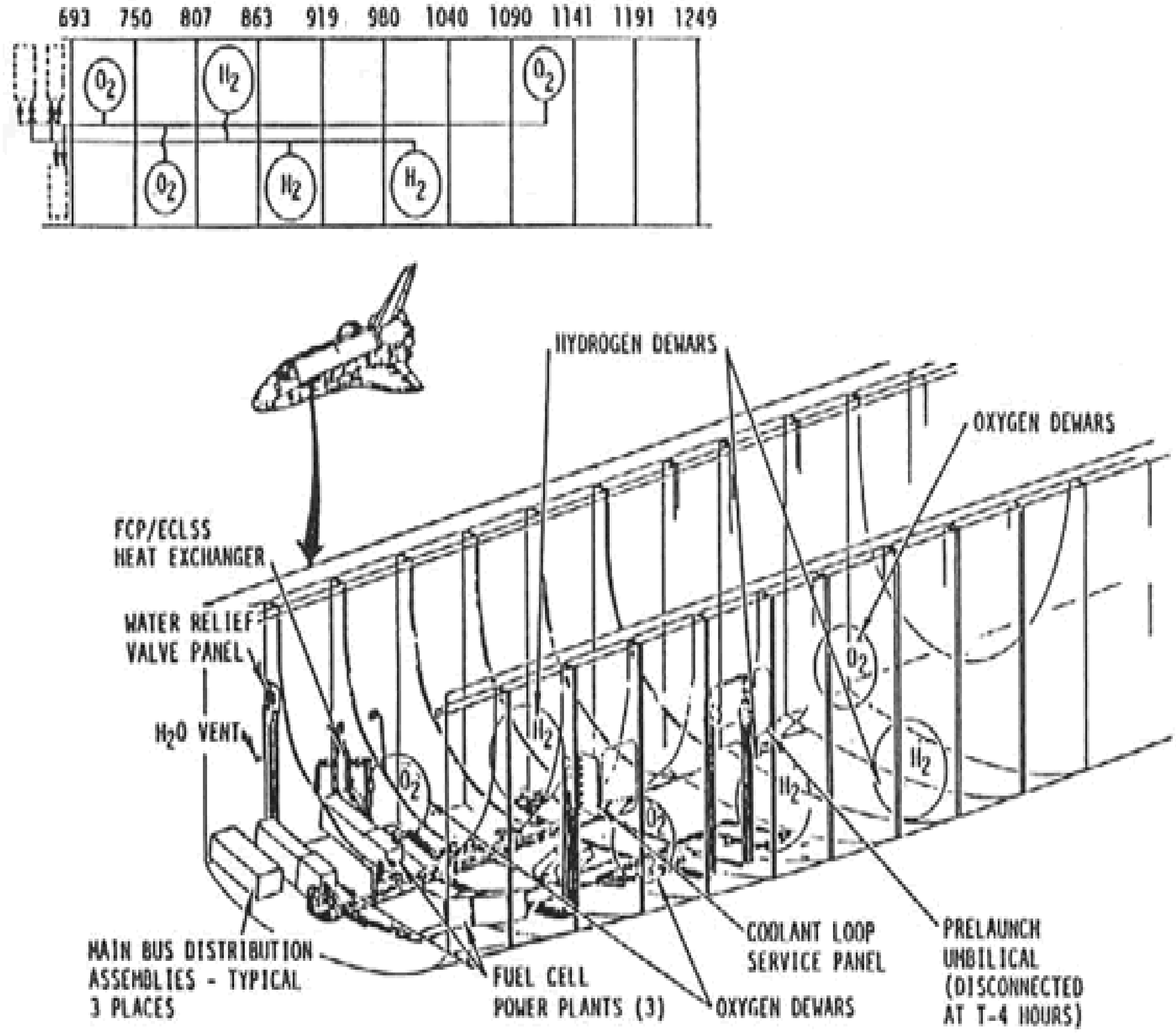
> D- Detection. Failures are detected by the mission controllers on the ground, the astronauts or the onboard computer.
>
> I – Isolation. If the fault is plumbing related (either a leak or regulatory failure) the following two steps are performed.
>
> > 1. “Safe” the system. This involves closing valves starting at the thrusters and working back to the helium tank. This prevents venting any section of the system unnecessarily.
> >
> > 2. Diagnose the problem. By reopening valves, pressure differences can be calculated to isolate the leak.
>
> R – Reconfiguration. Based on the source of the problem and remaining mission objectives certain portions of the system are cut off from the propellant flow.

Once the system has been reconfigured the system can be tested and made operational to restore RCS control and complete the mission.

CHAPTER 3

Electrical and Power Systems

ELECTRICAL POWER SUBSYSTEM



Introduction

All major systems within the space shuttle require electricity to operate. In order to meet this need, the shuttle uses fuel cells. Fuel cells are energy conversion devices that continuously transform the chemical energy of a fuel and an oxidant into electrical energy. This energy conversion process is accomplished by an electrochemical reaction whereby the reactants are consumed, by-product(s) are expelled, and heat may be released or consumed. Fuel cells will continue to generate electricity as long as both fuel and oxidant are available. Pure hydrogen, hydrocarbons, alcohols, and hydrazine are common fuels while pure oxygen and air are conventional oxidants.

Understanding Electrical Circuits

The three most basic units in electricity are voltage **(V),** current **(I**) and resistance **(r).** Voltage is measured in volts, current is measured in amps and resistance is measured in ohms. It is best to compare the flow of electricity to a system of plumbing pipes. The voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and the resistance is like the pipe size.

An Electric charge is nothing but the flow of electrons from one object to another. An electrical circuit or power circuit is the arrangement of an electrically conductive path for the flow and movement of electric charge or electricity. To make an electrical circuit, we need a path for the electrons to flow, and a power-source to push them along. Electrons travel well through metals. Therefore, in an electrical circuit, a path is made of thin metal in the form of a wire. The power source for the circuit could be an electrical generator or a battery.

For example, a light-bulb connected to a battery. In order to glow the bulb, electrons have to be pushed out of the battery; this is done through an electric field. The electrons then pass through the light-bulb, and back to the other end of the battery. During this process, the wire (normally tungsten) in the light-bulb gets so hot that it glows and emits bright light. Similarly, electricity traveling across wiring in a plane allows the equipment to work.

Resistance

An electron traveling through the wires and loads of the external circuit encounters resistance. Resistance is the hindrance to the flow of charge. For an electron, the journey from the terminal to terminal is not a direct route. Rather, it is a zigzag path that results from countless collisions with fixed atoms within the conducting material. The electrons encounter resistance, a hindrance to their movement. While the electric potential difference established between the two terminals encourages the movement of charge, it is resistance that *discourages* it. The rate at which charge flows from terminal to terminal is the result of the combined effect of these two quantities.

Variables Affecting Electrical Resistance

The flow of charge through wires is often compared to the flow of water through pipes. The resistance to the flow of charge in an electric circuit is analogous to the frictional effects between water and the pipe surfaces as well as the resistance offered by obstacles that are present in its path. It is this resistance that hinders the water flow and reduces both its flow rate and its *drift* speed. Like the resistance to water flow, the total amount of resistance to charge flow within a wire of an electric circuit is affected by some clearly identifiable variables.

First, the total length of the wires will affect the amount of resistance, therefore, the longer the wire, the more resistance that there will be. There is a direct relationship between the amount of resistance encountered by charge and the length of wire it must traverse. After all, if resistance occurs as the result of collisions between charge carriers and the atoms of the wire, then there is likely to be more collisions in a longer wire. More collisions mean more resistance.

Second, the cross-sectional area of the wires will affect the amount of resistance. Wider wires have a greater cross-sectional area. Water will flow through a wider pipe at a higher rate than it will flow through a narrow pipe. This can be attributed to the lower amount of resistance that is present in the wider pipe. Just like the pipe, the wider the wire is, the less resistance there will be to the flow of electric charge. When all other variables are the same, the charge will flow at higher rates through wider wires with greater cross-sectional areas than through thinner wires.

A third variable that is known to affect the resistance to charge flow is the material that a wire is made of. Not all materials are created equal in terms of their conductive ability. Some materials are better conductors than others and offer less resistance to the flow of charge. Silver is one of the best conductors but is never used in wires of household circuits due to its cost. Copper and aluminum are among the least expensive materials with the suitable conducting ability to permit their use in wires of household circuits.

Mathematical Nature of Electricity

Resistance

Resistance is a numerical quantity that can be measured and expressed mathematically. The standard metric unit for resistance is the ohm, represented by the Greek letter omega - Ω. An electrical device having a resistance of 5 ohms would be represented as **R = 5 Ω**. The equation representing the dependency of the resistance (**R**) of a cylindrically shaped conductor (e.g., a wire) upon the variables that affect it is

$$R = (P) \times (L/A)$$

where **L** represents the length of the wire (in meters), **A** represents the cross-sectional area of the wire (in meters^2), and **P** represents the resistivity of the material (in ohm•meter). Consistent with the discussion above, this equation shows that the resistance of a wire is directly proportional to the length of the wire and inversely proportional to the cross-sectional area of the wire. As shown by the equation, knowing the length, cross-sectional area and the material that a wire is made of (and thus, its resistivity) allows one to determine the resistance of the wire.

Ohm's Law

Ohm’s law states that in an electrical conductor the ratio of potential difference (voltage) to current is constant. For example, if the terminals of an electric battery are connected to an electric lamp, and the voltage output of the battery is then decreased by 20 percent, the amount of current flowing through the lamp will also be reduced by 20 percent.

Ohm's Law was derived experimentally by the German physicist Georg Simon Ohm in 1826. It is expressed by the following equation:

$$\mathbf{V = I \times R}$$

In this equation **V** represents the potential difference between one end of the conductor and the other (that is, the voltage applied to the conductor); **I** is the current flowing through the conductor, and **R** is called the resistance of the conductor. If **V** is given in volts and **I** is given in amperes, **R** will be in ohms. The law offers a simple method of calculating the voltage, current, or resistance in a conductor when two of these three quantities are known.

The Space Shuttles Electrical Power system

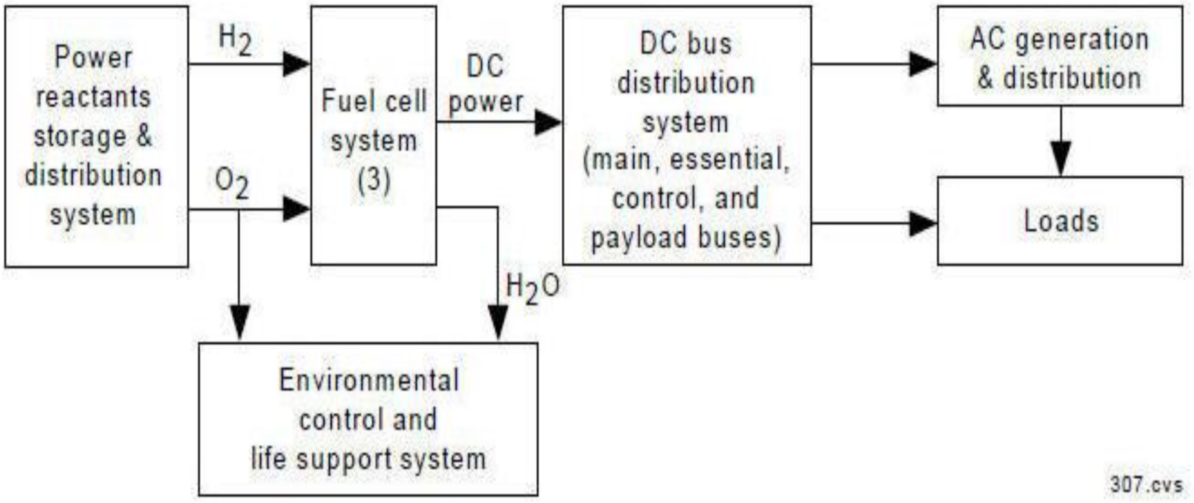
The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle, and fulfill all the external orbiter tank, solid rocket booster, and payload power requirements, when not connected to ground support equipment.

The fuel cells pick up full power load support after ground equipment is turned off at T minus 3 minutes 30 seconds, supporting power requirements for the solid rocket booster, orbiter, and some payloads. The EPS operates during all flight phases. For nominal operations, very little flight crew interaction is required by the EPS. The EPS is functionally divided into three subsystems:

- power reactants storage and distribution (PRSD)
- three fuel cell power plants (fuel cells)
- electrical power distribution and control (EPDC).

Through a chemical reaction, the three fuel cells generate all 28-volt direct-current electrical power for the vehicle from launch minus 3 minutes and 30 seconds through landing rollout. Prior to that, electrical power is provided by ground power supplies and the onboard fuel cells.

Power is controlled and distributed by assemblies located in the forward, mid, and aft sections of the orbiter. Each assembly is housing for electrical components such as remote switching devices, buses, resistors, diodes, and fuses. Each assembly usually contains a power bus or buses and remote switching devices for distributing bus power to subsystems located in its area.



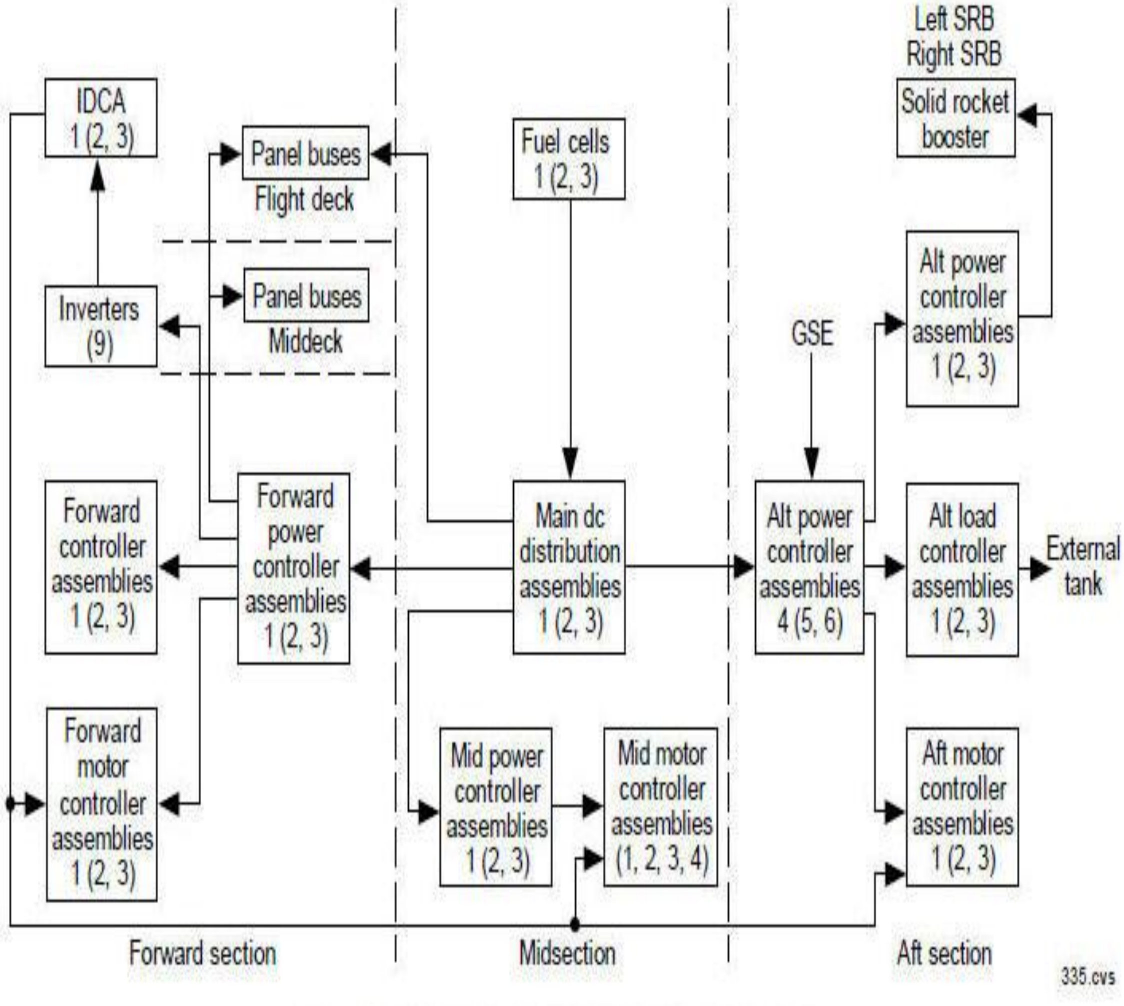
The Electrical Power System

Power Reactants Storage and Distribution System

The power reactants storage and distribution system store the reactants (cryogenic hydrogen and oxygen) and supplies them to the three fuel cells that generate all the electrical power for the vehicle during all mission phases.

In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system (ECLSS) for crew cabin pressurization. The hydrogen and oxygen are stored in tanks at cryogenic temperatures (-285°F for liquid oxygen and -420° F for liquid hydrogen) and supercritical pressures (above 731 psi for oxygen and above 188 psi for hydrogen).

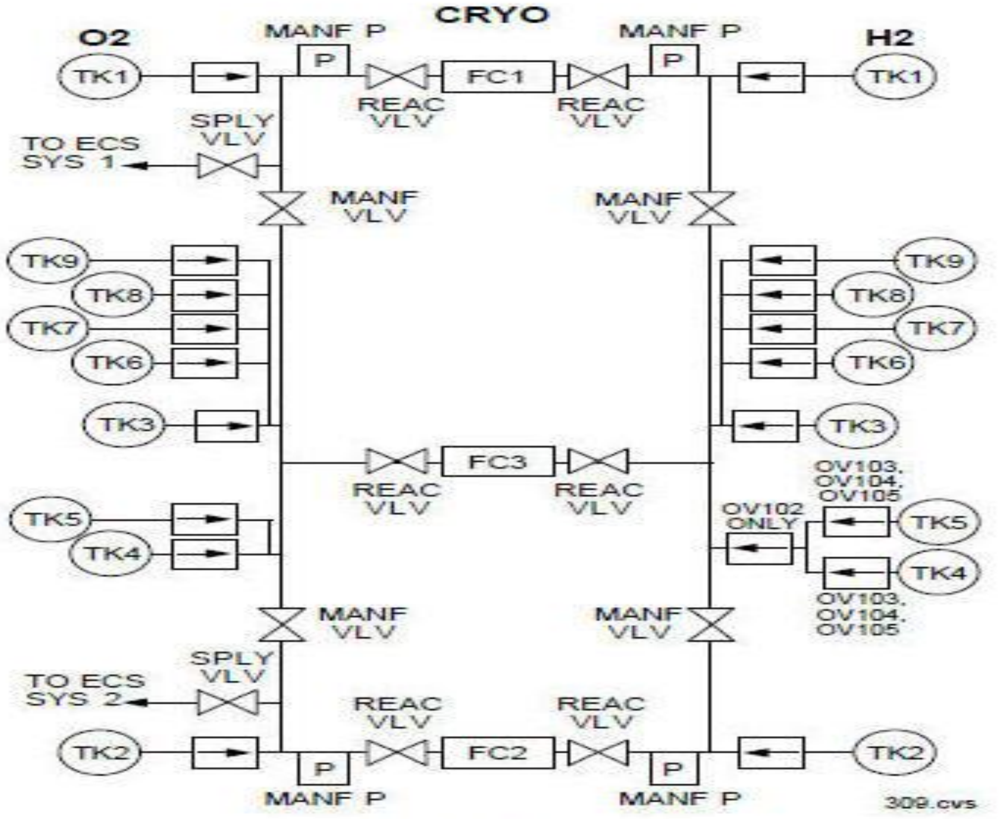
The system stores the reactants hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure.



Electrical Power Distribution Block Diagram

Fuel Cell System

The three fuel cells are located under the payload bay area in the forward portion of the orbiter's mid-fuselage. Each fuel cell is 14 inches high, 15 inches wide, 40 inches long, and weighs 255 pounds. Each fuel cell is reusable and re-startable. The three fuel cells are individually coupled to the PDRS subsystem, the active thermal control system (ATCS), the supply water storage subsystem, and the electrical power distribution and control (EPDC) subsystem.



The PDRS System

The fuel cells generate heat and water as by-products of electrical power generation. The excess heat is directed to the fuel cell heat exchanger, where it is rejected to the Freon coolant loops. The water is directed to the supply water storage subsystem for the environmental control and life support system.

The fuel cell generates power through an electrochemical reaction of hydrogen and oxygen. At the hydrogen electrode (anode), hydrogen is oxidized according to the following reaction:

$$\mathbf{2H_2 + 4OH \rightarrow 4H_2O + 4e}$$

forming water and releasing electrons. At the oxygen electrode (cathode), oxygen is reduced in the presence of water. It forms hydroxyl ions according to the following relationship:

$$\mathbf{O_2 + 2H_2O + 4e \rightarrow 4OH}$$

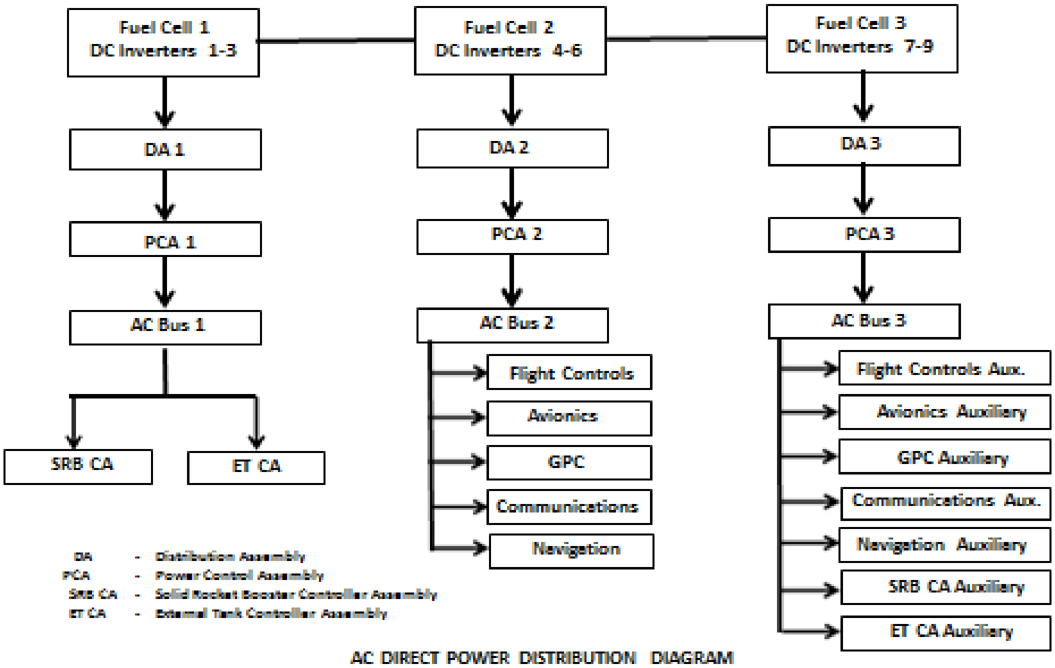
The net reaction consumes one oxygen molecule and two hydrogen atoms in the production of two water molecules, with electricity and heat formed as by-products of the reaction.

Electrical Power Distribution and Control

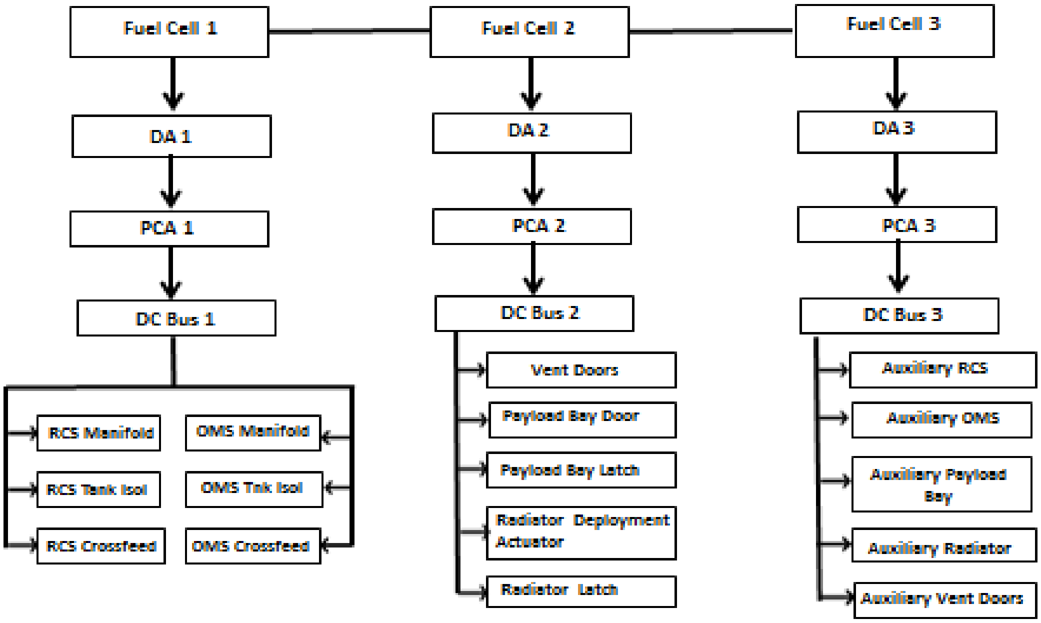
The electrical power distribution and control system distributes electrical power throughout the orbiter. It has five types of assemblies: power control, load control, motor control, main dc distribution, and ac distribution and control.

The 28 volts dc generated by each of the three fuel cells are distributed to the main dc bus. A bus is a distribution point in an aircraft electrical system to which the battery and the generator(s) are connected and from which the electrical loads derive their power.

The three main dc buses (MN A, MN B, and MN C) are the prime sources of power for the vehicle's dc loads. Each of the three dc main buses supplies power to three solid-state (static), single-phase inverters, each of which powers one three-phase alternating-current bus; thus, the nine inverters convert dc power to ac power for distribution to three ac buses (AC 1, AC 2, and AC 3) for the vehicle's ac loads.



AC DIRECT POWER DISTRIBUTION DIAGRAM



DA - Distribution Assembly
PCA - Power Control Assembly

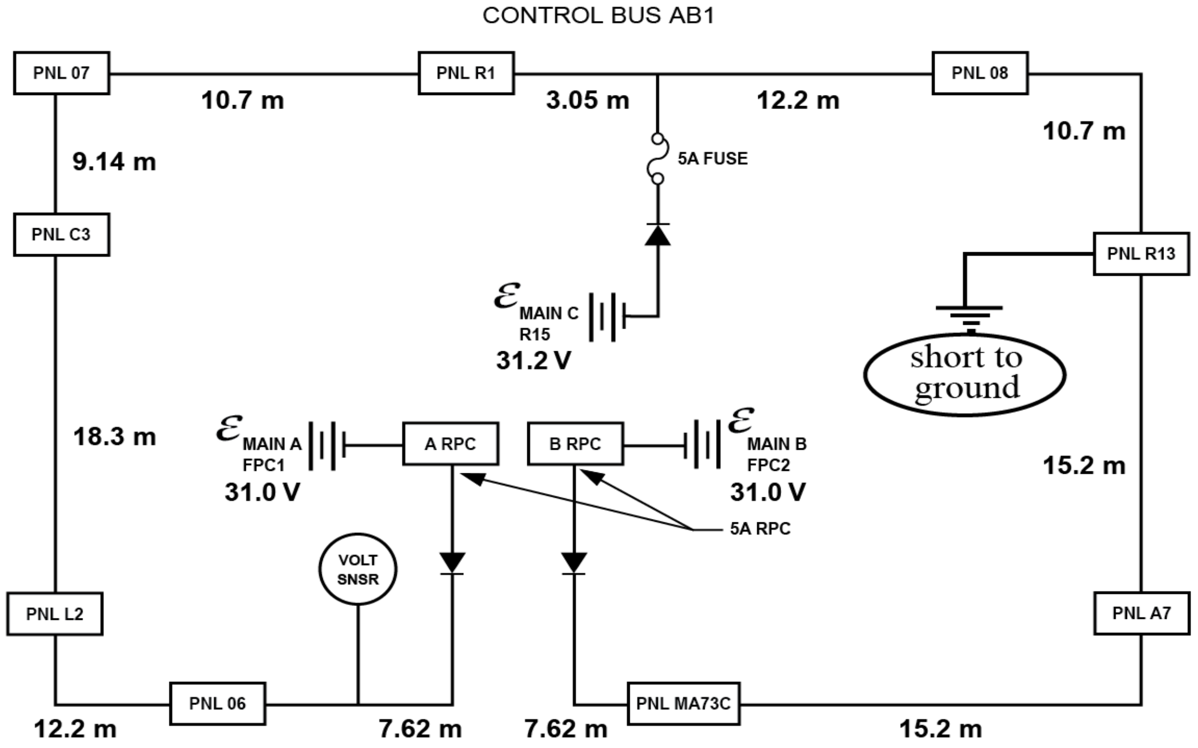
DC DIRECT POWER DISTRIBUTION DIAGRAM

Bus System

A Bus system is a distribution point in an aircraft electrical system to which the battery and the generator(s) are connected and from which the electrical loads derive their power.

The three main dc buses are main A (MN A), main B (MN B), and main C (MN C). Three ac buses, AC 1, AC 2, and AC 3, supply ac power to the ac loads. Three essential buses, ESS1BC, ESS2CA, and ESS3AB, supply dc power to selected flight crew controls and electrical loads that are deemed essential. Nine control buses -CNTL AB 1, 2, 3; CNTL BC 1, 2, 3; and CNTL CA 1, 2, 3 - are used to supply control power to flight crew controls. Two preflight buses, PREFLT 1 and PREFLT 2, are used only during ground operations.

Depending on the criticality of orbiter electrical equipment, some electrical loads may receive redundant power from two or three main buses. If an electrical load receives power from two or three sources, it is for redundancy only and not for total power consumption.



PNL=Panel RPC =Remote Power Controller SNSR = Sensor

The figure above is a simplified layout of a control bus for the space shuttle. At each end of the bus, there is a 31 V power source and a 5 A circuit protection device called a remote power controller (RPC). This is a closed loop because the return path is through vehicle ground (not shown in the diagram).

The RPC will break the circuit (trip) after exceeding the rated current for a specified duration and can be reset after a trip. There is also a 31.2V power source connected at the center of the electrical bus through a 5A fuse as shown above.

Over Current Protective Devices

Overcurrent protective devices (fuses and circuit breakers) are used to protect circuits and equipment against overloads and short circuits (faults). These devices vary in characteristic, design and function. Fuses and circuit breakers are designed to sense abnormal overloads and short circuits and open the circuit before catastrophic events occur.

Fuses - A fuse is an intentional weak link in a circuit. It is a thermally responsive device designed to provide overcurrent protection. The main function of a fuse is to protect conductors and equipment from damaging overcurrents and quickly de-energize faulted circuits minimizing hazards to personnel.

Fuses may be classified as fast-acting or time delay and as current-limiting or non-current limiting. Fast-acting fuses are designed to respond quickly to overload currents, while time

delay fuses are required to carry an overload current for a predetermined amount of time. This permits time-delay fuses to carry starting current and other temporary overloads. Fuses that limit the maximum peak current that could flow
during a short circuit are classified as current limiting fuses. Whether the fuse is classified as fast-acting or time-delay, current-limiting fuses will open quickly during short-circuit conditions.

Circuit breakers - circuit breakers are designed to protect circuits from overload and short circuit conditions when applied within their ratings. Most circuit breakers utilize a mechanical latching; spring assisted switching mechanism and a thermal, thermal-magnetic, hydraulic-magnetic, or electronic current sensing circuit that causes the switching mechanism to unlatch and open the circuit.

Space Shuttle Basic Electrical System

The majority of the control panels on the space shuttle are connected and powered by long, low amperage wires strung together to form what is called a “control bus.” A potential electrical problem is a short to ground (a low resistance current return path) somewhere on the wire. In the space shuttle, the negative poles of the fuel cells are tied to the airframe just like the negative battery pole in a car is tied to the frame. If a wire from a positive terminal touches the frame it will result in a large spark as a significant amount of current will take the path of least resistance.

A circuit is a closed loop because the return path is through vehicle ground. Each switch function in each control panel takes the powered control bus input, feeds it through the switch out to electronic devices in the circuit, and then returns it to ground. The control bus in normally uses 24-gauge wires; wire gauge is a measurement of how large a wire is.

As the diameter of the wire decreases, the gauge number increases as does the resistance in the wire. Because the wire gauge is small and the line length is long, the resistance in the wire is significant.

The 24-gauge wire used in the shuttle has a resistance of 0.0846 Ω/m. In the event of a short to ground somewhere on the wire, one source may draw enough current to trip the circuit protection. However, the resistance in the line may prevent a high enough current draw at the other sources to trip the circuit protection. This means that the short continues to be powered and could cause a fire.

Fuses and circuit breakers have characteristic trip curves that level off at somewhere above the rated trip current. This allows the user to safely operate a load at the rated current without fear of tripping the circuit. These thermal devices rely on heat buildup, so it takes some finite period of time to trip. The resistance (Ω Ohms) can be calculated by using the formula R= (resistance of the wire) (Length of the wire)

Electrical problems

Overload - An Overload is defined as an overcurrent that is confined to the normal current path. Excessive connected loads, stalled motors, overloaded machine tools, etc. can overload a circuit. Most conductors can carry a moderate overload for a short duration without damage. In fact, transient moderate overloads are part of normal operation.

Startup or temporary surge currents for motors, pumps, or transformers are common examples. Overcurrent protection must be selected that will carry these currents. However, if the overload persists for too long, excessive heat will be generated ultimately causing insulation failure. This may result in fires or lead to a short circuit.

Short Circuit - A Short Circuit is any current not confined to the normal path. The term comes from the fact that such currents bypass the normal load (i.e., it finds a “short” path around the load). Usually, when a current is greater than 6 times (600%) the normal current, it should be removed as quickly as possible from the circuit. Short Circuits are usually caused by accidental contact or worn insulation and are more serious than overloads. Damage occurs almost instantly.

Examples of Short Circuits include two or more conductors accidentally touching, someone touching or dropping tools across energized conductors or accidental connection between energized conductors and ground. Such ground faults may vary from a few amperes to the maximum available short circuit fault current.

Managing System Failures

Some general rules for managing problems within electrical power system:

1. Never close a circuit breaker or reset an RPC found out of configuration without Mission Control coordination.

2. Never connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets or bus ties.

3. If a system fault is discovered a circuit breaker or RPC may have to be bypassed to ensure adequate power supply to the systems that are served. This must be done under Mission Control Coordination.

4. Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.

5. Fuel cell run limit prior to shut-down for loss of cooling is 9 minutes at a 7 kW nominal load. Runtime is inversely proportional to fuel cell load.

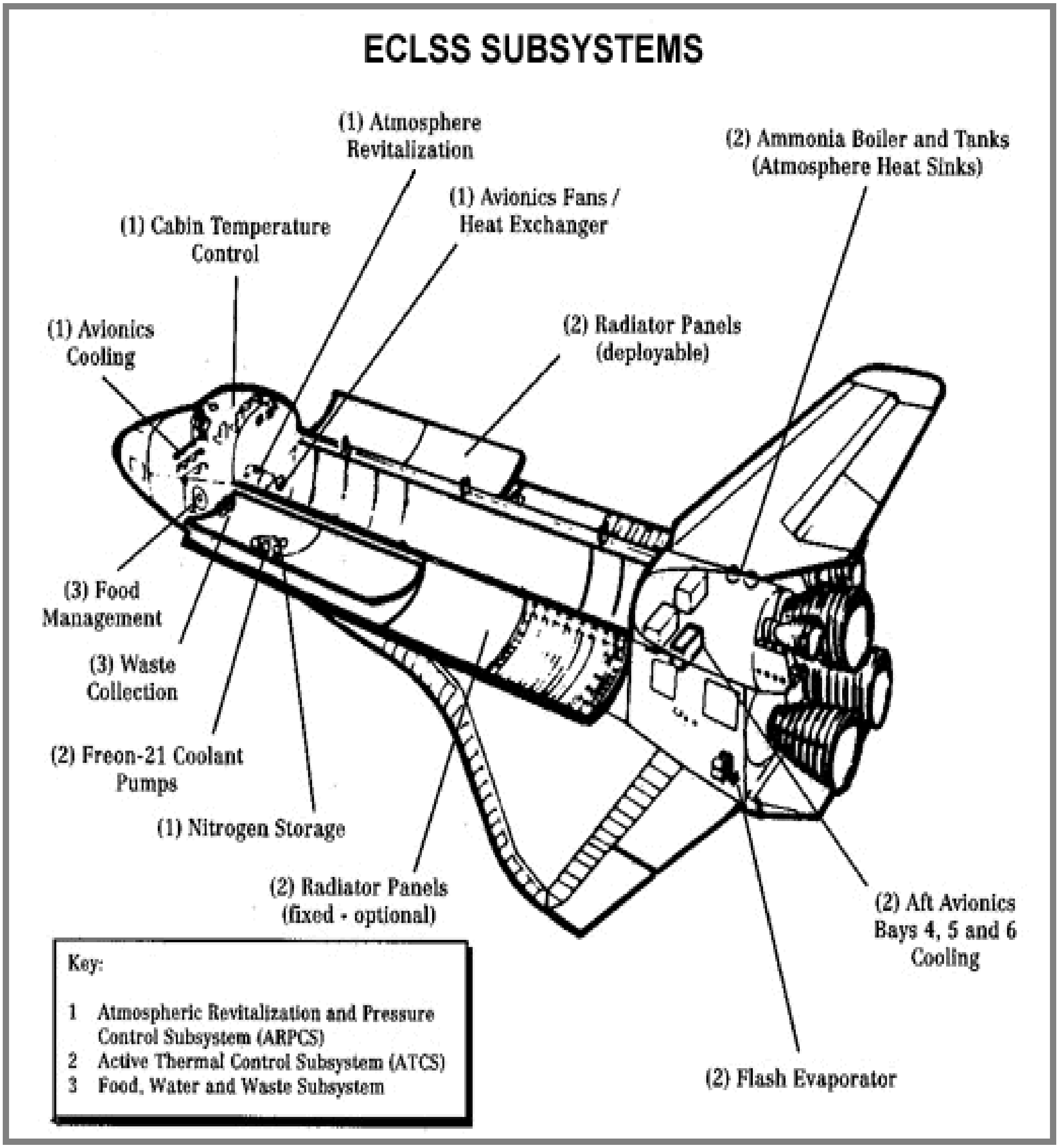
6. Any interruption of continuous ac power during ascent may result in the loss of main engine controller redundancy. Reconfiguration of ac powered equipment prior to Main engine cutoff (MECO) should be avoided.

7. Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Exact duration varies with crew complement and power load.

8. A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.

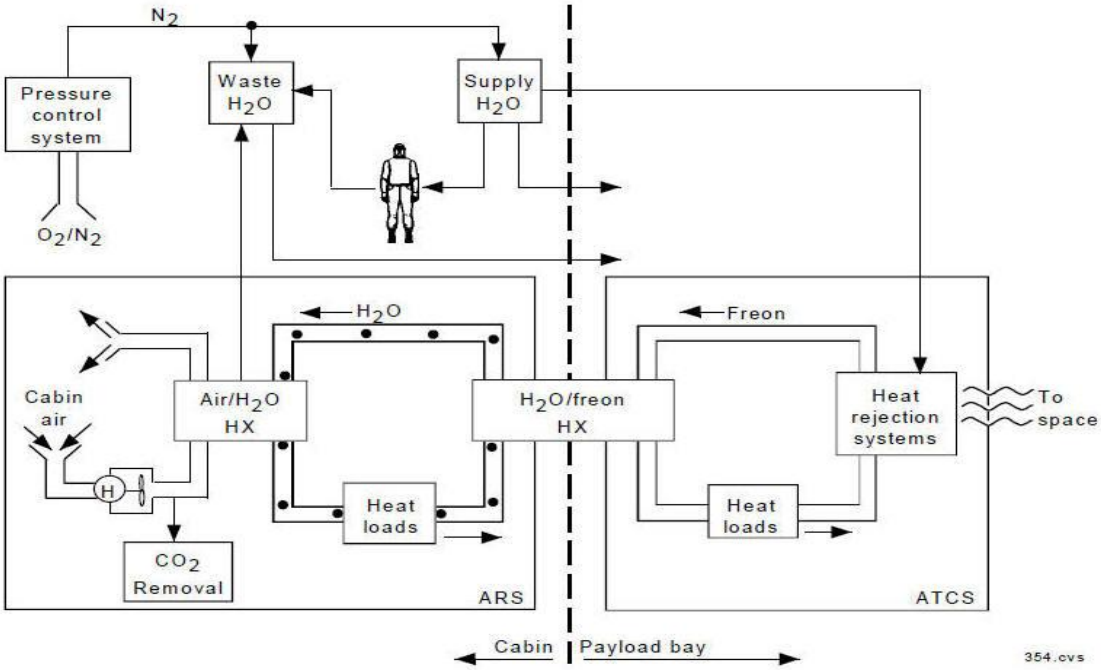
CHAPTER 4

Environmental Control and Life Support System



Introduction

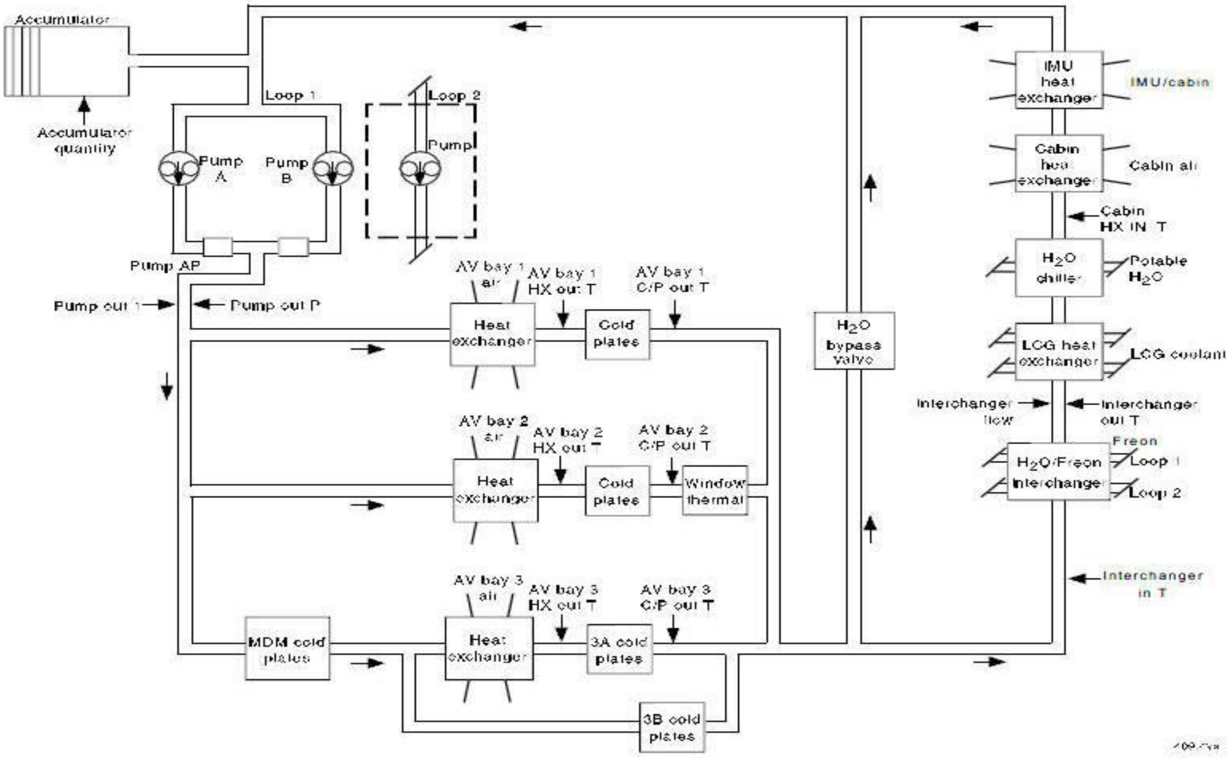
The Environmental Control and Life Support System (ECLSS) consists of an air revitalization system, water coolant loop systems, atmosphere revitalization pressure control system, active thermal control system, supply water and wastewater system, waste collection system and airlock support system. These systems interact to provide a habitable environment for the flight crew in the crew compartment in addition to cooling or heating various orbiter systems or components.



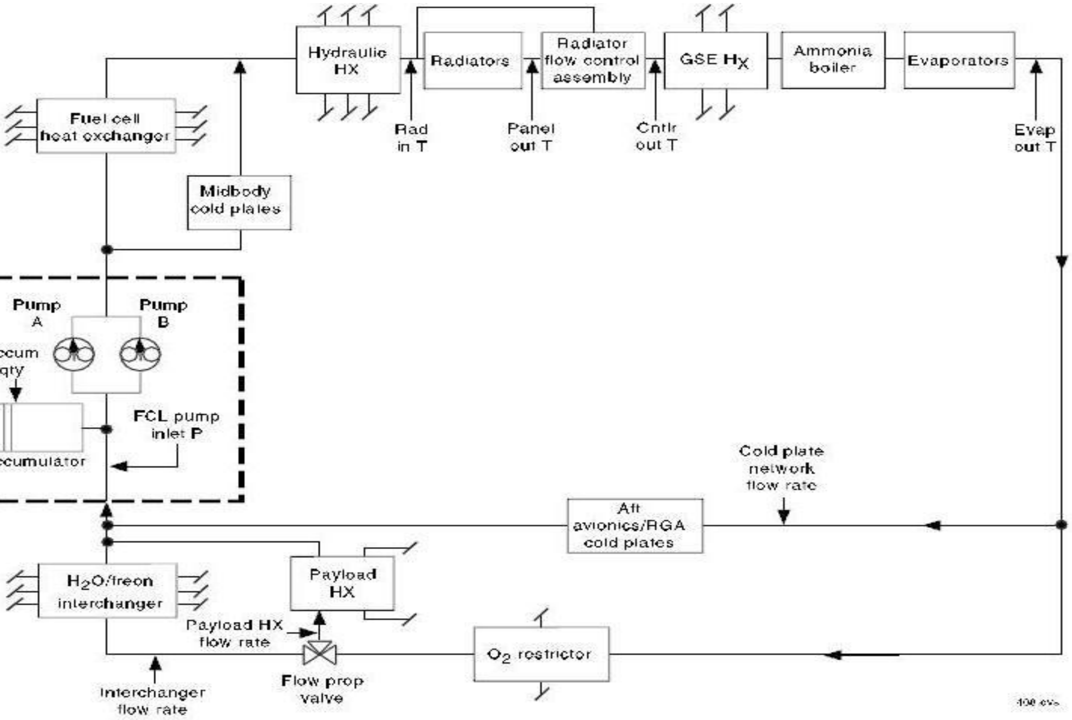
Environmental Control and Life Support System Overview

The Atmosphere Revitalization Pressure Control System (ARPCS) controls relative humidity between 30 and 75 percent, maintains carbon dioxide and carbon monoxide at non-toxic levels, controls temperature and ventilation in the crew compartment, and provides cooling to the various flight deck and mid-deck electronic avionics and the crew compartment.

The ARPCS consists of water coolant loops, cabin air loops, and pressure control. Cabin air is ducted to the crew compartment cabin heat exchanger, where the cabin air is cooled by the Water Coolant Loop System (WCLS) therefore; cabin air cools the crew cabin, flight crew and crew compartment electronic avionics. The water coolant loop system collects heat from the crew compartment cabin heat exchanger and heat from some of the electronic units in the crew compartment and transfers it to the water coolant/Freon-21 coolant loop heat exchanger of the Active Thermal Control System (ATCS).



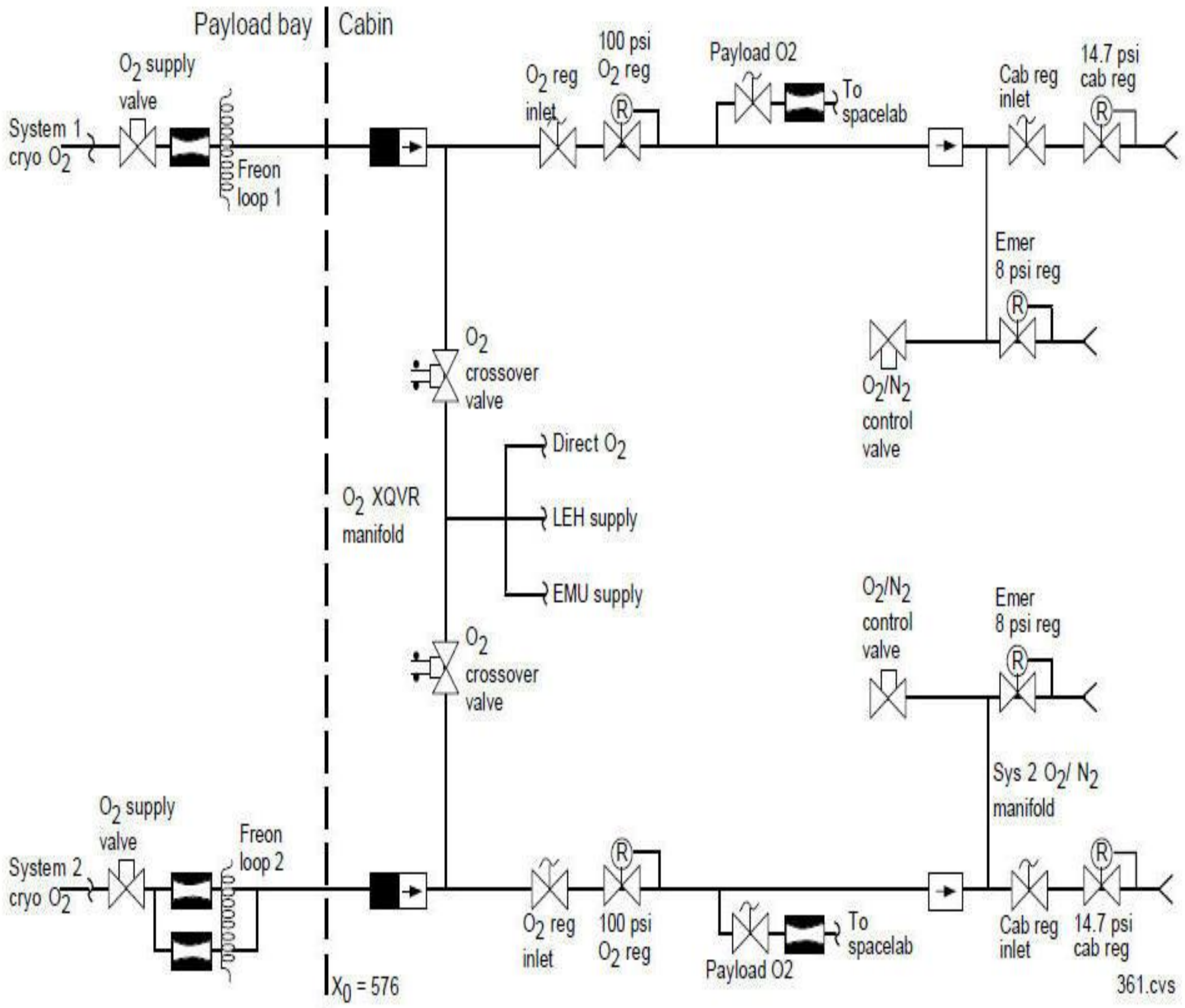
Water Loops



Freon Flow

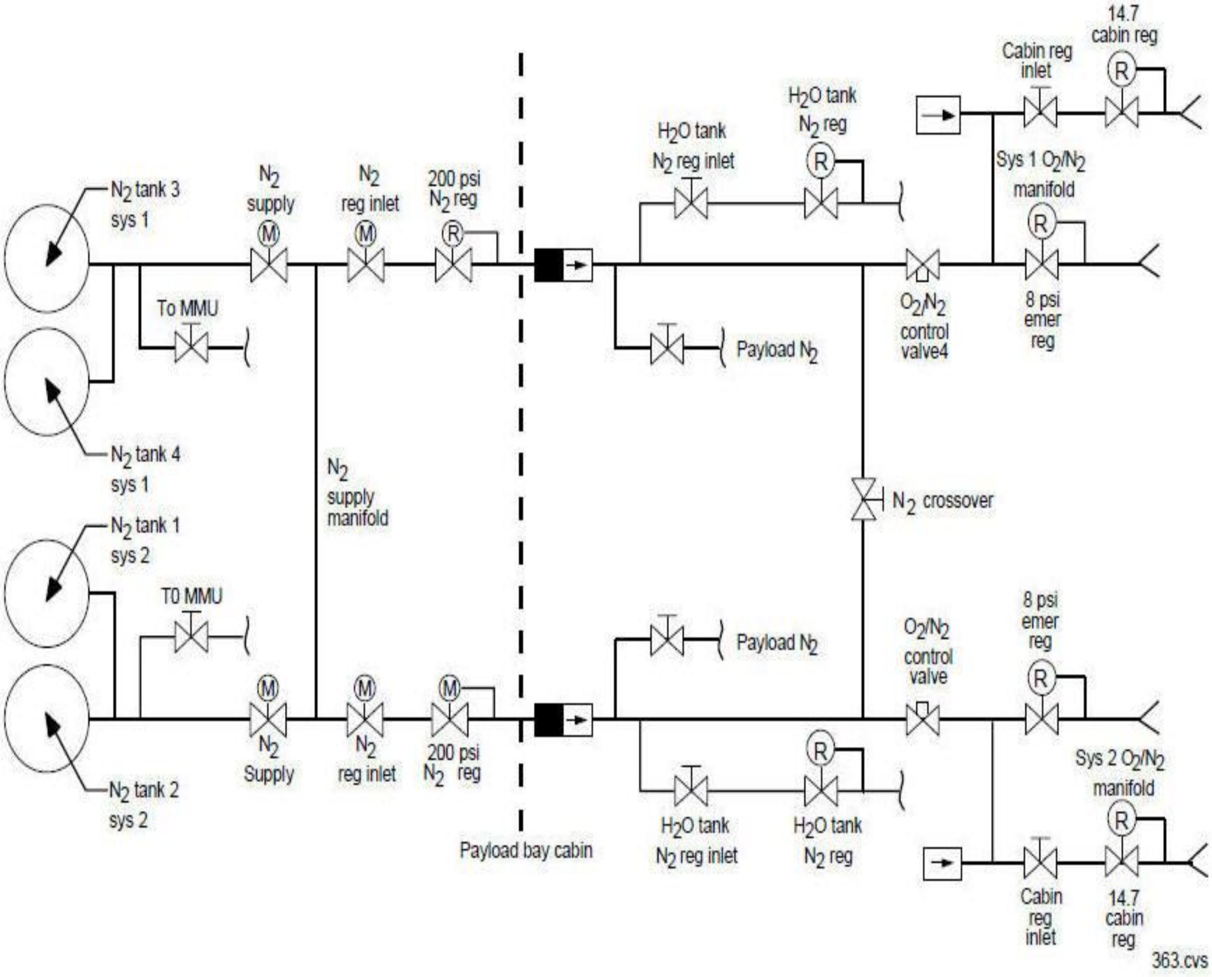
Cabin Oxygen and Nitrogen System

The ARPCS controls crew compartment cabin pressure at 14.7 psi, plus or minus 0.2 psi, with an average of 80-percent nitrogen and 20-percent oxygen mixture. Oxygen partial pressure is maintained between 2.95 psi and 3.45 psi, with sufficient nitrogen pressure of 11.5 psi added to achieve the total cabin pressure of 14.7 psi, plus or minus 0.2 psi. The pressurization control system receives oxygen from two power reactant storage and distribution cryogenic oxygen systems in the mid-fuselage of the orbiter.



Oxygen System

Gaseous nitrogen is supplied from two nitrogen systems consisting of two nitrogen tanks for each system located in the mid-fuselage of the orbiter. An optional mission kit consists of an emergency gaseous oxygen tank, and the system can be located in the mid-fuselage of the orbiter. The gaseous nitrogen system is also used to pressurize the potable and waste water tanks located below the crew compartment mid-deck floor.



Nitrogen System for Nominal Mission OV-104

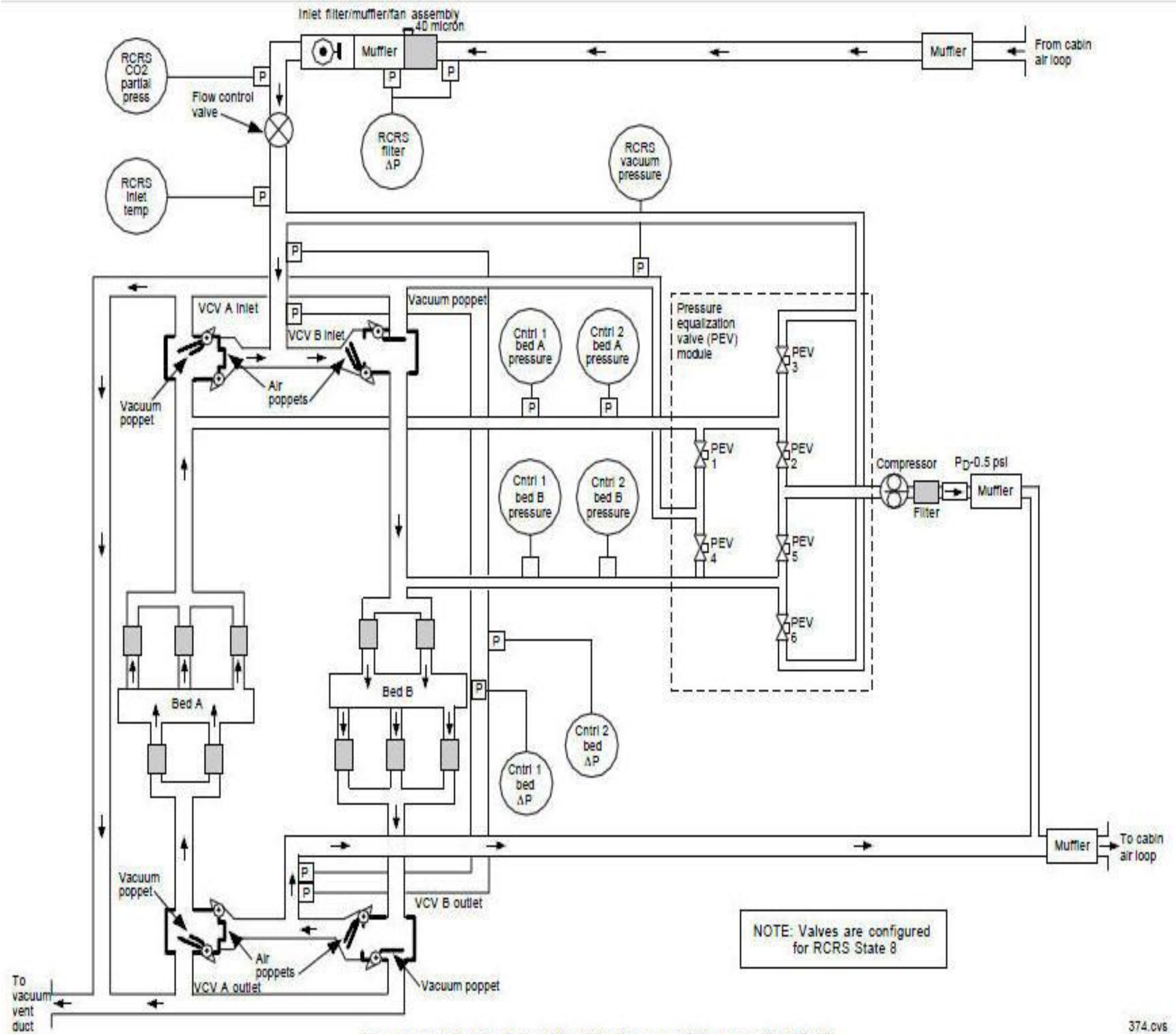
Potable water produced by the three fuel cell power plants is directed and stored in potable water tanks for flight crew consumption and personal hygiene. The potable water system is the supply to the flash evaporator system when it is used to cool the Freon-21 coolant loops. A wastewater tank is also located below the crew compartment mid-deck floor to collect wastewater from the crew cabin heat exchanger and flight crew wastewater. Solid waste remains in the waste management system in the crew compartment mid-deck until the orbiter is serviced during ground turnaround operations.

The orbiter crew compartment provides a life-sustaining environment for a flight crew of eight. The crew cabin volume with the airlock inside the mid-deck is 2,325 cubic feet. For extravehicular activity requirements, only the airlock is depressurized and re-pressurized. If the airlock is located outside of the mid-deck in the payload bay, the crew cabin volume would be 2,625 cubic feet.

The oxygen and nitrogen supply systems provide the makeup cabin oxygen gas consumed by the flight crew and nitrogen for pressurizing the potable and waste water tanks and re-pressurizing the airlock. An average of 1.76 pounds of oxygen is used per flight crew member per day. Up to 7.7 pounds of nitrogen and 9 pounds of oxygen are expected to be used per day for the normal loss of crew cabin gas to space and metabolic usage. The potable and waste water tanks are pressurized to 17 psi.

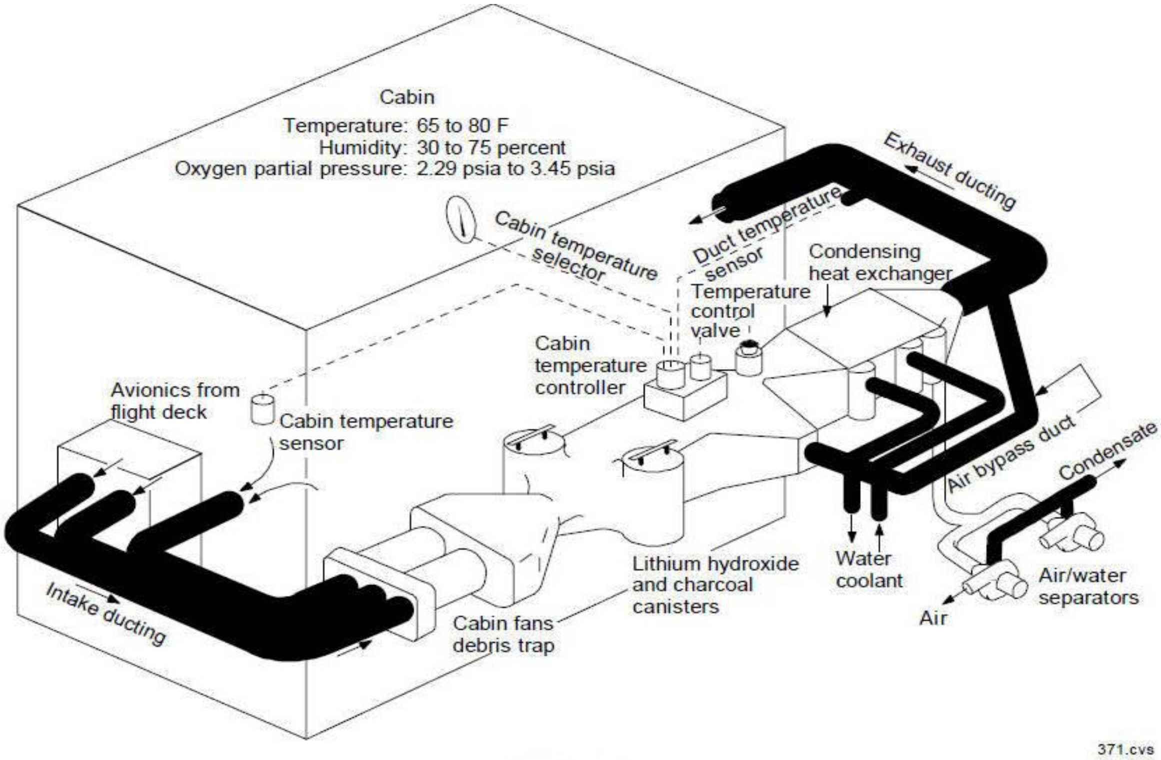
Cabin Air Revitalization

There are five independent air loops in the cabin: the cabin itself, three avionics bays and inertial measurement units. The cabin pressure atmosphere is circulated by the air revitalization system. The air circulated through the flight crew cabin picks up the heat, moisture, odor, carbon dioxide and debris with additional heat from electronic units in the crew cabin. The cabin air is drawn through the cabin loop and through a 300-micron filter by one of two cabin fans located downstream of the filter.



Regenerable Carbon Dioxide Removal System (RCRS)

The cabin air from the cabin fan is ducted to the two lithium hydroxide canisters, where carbon dioxide is removed, and activated charcoal removes odors and traces contaminants. An orifice in the duct directs a specific amount of cabin air through each lithium hydroxide canister. The canisters are also located under the mid-deck floor. For a flight crew of seven, the lithium hydroxide canisters are changed alternately every 11 hours. Replacement canisters are stored under the mid-deck floor between the cabin heat exchanger and water tanks.



Cabin Air

Cabin air is then directed to the crew cabin heat exchanger located under the mid-deck floor and cooled by the water coolant loops. Humidity condensation that forms in the slurper of the cabin heat exchanger is removed by a fan separator that draws air and water from the cabin heat exchanger. The moist air is drawn from the slurper into the humidity separator fan, where centrifugal force separates the water from the air. The fan separator removes up to approximately 4 pounds of water per hour. The water is routed to the waste water tank, and the air is ducted through the exhaust for a return to the cabin. The relative humidity in the crew cabin is maintained between 30 and 65 percent in this manner. A small portion of the revitalized and conditioned air from the cabin heat exchanger is ducted to the carbon monoxide removal unit, which converts carbon monoxide to carbon dioxide.

Based on the crew cabin volume of 2,300 cubic feet and 330 cubic feet of air per minute, one volume crew cabin air change occurs in approximately seven minutes, and approximately 8.5 air changes occur in one hour.

Environmental Control and Life Support System Malfunctions

The red cabin atm. caution and the warning light are illuminated for any of the following monitored parameters:

- Cabin pressure below 14.0 psi or above 15.4 psi.
- PPO2 below 2.8 psi or above 3.6 psi.
- Oxygen flow rate above 5 pounds per hour.
- Nitrogen flow rate above 5 pounds per hour.

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

The temperature and pressure of the primary and secondary nitrogen and emergency oxygen tanks are monitored and transmitted to the systems management computer. This information is used to compute oxygen and nitrogen quantities.

The two cabin relief valves are in parallel to provide overpressurization protection of the crew module cabin above 16 psi. Each cabin relief valve is controlled by its corresponding switch. The cabin relief A switch controls cabin relief A, and the cabin relief B switch controls cabin relief B. When the switch is positioned to enable; the corresponding motor-operated valve allows the cabin pressure to a corresponding positive pressure relief valve that relieves at 16 psi and reseats at 15.5 psi. The relief valve maximum flow capability is 150 pounds per hour.

Waste Control System

The waste collection system (WCS) is an integrated, multifunctional system used primarily to collect and process biological wastes from crew members in a zero-gravity environment. The WCS is located in the mid-deck of the orbiter crew compartment in a 29-inch wide area immediately aft of the crew ingress and egress side hatch. The commode is 27 by 27 by 29 inches and is used as a standard toilet.

The system collects, stores and dries fecal wastes and associated tissues; processes urine and transfers it to the wastewater tank; processes extravehicular mobility unit (EMU) condensate water from the airlock and transfers it to the wastewater tank if an extravehicular activity is required on a mission; provides an interface for venting trash container gases overboard; provides an interface for dumping air revitalization system (ARS) waste water overboard in a contingency situation; and transfers ARS wastewater to the wastewater tank.

The WCS consists of a commode, urinal, fan separators, odor and bacteria filter, vacuum vent quick disconnect and waste collection system controls. The commode contains a single multilayer hydrophobic porous bag liner for collecting and storing solid waste. When the commode is in use, it is pressurized, and transport air flow is provided by the fan separator. When the commode is not in use, it is depressurized for solid waste drying and deactivation. The urinal is essentially a funnel attached to a hose and provides the capability to collect and transport liquid waste to the wastewater tank. The fan separator provides transport air flow for the liquid. The fan separators separate the waste liquid from the air flow. The liquid is drawn off to the wastewater tank, and the air returns to the crew cabin through the odor and bacteria filter. The filter removes odors and bacteria from the air that returns to the cabin. The quick vacuum disconnect is used to vent liquid directly overboard from equipment connected to the quick disconnect through the vacuum line.

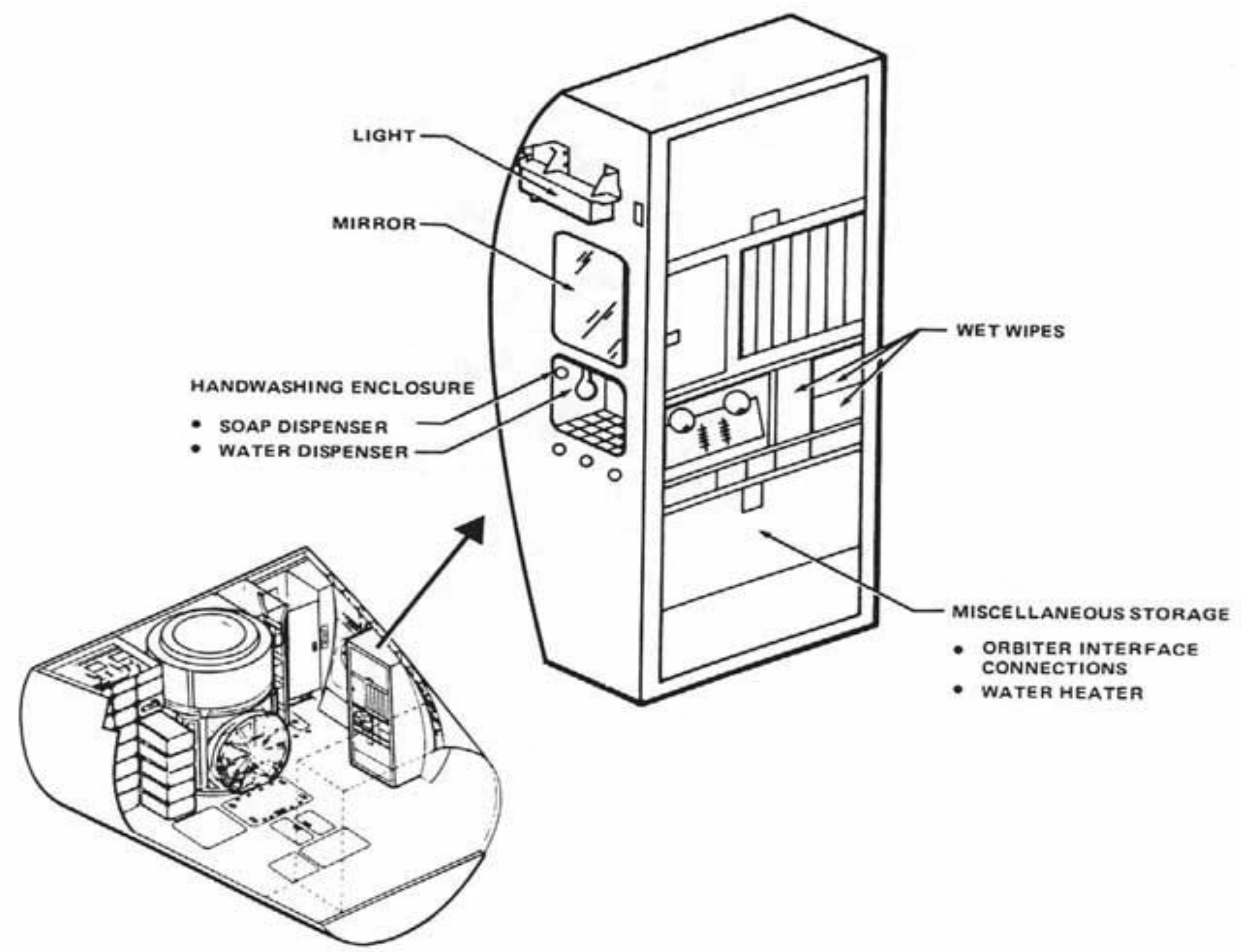
The urinal can accommodate both males and females. The urinal assembly is a flexible hose with attachable funnels for males or females. It can be used in a standing position or can be attached to the commode by a pivoting mounting bracket for use in a sitting position.

All waste collection system gases are ducted from the fan separator into the odor and bacteria filter and then mixed with cabin air. The filter can be removed for in-flight replacement.

The system employs various restraints and adjustments to enable the user to achieve the proper body positioning to urinate or defecate in a zero-gravity environment. Two-foot restraints are provided. A toe bar is located at the commode base and is used to urinate standing. It consists of two flexible cylindrical pads on a shaft that can be adjusted to various heights by releasing two locking levers that are turned 90 degrees counterclockwise. The crew member is restrained by slipping the feet under the toe bar restraint. A footrest restrains the feet of a crew member sitting on the commode. It consists of an adjustable platform with detachable Velcro straps for securing the feet. The Velcro straps are wrapped crosswise over each foot and secured around the back. The footrest can be adjusted to various angles and heights. Two locking handles pulled outward adjust the angle; two other locking levers adjust the height of the footrest.

Two body restraints are provided for use when crew members are seated on the commode. The primary restraint is a thigh bar that the crew member lifts up out of the detent position, rotates over the thigh and releases. It exerts a preloaded force on each thigh of approximately 10 pounds. The second restraint is a backup method. It consists of four Velcro fabric thigh straps with a spring hook on one end. Two of the straps are attached to the top front commode surface mating attach points, and the other two are installed on a bracket with five holes on the upper sides of the commode, below and outboard of the thigh bars. The crew member is secured in position by wrapping two straps over each thigh and attaching the mating Velcro surfaces.

Handholds are used for positioning or stabilizing the crew member while using the WCS and form an integral part of the top cover of the waste management collection system assembly.



Personal Hygiene Equipment on Orbit Locations (with galley)

Waste System Malfunctions

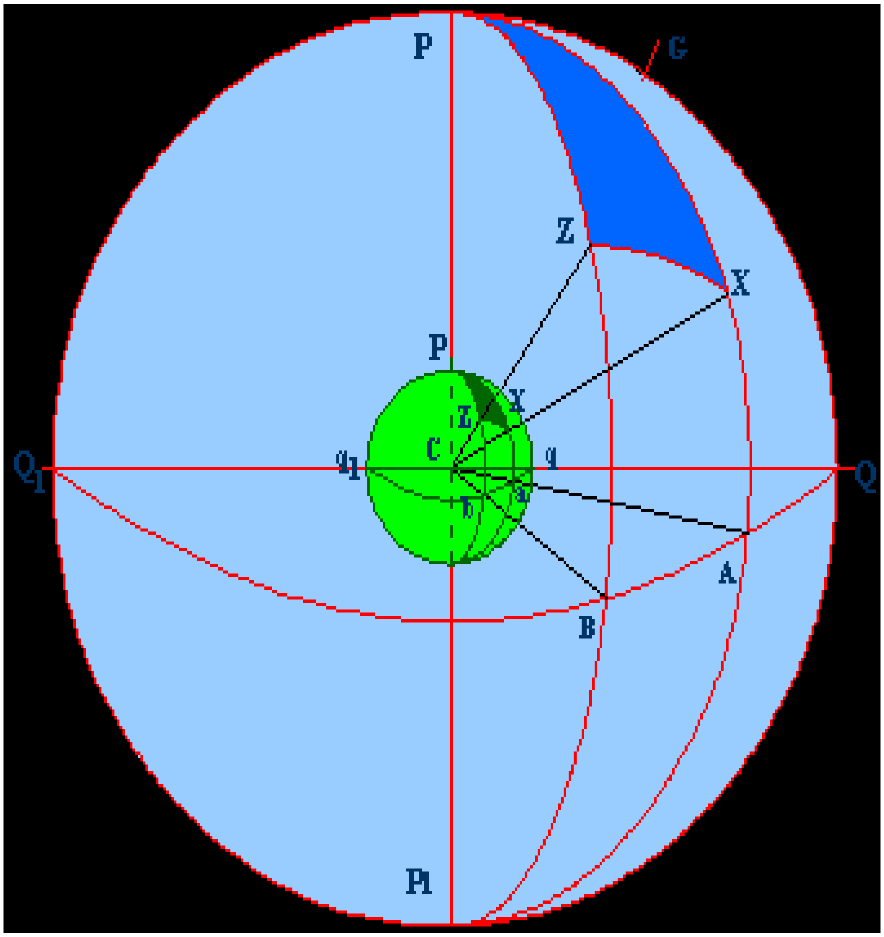
If fan separator 1 is inoperative or fails to achieve proper operational speed (which can be verified by a reduced noise level or lack of air flow), the fan step switch is positioned from 1 to 2, and fan separator 2 will operate in the same manner as 1.

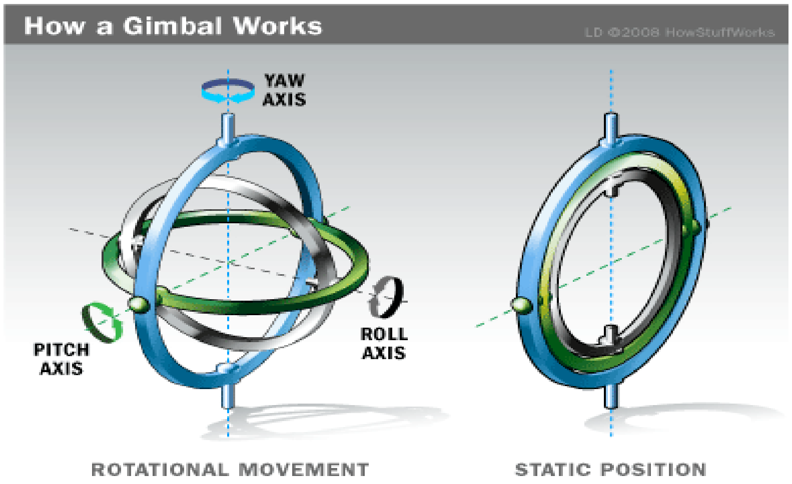
If both fan separators in the waste collection system fail, feces are collected by the Apollo fecal bag. To dispose of the Apollo fecal bag, the waste collection system is configured as in the urine and feces collection mode and the bag is stowed in the commode.

If both fan separators in the waste collection system fail and it is not possible to dump urine overboard, urine may be collected using a contingency urine collection device.

Chapter 5

Guidance and Navigation





Introduction

The navigation system maintains an accurate estimate of vehicle position and velocity, referred to as a state vector. From position, attitude and velocity, other parameters (acceleration, the angle of attack) are calculated for use in guidance and for display to the crew. The current state vector is mathematically determined from the previous state vector by integrating the equations of motion using vehicle acceleration as sensed by the IMUs and/or computed from gravity and drag models.

The alignment of the IMU and, hence, the accuracy of the resulting state vector deteriorates as a function of time. Celestial navigation instruments (star trackers and crewman optical alignment sight) are used to maintain IMU alignment in orbit. For entry, the accuracy of the IMU-derived state vector is, however, insufficient for either guidance or the flight crew to bring the spacecraft to a pinpoint landing. Therefore, data from other navigation sensors-air data system, tactical air navigation, microwave scan beam landing system and radar altimeter-is blended into the state vector at different phases of entry to provide the necessary accuracy.

The three IMUs maintain an inertial reference and provide velocity changes until the microwave scan beam landing system is acquired. Navigation-derived air data are needed during entry as inputs to guidance, flight control, and flight crew dedicated displays. Such data are provided by tactical air navigation, which supplies range and bearing measurements beginning at 160,000 feet; the air data system provides information at about Mach 3. Tactical air navigation is used until the microwave scan beam landing system is acquired or an altitude of 1,500 feet is reached if MSBLS is not available.

During rendezvous and proximity operations, the onboard navigation system maintains the state vectors of both the orbiter and the target vehicle. During close operations (separation of fewer than 15 miles), these two state vectors must be very accurate in order to maintain an accurate relative state vector. Rendezvous radar measurements (range and range rate) are used for separation of about 15 miles to 100 feet to provide the necessary relative state vector accuracy. When two vehicles are separated by less than 100 feet, the flight crew relies primarily on visual monitoring (aft and overhead windows and closed-circuit television).

Inertial Measurement Units

The IMUs consist of an all-attitude, four-gimbal, inertially stabilized platform. They provide inertial attitude and velocity data to the GN&C software functions. Navigation software uses the processed IMU velocity and attitude data to propagate the orbiter state vector. Guidance uses the attitude data, along with state vector from the navigation software, to develop steering commands for flight control. Flight control uses the IMU attitude data to convert the steering commands into control surface, engine gimbal (thrust vector control) and reaction control system thruster fire commands.

Although flight could be accomplished with only one, three IMUs are installed on the orbiter for redundancy. The IMUs are mounted on the navigation base, which is located inside the crew compartment flight deck forward of the flight deck control and display panels

Very precise thermal control must be maintained in order to meet IMU performance requirements. The IMU thermal control system consists of an internal heater system and a forced-air cooling system. The internal heater system is completely automatic and is powered on when power is initially applied to the IMU. It continues to operate until the IMU is powered down. The forced-air cooling consists of three fans that serve all three IMUs. Only one fan is necessary to provide adequate air flow. The IMU fan pulls cabin air through the casing of each IMU and cools it in an IMU heat exchanger before returning it to the cabin. Each IMU fan is controlled by an individual on/off switch.

Each IMU is supplied with redundant 28-volt dc power through separate remote power controllers when control bus power is applied to the RPCs by the IMU power switch. Loss of one control bus or one main bus will not cause the loss of an IMU.

Each IMU has two modes of operation: a warm-up/standby mode and an operate mode. When the respective IMU switch is positioned to on that IMU is powered and enters the warm-up/standby mode, which applies power only to the heater circuits. It takes approximately 30 minutes for the IMU to reach its operating range, at which time the IMU enters a standby mode when it can be moded to the operate mode by flight crew command.

During ascent, the IMUs provide accelerometer and resolver data to the GN&C software to propagate the state vector, determine attitude and display flight parameters. During the orbital flight phase, the IMUs provide GN&C software with attitude and accelerometer data. On-orbit alignments are necessary to correct platform misalignment caused by uncompensated gyro drift.

During entry, IMU operation differs only in the manner in which accelerometer data are used by navigation. The IMU software scheme is designed to select the best data for GPC use and to detect system failures. This scheme is referred to as redundancy management.

In the event of an IMU failure, the IMU red caution and warning light will be illuminated. If temperatures are out of limits or if built-in test equipment detects a failure, a fault message and SM alert will be annunciated.

The accuracy of the IMU deteriorates with time. If the errors are known, they can be physically or mathematically corrected. Software based on preflight calibrations is used to compensate for most of the inaccuracy. The star trackers and crewman optical alignment sight are used to determining additional inaccuracies.

Star Tracker

The star tracker system is part of the orbiter's navigation system. Its two units are located just forward and to the left of the commander's plus X window in a well outside the pressurized crew compartment-an extension of the navigation base on which the IMUs are mounted. The star trackers are slightly inclined off the vehicle's negative Y and negative Z axes, for which they are named. The star trackers are used to align the IMUs on board the orbiter as well as to track targets and provide line-of-sight vectors for rendezvous calculations.

Alignment of the IMUs is required approximately every 12 hours to correct IMU drift, within one to two hours before major on-orbit thrusting duration or after a crewman optical alignment sight IMU alignment. IMU alignment is accomplished by using the star trackers to measure the line-of-sight vector to at least two stars. With this information, the GPC calculates the orientation between these stars and the orbiter to define the orbiter's attitude. A comparison of this attitude with the attitude measured by the IMU provides the correction factor necessary to null the IMU error.

The GPC memory contains inertial information for 50 stars chosen for their brightness and their ability to provide complete sky coverage.

The star trackers are oriented so that the optical axis of the negative Z star tracker is pointed approximately along the negative Z axis of the orbiter and the optical axis of the negative Y star tracker is pointed approximately along the negative Y axis of the orbiter. Since the navigation base provides the mount for the IMUs and star trackers, the star tracker line of sight is referenced to the navigation base and the orbiter coordinate system; thus, the GPC knows where the star tracker is pointed and its orientation with respect to the IMUs.

Each star tracker has a door to protect it during ascent and entry. The doors are opened on orbit to permit the use of the star trackers. In addition to aligning the IMUs, the star trackers can be used to provide angular data from the orbiter to a target. This capability can be used during rendezvous or proximity operations with a target satellite.

There is no redundancy management for the star tracker assemblies; they operate independently, and either can do the whole task. They can be operated either separately or concurrently. In addition, the star tracker SOP maintains the star table. When a star tracker has acquired and tracked a star, and the data has passed software checks, the star identification, time tag, and line-of-sight vector are stored. The identification and time elapsed since time tag are displayed in the star table. When two or three stars are in the table, the angular difference between their line-of-sight vectors is displayed. The difference between the star tracker and star catalog angular differences is displayed as an error. The star tracker SOP selects line-of-sight vectors of two stars in the star table for IMU alignment and outputs an alignment discrete. The software selects the star pair whose angular difference is closest to 90 degrees or the pair whose elapsed time of entry into the table is less than 60 minutes. The flight crew may manually override the SOP selection or clear the table if desired. The SOP also determines and displays star tracker status.

Crewman Optical Alignment Sight

The crewman optical alignment sight is used if inertial measurement unit alignment is in error by more than 1.4 degrees, rendering the star tracker unable to acquire and track stars. The COAS must be used to realign the IMUs to within 1.4 degrees. The star trackers can then be used to realign the IMUs more precisely.

The COAS is mounted at the commander's station so the crew can check for proper attitude orientation during ascent and deorbit thrusting periods. For on-orbit operations, the COAS at the commander's station is removed and installed next to the aft flight deck overhead right minus Z window.

By knowing the star being sighted and the COAS's location and mounting relationship in the orbiter, the software can determine a line-of-sight vector from the COAS to the star in an inertial coordinate system. Line-of-sight vectors to two stars define the attitude of the orbiter in inertial space. This attitude can be compared to the attitude defined by the IMUs and can be realigned to the correct orientation by the COAS sightings if the IMUs are in error.

COAS can also be used to track targets during proximity operations visually or to visually verify tracking of the correct star by the minus Z star tracker. COAS data processing is accomplished in the star tracker SOP. This SOP accepts and stores crew inputs on COAS location, star identification or calibration mode; accepts marks; computes and stores the line-of-sight vectors; enables IMU alignment when two marks have been accepted; and computes, updates and provides display data.

Orbiter Rate Gyro Assemblies

The orbiter rate gyro assemblies are used by the flight control system during ascent, entry, and aborts as feedbacks to final rate errors that are used to augment stability and for display on the commander's and pilot's attitude director indicator rate needles on panels F6 and F8. The four orbiter RGAs are referred to as RGAs 1, 2, 3 and 4.

The RGAs sense roll rates (about the X axis), pitch rates (about the Y-axis) and yaw rates (about the Z axis). These rates are used by the flight control system to augment stability during both ascent and entry.

Each RGA contains three identical single-degree-of-freedom rate gyros so that each gyro senses rotation about one of the vehicle axes. Thus, each RGA contains one gyro-sensing roll rate (about the X axis), one gyro-sensing pitch rate (about the Y-axis) and one gyro-sensing yaw rate (about the Z axis).

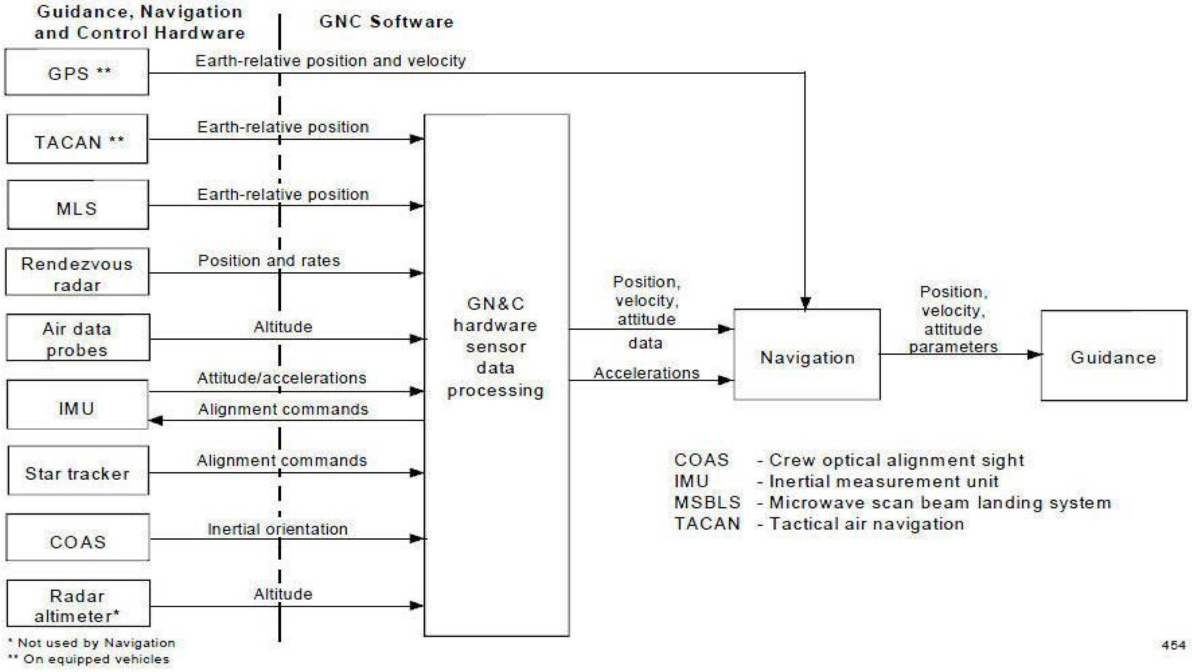
Each gyro has three axes. A motor forces the gyro to rotate about its spin axis. When the vehicle rotates about the gyro input axis, a torque results in a rotation about the output axis. An electrical voltage is proportional to the angular deflection about the output axis-representing vehicle rate about the input axis is generated and transmitted through the flight aft MDMs to the GPCs and RGA SOP. This same voltage is used within the RGA to generate a counteracting torque that prevents excessive gimbal movement about the output axis. The maximum output for roll rate gyros is plus or minus 40 degrees per second; for the pitch and yaw gyros, the maximum output is plus or minus 20 degrees per second.

The RGA SOP converts the voltage rate into units of degrees per second.

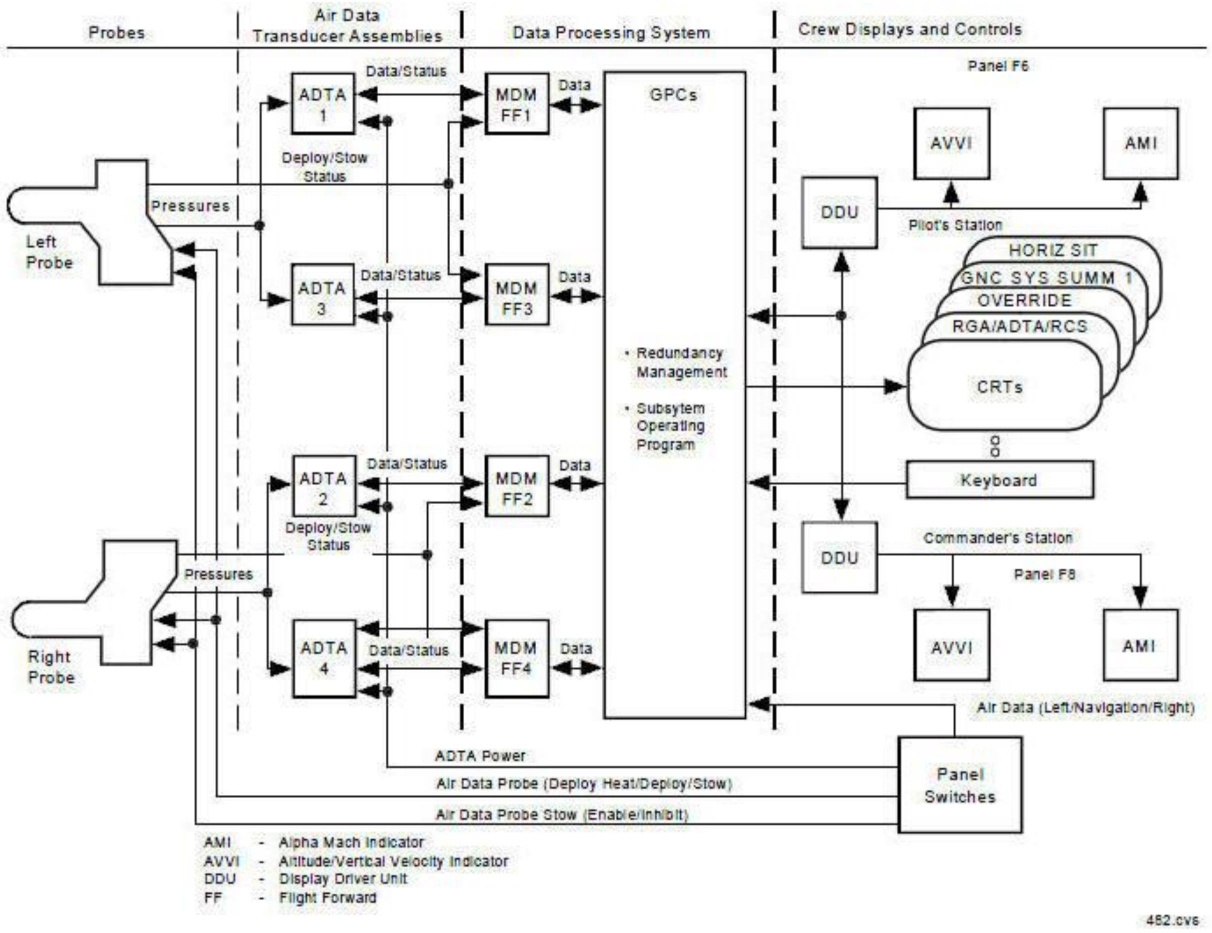
The RGAs remain off on orbit except during flight control system checkout to conserve power. The RGAs afford fail-operational redundancy during both ascent and entry. A quad mid value software scheme selects the best data for use in redundancy management and failure detection.

The RGAs are located on the aft bulkhead below the floor of the payload bay. They are mounted on cold plates for cooling by the Freon-21 coolant loops. The RGAs require five-minute warm-up time.

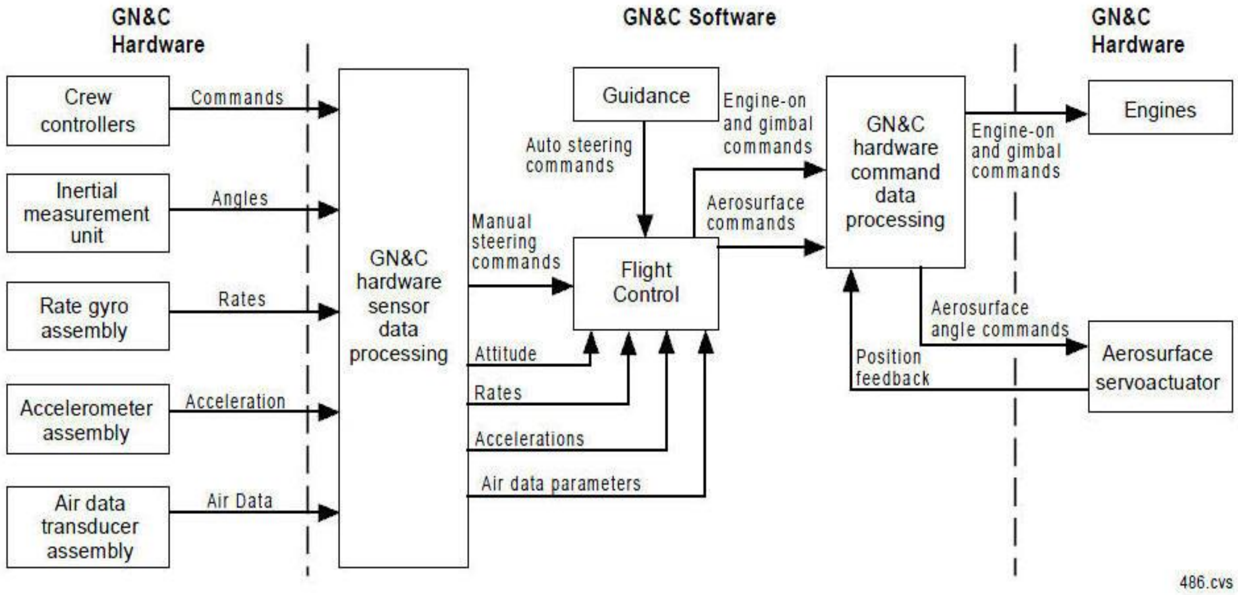
Navigational Control System Schematics



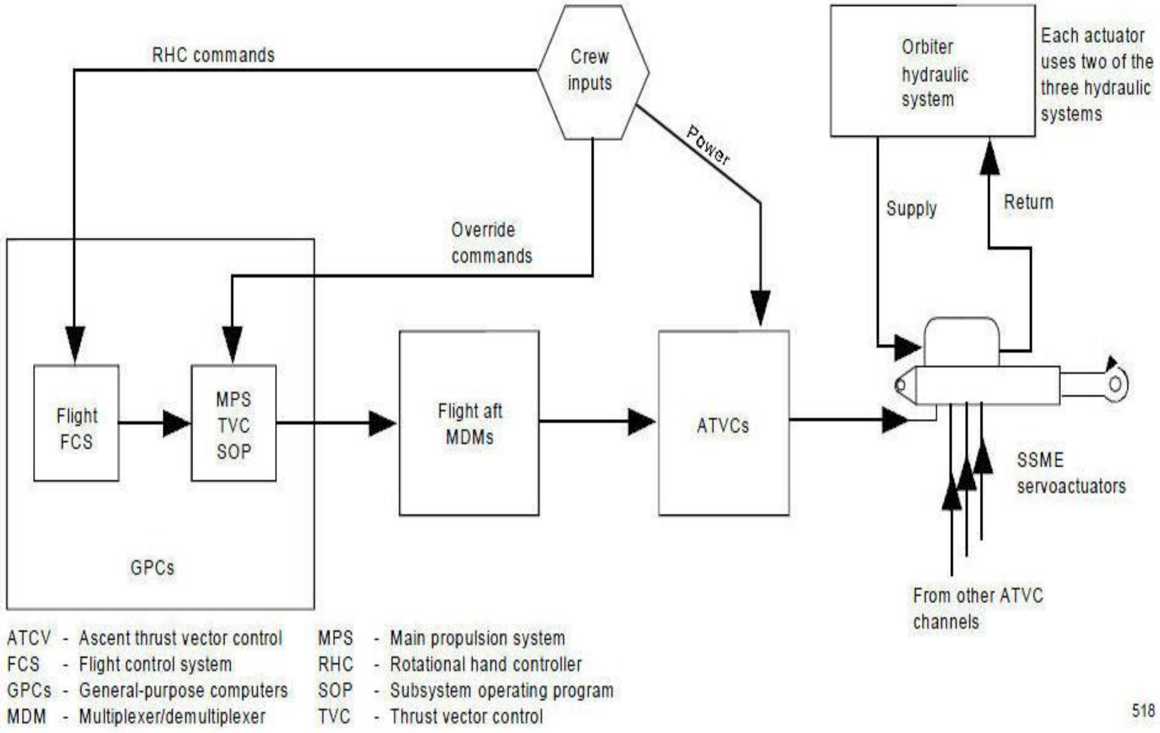
Navigation Interfaces



Air Data System Functional Block Diagram



Flight Control Interfaces



SSME Thrust Vector Control Interface Flow

Orbital Management

Mission control is responsible for monitoring the orbital path of the shuttle. The key position that is responsible for this is “FDO" (pronounced 'Fido'), the flight dynamics officer. FDO is responsible for the space shuttle's motion - predicting the shuttle's path. While the shuttle's on orbit, the FDO is responsible for calculating the shuttle's orbit, maneuvers from the shuttle's maneuvering engines. During the shuttle's entry, the FDO is responsible for calculating whether the shuttle should land from north to south or south to north based on the winds and the sun angles, where the shuttle should touchdown on the runway, and coordinating with emergency landing facilities among other tasks.

CHAPTER 6

The Space Shuttle Landing Systems

Shuttle Landing and Flight Information

Landing the Space Shuttle takes significant practice in that it operates as a glider. Therefore, there is very little room for error. The information in this chapter is not derived from the actual Space Shuttle but from the operation of the Space Shuttle software program in Orbiter which is used for the Student Astronaut Challenge competition and is very similar in many aspects.

Landing Controls

Reaction Control System (RCS) - this is found in the upper left corner of the shuttle HUD displayed in the “Engine Information” area. The RCS must be turned **off** to transfer controls to terrestrial flight and enable the yoke and rudder to operate properly. This is normally done at 35,000 meters.

Flight stick (yoke) – the stick or yoke will operate as the control yoke of the aircraft, it governs the aircraft's roll and pitch by moving the ailerons left and right and moves the elevators backward or forward.

Rudder pedals- the rudder pedals control yaw and move the rudders left or right.

Trim Control - trim tabs are small surfaces connected to the trailing edge of a larger control surface on an aircraft. The trim control is used to manage aerodynamic forces and stabilize the aircraft in a, particularly desired attitude without the need for the operator to constantly apply a control force. As the desired position of a control surface changes (corresponding mainly to different speeds), an adjustable trim tab will allow the operator to reduce the manual force required to maintain that position to zero if used correctly. This is done by adjusting the angle of the tab relative to the larger surface.

Landing Gear – this is the support arms and wheels that are deployed just before landing.

Speed brake – speed brakes are a type of flight control surface used on an aircraft to increase drag or increase the angle of approach during landing. In flight, the air brake will rapidly decrease the speed of an aircraft. On landing the speed, brake helps transfer the weight of the aircraft from the wings to the undercarriage, allowing the wheels to be mechanically braked with much less chance of skidding while assisting the braking effect.

Wheel brakes – the wheel brakes are used in conjunction with the tail chute to slow down the orbiter after touchdown.

Landing Aids

The Shuttle Landing Facility (SLF) at the Kennedy Space Center has two visual approach indicators to aid in shuttle landings. These indicators are the Precision Approach Path Indicator and the Visual Approach Slope Indicator.

Precision Approach Path Indicator- the PAPI consists of an array of 4 lights, which appear white or red to the pilot depending on his position above or below the glide slope. At the correct slope, there will be 2 white and 2 red lights. At Kennedy, there are 2 PAPI units per approach direction at the SLF, located about 2000 meters in front of the runway threshold.

Visual Approach Slope Indicator - The VASI consists of a red bar of lights, and a set of white lights in front of them. At the correct slope, the white lights are aligned with the red bar. At the SLF, the VASI is located about 670 meters behind the runway threshold.

Horizontal Situation Indicator (HSI)

The horizontal situation indicator (3) combines the directional gyro and the NAV indicator into one instrument that provides heading, course reference, and course deviation and glide slope information. The HSI makes it easier to visualize the aircraft's position with reference to the selected course.

- **VOR:** surface-based omnidirectional radio beacons (1), typically with a range of several hundred kilometers. VOR signals can be fed into the HSI (horizontal situation indicator) to obtain direction and distance to the designated runway.

- **ILS:** Many runways are equipped with Instrument Landing Systems (2) to provide heading and glideslope information and are provided by the HSI. The standard ILS for Cape Canaveral pointing North is runway 33 which is the runway most commonly used. The South orientation is designated as runway 15.

- **NAV –** The frequency at which the navigation indicator is broadcasting, it is specific to individual locations. (Kennedy Space Center- 112.70 KHz; Runway 33 at Cape Canaveral 134.20 kHz)**.** For the shuttle, the VOR for KSC will be received immediately. The ILS for Runway 33, when programmed, will be received 30 kilometers from the runway.

- **DST-** Distance to the NAV selected.

- **CRS** – Course is the direction you are currently navigating in

- **BRG-** Bearing is the direction (relative to true north) in which your destination lies.

- **Compass Card / Compass Rose -** The Compass Card (4) is driven by the internal gyro and shows the magnetic heading of the aircraft.

- **Lubber Line -** The number on the Compass Card (4) under the Lubber Line (5) shows the current aircraft magnetic heading.

- **Course Deviation Indicator Bar -** The CDI (6) shows how far the aircraft is off the selected course. When the bar is in line with the yellow arrowhead and tail of the aircraft is exactly on the selected course. When the bar moves to the right when looking in the direction of the arrow, the desired course is on the right (with respect to the aircraft's heading). The scale under the bar shows how far off course the aircraft is. In VOR navigation, each line corresponds to a deviation of two degrees, allowing a total of +/- 10 degrees. The advantage to a standard CDI is that the entire indicator rotates with the Compass Card, giving the pilot a pictorial, symbolic view of the relationship of the aircraft's heading, the selected course, and the current position.

- **DEV-** Numerical course deviation for the deviation bar located at (6).

- **Course Select Pointer/Cursor -** The Course Select Pointer (7), often simply called Cursor, is set to the desired VOR course which is shown under the head of the arrow while the tail marks the reciprocal course. This is also referred to as the Omni Bearing Selector or OBS.

- **Glideslope Line -** The Glideslope Line (8) come into view when a glideslope signal is being received during an ILS approach, and the aircraft's position is within the defined range and slope of the glideslope signal. This is a very sensitive display. A full deflection corresponds to a 1.4 degrees difference in the glideslope.

- **FROM-**In, the lower left corner of the instrument, is the TO/FROM indicator. If you see “TO” displayed it means that you are working with a bearing from you to the ground station. If you see “FROM” displayed it indicates a radial from the ground station to you.

Surface Earth Multi-function display

The Surface Earth MFD assists in flight close to the planetary surface. It provides the pilot with information for operating the aircraft when it is in the earth’s atmosphere. The most important component is the “Artificial Horizon” which is a pictorial representation of the earth. The blue portion represents the sky, and the green or brown portion represents the ground. The horizon line represents the aircraft. The pitch ladder and sky pointer move in relation to it, providing the indications of pitch, roll, and “which way is up.” The Sky Pointer is the white triangle in the middle of the bank indicator hash marks; this simply points up at all times.

- Artificial horizon (1)
  - Pitch
  - Bank
- Heading indicator (2)
- Altitude (3)
- Vertical speed (4)
- Vertical acceleration in m/sec^2 (5)
- Ground Speed (6)
- Acceleration in m/sec^2 (7)
- The angle of attack (8)
- Atmospheric data (9)
  - OAT: Outside Air Temperature in Kelvin
  - M: Mach number M=v/a, with airspeed v and speed of sound a.
  - DNS: Atmospheric density [kg m^{-3}]
- Equatorial position (longitude and latitude, and rate of change (10)

ATM DATA | DNS 1.224
OAT 288K | STP 101.3kPa
M 0.00 | DNP 0.00Pa

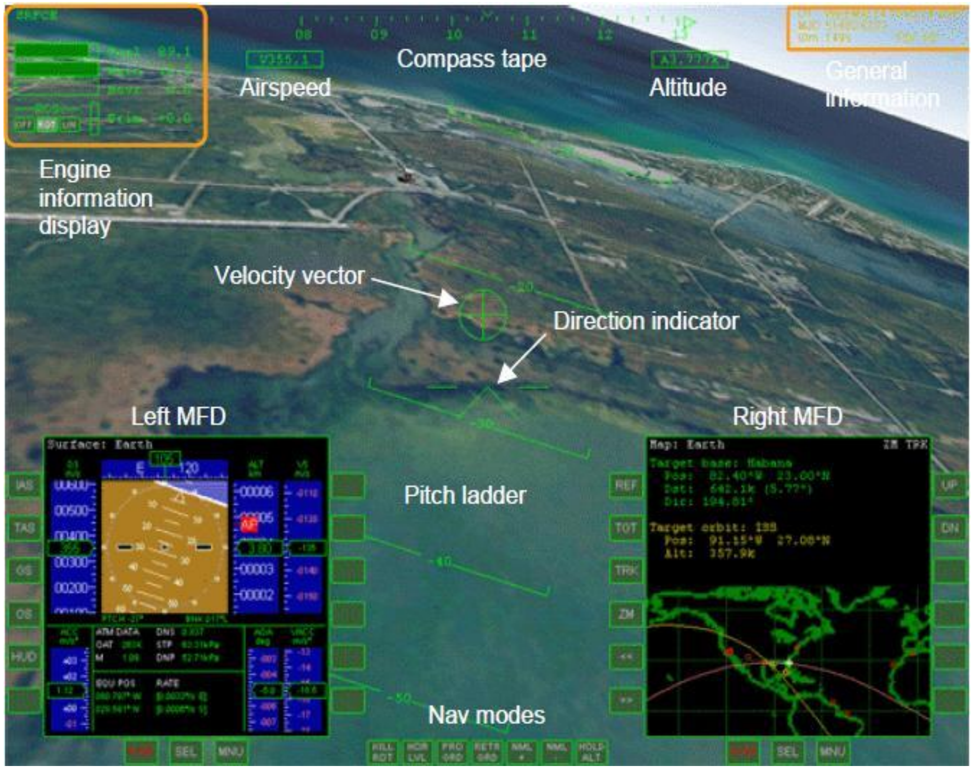
EQU POS | RATE
080.683° W | [0.0000°/s E]
028.597° N | [0.0000°/s N]

Heads-up Display

A head-up display or heads-up display (also known as a HUD) is any transparent display that presents data without requiring users to look away from their usual viewpoints. The origin of the name stems from a pilot being able to view information with the head positioned "up" and looking forward, instead of angled down looking at lower instruments. The heads-up display provides the important data from the Surface Earth Multi-function display and provides essential information for landing.

When landing the HUD should be set on “Surface Earth” mode to ensure the proper information for landing is being used. Two important aspects are the “direction indicator” and the “velocity vector.” The “direction indicator” is the fixed forward point that shows the up orientation of the craft or the nose of the aircraft. The “velocity vector” is the flight path based on current heading, velocity, and rate of descent. The “velocity vector” will continuously change as the pilot changes any of the three flight aspects.

The “pitch ladder” corresponds with the “pitch ladder” in the artificial horizon. This depicts the pitch angle of the aircraft in relation to the horizon. It consists of horizontal lines above and below the neutral “zero-pitch” line, which is a thin white line stretched across the entire screen, the ladder rungs are in 10-degree increments. Small horizontal lines below the zero-pitch line are found on the artificial horizon. This is done to provide for precise pitch control during landing approach and is not reproduced on the HUD.



Landing Locations

There are two runways at Cape Canaveral that can be seen. The first runway is the military airport located on the southern end of Merritt Island; it is referred to as the Air Force Skid Strip. The ‘Skid Strip” is 10,000 feet by 200 feet and is used by USAF and NASA to land transport and training aircraft. The second runway is the shuttle landing facility located on the northern end of Merritt Island. When the approach is coming out of the south the runway is designated SLF 33, when the approach is from the North it is designated SLF 15.such This runway is designated as the Space Shuttle landing site in Florida. The SLF is 15,000 feet long and 300 feet wide with an extra 1,000 feet of paved overruns at each end. There are two additional landing areas for the space shuttle; Edwards Air Force Base in California and White Sands Space Harbor in New Mexico.

1. Initial Approach of the Space Shuttle

a. The Reaction Control System (RCS), found in the upper left corner of the HUD display, in the “Engine Information” area is turned off to transfer controls to terrestrial flight and enable the yoke and rudder to operate properly. This is normally done at 35,000 meters. However, the full effects of lift and control over the shuttle’s flight path will not occur until 28,000 meters is reached.
b. The VOR is tuned to the Kennedy Space Center. The ILS is oriented to the correct runway 33 or 15 which is at Cape Canaveral.
c. All in-flight maneuvers follow the “Direction Indicator” and are managed by operating the yoke and rudder.
d. The “Velocity vector” will slowly orient to the correct position, this helps judge the flight path.
e. To increase airspeed, the yoke is pushed forward. However, this will decrease altitude rapidly. To increase altitude, the yoke is pulled back, but this will decrease airspeed.
f. The space shuttle is a very heavy glider that relies on its descent speed to provide lift.
g. The Orbiter Shuttle stalls between 100 and 125 m/s, however, if the pitch is above + 20 degrees, this may occur as high as 150 m/s.

2. Final Approach of the Space Shuttle

a. When performing an ILS approach to runway 33or 15 at the Kennedy Space Center, the initial pitch is -15° and the PAPI indicators ahead of the runway are used for glideslope adjustment.
b. The split rudder speed brake is used to bleed off airspeed if necessary during the approach.
c. On approach, the nose is slowly raised to touch down with an AOA of approx. +10°.
d. The gear is lowered during the final flare-up, about 10 seconds before touchdown.
e. Touchdown speed is approximately 180-200 m/s., anything below 150 m/s can damage the landing gear and tires.

In Space Flight Operation

When operating in a zero-atmosphere condition (outer space) the Reaction Control System (RCS) is turned **on**. The RCS mode is displayed in the upper left corner of the HUD display in the “Engine Information” area. Turning on the RCS allows the yoke and rudder control to operate the “Reaction Control Engines” (RCS). In this mode, the pilot can use the yoke and rudder to orient the space shuttle manually.

The Reaction Control System (RCS) is composed of 44 small liquid-fueled rocket thrusters and a very sophisticated computerized (fly-by-wire) flight control system. This control system provides attitude control along the pitch, roll, and yaw axes so as to allow manual orbital maneuvers.

In order to operate the shuttle in space, the HUD should be in “**Orbit Earth Mode**” to provide the necessary information for positioning the shuttle in either a pro-grade or retro-grade orientation.

```
Mon Aug 13 20:31:42 2012
MJD 56152.8554   WRP 0.1x
SIM 85s          FOV 60°
FPS 70           [1018x742x32]
```

```
Orbit: Earth                 Frm ECL  Prj ECL
--OSC.EL.--
SMa 6.673M
SMi 6.673M
PeR 6.670M
ApR 6.675M
Rad 6.671M
Ecc 0.0003
T   5.424k
PeT 716.5
ApT 3.429k
Vel 7.731k
Inc 113.31°
LAN 183.30°
LPe 350.61°
AgP 167.31°
TrA 312.42°
TrL 303.03°
MnA 312.45°
MnL 303.06°
G 1.00
```

```
Surface: Earth
PTCH +05°        BNK 127°L
ATM DATA  DNS 0.000
OAT N/A   STP 0.00Pa
M   N/A   DNP 0.00Pa
EQU POS        RATE
092.780° E     [0.0037°/s W]
061.656° N     [0.0664°/s S]
```

When the HUD is in “Orbit Earth” mode, the flight path ladder is aligned with the orbital plane instead of the horizon plane, and there is a ribbon showing the orbital azimuth angle. It also shows indicators for pro-grade (the direction of your orbital velocity vector) and retrograde (the opposite direction). When in pro-grade the orbital plane is 000 degrees, and the azimuth angle is 000 degrees when in retrograde the orbital plane is 180 degrees, and the azimuth angle is 00 degrees.

The HUD provides Orbital Speed data in K/sec. (OS) and “Eccentric Anomaly in the Nominal Orbit” (rad.) data. To demonstrate the maneuver and place the shuttle in either pro-grade or retro-grade select the computer directed maneuver icons on the bottom of the HUD screen. The flight computer will automatically position the shuttle to the correct position for pro-grade and retro-grade.

Glossary of Essential Terms

A

a, A -- Acceleration. a = Δ velocity / Δ time. Acceleration = Force / Mass

A -- Ampere, the SI base unit of electric current.

AC -- Alternating current

AC Bus - A system that distributes alternating current electrical power

Acceleration -- Change in velocity. Note that since velocity comprises both direction and magnitude (speed), a change in either direction or speed constitutes acceleration.

ALT – Altitude or Altimetry data.

AO -- Announcement of Opportunity.

AOS -- Acquisition of Signal.

Aphelion -- Apoapsis in solar orbit.

Apoapsis -- The farthest point in an orbit from the body being orbited.

Apogee -- Apoapsis in Earth orbit.

APU – Auxiliary Power Unit is a device that provides energy for functions other than propulsion. They can provide hydraulic power for gimballing of engines and control surfaces. During landing, they power the control surfaces and brakes.

Argument -- Angular distance.

Argument of periapsis -- The argument (angular distance) of periapsis from the ascending node.

Ascending node -- The point at which an orbit crosses a reference plane (such as a planet's equatorial plane or the ecliptic plane) going north.

Asteroids -- Small bodies composed of rock and metal in orbit about the sun.

AU -- Astronomical Unit, based on the mean Earth-to-sun distance, 149,597,870 km. Refer to "Units of Measure" section for complete information.

AZ -- Azimuth.

B

Boiler System – this water system cools the Auxiliary Power Unit (APU) lubrication oil and hydraulic fluid. Three independent Water Spray Boilers each serve a corresponding APU. The Water Spray Boiler System sprays water onto the APU lubrication oil and hydraulic fluid lines, thus cooling the fluids within them.

BPS -- Bits per Second, same as Baud rate.

C

c -- The speed of light, 299,792 km per second.

C-band -- A range of microwave radio frequencies in the neighborhood of 4 to 8 GHz.

Carrier -- The main frequency of a radio signal generated by a transmitter prior to application of any modulation.

Centrifugal force -- The outward-tending apparent force of a body revolving around another body.

Centripetal acceleration -- The inward acceleration of a body revolving around another body.

Chandler wobble -- A small motion in the Earth's rotation axis relative to the surface, discovered by American astronomer Seth Carlo Chandler in 1891. Its amplitude is about 0.7 arcseconds (about 15 meters on the surface) with a period of 433 days. It combines with another wobble with a period of one year, so the total polar motion varies with a period of about 7 years. The Chandler wobble is an example of free nutation for a spinning non-spherical object.

Channel -- In telemetry, one particular measurement to which changing values may be assigned.

Clarke orbit -- Geostationary orbit.

Conjunction -- A configuration in which two celestial bodies have their least apparent separation.

Coma -- The cloud of diffuse material surrounding the nucleus of a comet.

Comets -- Small bodies composed of ice and rock in various orbits about the sun.

COMM – communication system

CRT -- Cathode ray tube video display device.

CST -- Central Standard Time.

D

DAP – The Digital Auto Pilot controls the RCS thrusters when in orbit.

DC -- Direct current.

DEC -- Declination.

Declination -- The measure of a celestial body's apparent height above or below the celestial equator.

Density -- Mass per unit volume. For example, the density of water can be stated as 1 gram/cm3.

Descending node -- The point at which an orbit crosses a reference plane (such as a planet's equatorial plane or the ecliptic plane) going south.

Doppler Effect -- The effect on frequency imposed by relative motion between transmitter and receiver. See Chapters 2, 4 and 5.

Downlink -- Signal received from a spacecraft.

DSN – NASA’s Deep Space Network.

E

Eccentricity -- The distance between the foci of an ellipse divided by the major axis.

Ecliptic -- The plane in which Earth orbits the sun and in which solar and lunar eclipses occur.

EDL -- (Atmospheric) Entry, Descent, and Landing.

EGT – APU Exhaust Gas Temperature.

Ellipse -- A closed plane curve generated in such a way that the sums of its distances from the two fixed points (the foci) is constant.

ELV -- Expendable launch vehicle.

EM – Electromagnetic

EMF -- Electromagnetic force

(radiation). EMR --

Electromagnetic radiation.

Equator -- An imaginary circle around a body which is everywhere equidistant from the poles, defining the boundary between the northern and southern hemispheres.

Equinox -- The equinoxes are times at which the center of the Sun is directly above the Earth's equator. The day and night would be of equal length at that time if the Sun were a point and not a disc, and if there were no atmospheric refraction. Given the apparent disc of the Sun and the Earth's atmospheric refraction, day and night actually become equal at a point within a few days of each equinox. The vernal equinox marks the beginning of spring in the northern hemisphere, and the autumnal equinox marks the beginning of autumn in the northern hemisphere.

ERT -- Earth-received time, UTC of an event at DSN receive-time, equal to SCET plus OWLT.

EST -- Eastern Standard Time.

ET -- Ephemeris time, a measurement of time defined by orbital motions. Equates to Mean Solar Time corrected for irregularities in Earth's motions. Obsolete, replaced by TT, Terrestrial Time.

eV -- Electron volt, a measure of the energy of subatomic particles.

F

f, F -- Force. Two commonly used units of force are the Newton and the dyne. Force = Mass X Acceleration.

FDS -- Flight Data Subsystem.

FE -- Far Encounter phase of mission operations.

Fluorescence -- The phenomenon of emitting light upon absorbing radiation of an invisible wavelength.

FM -- Frequency modulation.

FTS -- DSN Frequency and Timing System. Also, frequency and timing data.

G

G -- Universal Constant of Gravitation. Its tiny value (G = 6.6726 x 10-11 Nm2/kg2) is unchanging throughout the universe.

g -- Acceleration due to a body's gravity. Constant at any given place, the value of g varies from object to object (e.g., planets), and also with the distance from the center of the object. The relationship between the two constants is g = GM/r2 where r is the radius of separation between the masses' centers, and M is the mass of the primary body (e.g., a planet). At Earth's surface, the value of g = 9.8 meters per second per second (9.8m/s2). See also weight.

Gamma rays -- Electromagnetic radiation in the neighborhood of 100 femtometers wavelength.

GEO -- Geosynchronous Earth Orbit.

Geostationary -- A geosynchronous equatorial circular orbit. Also called Clarke orbit.

Geosynchronous -- A direct, circular, low inclination orbit about the Earth having a period of 23 hours 56 minutes 4 seconds.

GMT -- Greenwich Mean Time. Obsolete. UT, Universal Time is preferred.

GPC – General Purpose Computer Control. When the toggle switch is in the straight up or middle position (not on or off) it allows the valve to be controlled by the flight software loaded in the general purpose computer.

Gravitation -- The mutual attraction of all masses in the universe. Newton's Law of Universal Gravitation holds that every two bodies attract each other with a force that is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. This relation is given by the formula: **$F = Gm_1m_2/d^2$**, where **F** is the force of attraction between the two objects, given **G** the Universal Constant of Gravitation, masses **m1** and **m2**, and **d** distance. Also stated as **$F_g = GMm/r^2$** where **F_g** is the force of gravitational attraction, **M** the larger of the two masses, **m** the smaller mass, and **r** the radius of separation of the centers of the masses. See also weight.

Gravitational waves -- Einsteinian distortions of the space-time medium predicted by general relativity theory (not yet directly detected as of March 2010). (Not to be confused with gravity waves, see below.)

Gravity assist -- Technique whereby a spacecraft takes angular momentum from a planet's solar orbit (or a satellite's orbit) to accelerate the spacecraft or the reverse.

Gravity waves -- Certain dynamical features in a planet's atmosphere (not to be confused with gravitational waves, see above).

GTO -- Geostationary (or geosynchronous) Transfer Orbit.

H

H_2 Main Propulsion System - Within the orbiter aft fuselage, liquid hydrogen and liquid oxygen pass through the manifolds, distribution lines and valves of the propellant management subsystem. During prelaunch activities, this subsystem is used to control the loading of liquid oxygen and liquid hydrogen in the external tank. During SSME thrusting periods, propellants from the external tank flow into this subsystem and to the three SSMEs. The subsystem also provides a path that allows gases tapped from the three SSMEs to flow back to the external tank through two gas umbilical's to maintain pressure in the external tank's liquid oxygen and liquid hydrogen tanks. After MECO, this subsystem controls MPS dumps, vacuum inerting and MPS re-pressurization for entry.

HA -- Hour Angle.

Halo orbit -- A spacecraft's pattern of controlled drift about an unstable Lagrange point (L1 or L2 for example) while in orbit about the primary body (e.g., the Sun).

Heliocentric -- Sun-centered.

Heliopause -- The boundary theorized to be roughly circular or teardrop-shaped, marking the edge of the sun's influence, perhaps 100 AU from the sun.

Heliosphere -- The space within the boundary of the heliopause, containing the sun and solar system.

Helium System - During prelaunch, the pneumatic helium supply provides pressure to operate the liquid oxygen and hydrogen pre-valves and outboard and inboard fill and drain valves. The three engine helium supply systems are used to provide anti-icing purges.

HGA -- High-Gain Antenna onboard a spacecraft.

Hohmann Transfer Orbit -- Interplanetary trajectory using the least amount of propulsive energy.

Horizon -- The line marking the apparent junction of Earth and sky.

h -- Hour, 60 minutes of time.

Hour Angle -- The angular distance of a celestial object measured westward along the celestial equator from the zenith crossing. In effect, HA represents the RA for a particular location and time of day.

HSI – the Horizontal Situation Indicator is used to follow both the glideslope and localizer. When tuned to the proper frequency, the navigation radio, or NAV, sends a signal to the HSI and two indicators will appear. The indicators are oriented perpendicular to each other - one oriented horizontally and the other vertically. The pilot maneuvers the aircraft so that the indicators form a "+" in the center of the HSI. When this occurs, the pilot knows that the aircraft is both on the proper glide path and is lined up with the runway.

HUD -- Head-Up Display or Heads-Up Display is any transparent display that presents data without requiring users to look away from their usual viewpoints. The origin of the name stems from a pilot being able to view information with the head positioned "up" and looking forward, instead of angled down looking at lower instruments.

Hydraulic System -- This system distributes the hydraulic pressure produced by the Auxiliary Power Unit (APU) System. The Hydraulic System is made up of three independent hydraulic systems, each of which is mated to a corresponding APU.

I

IF -- Intermediate Frequency. In a radio system, a selected processing frequency between RF (Radio Frequency) and the end product (e.g., audio frequency).

IMU – The Inertial Measurement Units consist of an all-attitude, four-gimbal, inertially stabilized platform. They provide inertial attitude and velocity data to the navigation software. Guidance uses the attitude data, along with state vectors from the navigation software, to develop steering commands for flight control.

Inclination -- The angular distance of the orbital plane from the plane of the planet's equator, stated in degrees.

Inferior planet -- Planet which orbits closer to the Sun than the Earth's orbit.

Inferior conjunction -- Alignment of Earth, sun, and an inferior planet on the same side of the sun.

Ion -- A charged particle consisting of an atom stripped of one or more of its electrons.

IR -- Infrared, meaning "below red" radiation. Electromagnetic radiation in the neighborhood of 100 micrometers wavelength.

ISOE -- Integrated Sequence of Events.

Isolation valves - The propellant tank isolation valves are located between the propellant tanks and the manifold isolation valves and are used to isolate the propellant tanks from the remainder of the propellant distribution system

Isotropic -- Having uniform properties in all directions.

IUS -- Inertial Upper Stage.

K

K-band -- A range of microwave radio frequencies in the neighborhood of 12 to 40 GHz.

Keyhole -- An area in the sky where an antenna cannot track a spacecraft because the required angular rates would be too high. Mechanical limitations may also contribute to keyhole size.

Klystron -- A microwave traveling wave tube power amplifier used in transmitters.

Kuiper belt -- A disk-shaped region about 30 to 100 AU from the sun considered to be the source of the short-period comets.

L

Lagrange points -- Five points with respect to an orbit which a body can stably occupy. Designated L1 through L5.

LAN -- Local area network for inter-computer communications.

Laser -- Light Amplification by Stimulated Emission of Radiation. Compare with Maser.

Latitude -- Circles in parallel planes to that of the equator defining north-south measurements, also called parallels.

L-band -- A range of microwave radio frequencies in the neighborhood of 1 to 2 GHz.

LCP -- Left-hand circular polarization.

LEO -- Low Equatorial Orbit.

LGA -- Low-Gain Antenna onboard a spacecraft.

Light -- Electromagnetic radiation in the neighborhood of 1-nanometer wavelength.

Lightspeed -- 299,792 km per second, the constant c.

Light time -- The amount of time it takes light or radio signals to travel a certain distance at light speed.

Lightyear -- A measure of distance, the distance light travels in one year, about 63,197 AU.

Local time -- Time adjusted for location around the Earth or other planets in time zones.

Longitude -- Great circles that pass through both the north and south poles, also called meridians.

LOS -- Loss of Signal, used in DSN operations.

LOX -- Liquid oxygen.

M

m, M -- Mass. The kilogram is the standard unit of mass. Mass = Acceleration / Force.

Major axis -- The maximum diameter of an ellipse.

Maser -- A microwave traveling wave tube amplifier named for its process of Microwave Amplification by Stimulated Emission of Radiation. Compare with Laser. In the Deep Space Network, masers are used as low-noise amplifiers of downlink signals, and also as frequency standards.

Mass -- A fundamental property of an object comprising a numerical measure of its inertia; the amount of matter in the object. While an object's mass is constant (ignoring Relativity for this purpose), its weight will vary depending on its location. Mass can only be measured in conjunction with force and acceleration.

Mean solar time -- Time based on an average of the variations caused by Earth's non-circular orbit. The 24-hour day is based on mean solar time.

MECO - Main Engine Cut Off point is where the engines shut down at about 8 minutes and 30 seconds into the flight.

Meridians -- Great circles that pass through both the north and south poles, also called lines of longitude.

Meteor -- A meteoroid which is in the process of entering Earth's atmosphere. It is called a meteorite after landing.

Meteorite -- Rocky or metallic material which has fallen to Earth or to another planet.

Meteoroid -- Small bodies in orbit about the sun which are candidates for falling to Earth or to another planet.

MFD -- Multi-function display is a small screen in an aircraft that can be used to display information to the pilot in numerous configurable ways.

MGA -- Medium-Gain Antenna onboard a spacecraft.

MLI -- Multi-layer insulation (spacecraft blanketing).

Modulation -- The process of modifying a radio frequency by shifting its phase, frequency, or amplitude to carry information.

MST -- Mountain Standard Time.

Multiplexing -- A scheme for delivering many different measurements in one data stream.

N

N -- Newton, the SI unit of force equal to that required to accelerate a 1-kg mass 1 m per second per second (1m/sec2).

Nadir -- The direction from a spacecraft directly down toward the center of a planet. Opposite the zenith.

NE -- Near Encounter phase in flyby mission operations.

NiCad -- Nickel-cadmium rechargeable battery.

Nodes -- Points where an orbit crosses a reference plane.

Non-coherent -- Communications mode wherein a spacecraft generates its downlink frequency independent of any uplink frequency.

Nucleus -- The central body of a comet.

Nutation -- A small nodding motion in a rotating body. Earth's nutation has a period of 18.6 years and an amplitude of 9.2 arc seconds.

O

OB -- Observatory phase in flyby mission operations encounter period.

OMS - The Space Shuttle Orbital Maneuvering System, is a system of rocket engines for use on the space shuttle orbiter for orbital injection and modifying its orbit

One-way -- Communications mode consisting only of downlink received from a spacecraft.

Oort cloud -- A large number of comets theorized to orbit the sun in the neighborhood of 50,000 AU.

Opposition -- Configuration in which one celestial body is opposite another in the sky. A planet is in opposition when it is 180 degrees away from the sun as viewed from another planet (such as Earth). For example, Saturn is at opposition when it is directly overhead at midnight on Earth.

OTM -- Orbit Trim Maneuver, spacecraft propulsive maneuver.

OWLT -- One-Way Light Time, the elapsed time between Earth and spacecraft or solar system body.

P

PAM -- Payload Assist Module upper stage.

Parallels -- Circles in parallel planes to that of the equator defining north-south measurements, also called lines of latitude.

PDT -- Pacific Daylight Time.

PE -- Post Encounter phase in flyby mission operations.

Periapsis -- The point in an orbit closest to the body being orbited.

Perigee -- Periapsis in Earth orbit.

Phase -- The angular distance between peaks or troughs of two waveforms of similar frequency.

Phase -- The particular appearance of a body's state of illumination, such as the full or crescent phases of the Moon.

Phase -- Any one of several predefined periods in a mission or other activity.

Photovoltaic -- Materials that convert light into electric current.

Plasma -- Electrically conductive fourth state of matter (other than solid, liquid, or gas), consisting of ions and electrons.

PM -- Post meridiem (Latin: after midday), afternoon.

Prograde -- Orbit in which the spacecraft moves in the same direction as the planet rotates. See retrograde.

PST -- Pacific Standard Time.

Q

Quasar -- Quasi-stellar object observed mainly in radio waves. Quasars are extragalactic objects believed to be the very distant centers of active galaxies.

R

RA -- Right Ascension.

Radian -- Unit of angular measurement equal to the angle at the center of a circle subtended by an arc equal in length to the radius. Equals about 57.296 degrees.

RAM -- Random Access Memory.

RCS – The reaction control system is a subsystem of a spacecraft whose purpose is attitude control and steering by the use of thrusters. An RCS system is capable of providing small amounts of thrust in any desired direction or combination of directions The RCS engines use a Hypergolic Fuel which lights up when its two components (Fuel and Oxidizer) come into contact. This allows the system to be almost fail-safe due to the simple nature of the system.

Reflection -- The deflection or bouncing of electromagnetic waves when they encounter a surface.

Refraction -- The deflection or bending of electromagnetic waves when they pass from one kind of transparent medium into another.

Retrograde -- Orbit in which the spacecraft moves in the opposite direction from the planet's rotation. See prograde.

RF -- Radio Frequency.

RFI -- Radio Frequency Interference.

RGA - The rate gyro assemblies are used by the flight control system during ascent, entry, and aborts as feedbacks to final rate errors that are used to augment stability and for display on the commander's and pilot's attitude director indicator.

Right Ascension -- The angular distance of a celestial object measured in hours, minutes, and seconds along the celestial equator eastward from the vernal equinox.

Rise -- As in ascending above the horizon,

ROM -- Read Only Memory.

S

s -- Second, the SI base unit of time.

SA -- Solar Array, photovoltaic panels onboard a spacecraft.

SAR -- Synthetic Aperture Radar

Satellite -- A small body which orbits a larger one. A natural or an artificial moon. Earth-orbiting spacecraft are called satellites. While deep-space vehicles are technically satellites of the sun or of another planet, or of the galactic center, they are generally called spacecraft instead of satellites.

S-band -- A range of microwave radio frequencies in the neighborhood of 2 to 4 GHz.

SCET -- Spacecraft Event Time, equal to ERT minus OWLT.

SCLK -- Spacecraft Clock Time, a counter onboard a spacecraft.

Sec -- Abbreviation for Second.

Second -- the SI base unit of time.

Semi-major axis -- Half the distance of an ellipse's maximum diameter, the distance from the center of the ellipse to one end.

Set -- As in going below the horizon.

SI -- The International System of Units (metric system).

SI base unit -- One of seven SI units of measure from which all the other SI units are derived.

SI derived unit -- One of many SI units of measure expressed as relationships of the SI base units. For example, the watt, W, is the SI derived unit of power. It is equal to joules per second. W = m2 · kg · s–3 (Note: the joule, J, is the SI derived unit for energy, work, or quantity of heat.)

Sidereal time -- Time relative to the stars other than the sun.

SSME - Space Shuttle Main Engines are reusable liquid-fuel rocket engines, each Space Shuttle ascent to orbit is propelled by three engines

SOE -- Sequence of Events.

Solar wind -- Flow of lightweight ions and electrons (which together comprise plasma) thrown from the sun.

SNR -- Signal-to-Noise Ratio.

Specific Impulse -- A measurement of a rocket's relative performance. Expressed in seconds, the number of which a rocket can produce one pound of thrust from one pound of fuel. The higher the specific impulse, the less fuel required to produce a given amount of thrust.

Spectrum -- A range of frequencies or wavelengths.

Star tracker - The star tracker system is part of the orbiter's navigation system which works to help maintain the IMU during flight.

STS -- Space Transportation System (Space Shuttle).

Subcarrier -- Modulation applied to a carrier which is itself modulated with information-carrying variations.

T

TCM -- Trajectory Correction Maneuver, spacecraft propulsive maneuver.

TCS - Thermal Conditioning System consists of an air revitalization system, water coolant loop systems, atmosphere revitalization pressure control system, active thermal control system, supply water and wastewater system, waste collection system and airlock support system. These systems interact to provide a habitable environment for the flight crew in the crew compartment in addition to cooling or heating various orbiter systems or components.

TOS -- Transfer Orbit Stage, upper stage.

Transducer -- Device for changing one kind of energy into another, typically from heat, microphone or speaker.

Transponder -- an Electronic device which combines a transmitter and a receiver.

TRM -- Transmission Time, UTC Earth time of uplink.

True anomaly -- The angular distance of a point in an orbit past the point of periapsis, measured in degrees.

U

UHF -- Ultra-high frequency (around 300MHz).

µm -- Micrometer (10-6 m).

Uplink -- Signal sent to a spacecraft.

UT -- Universal Time, also called Zulu (Z) time, previously Greenwich Mean Time. UT is based on the imaginary "mean sun," which averages out the effects on the length of the solar day caused by Earth's slightly non-circular orbit about the sun. UT is not updated with leap seconds as is UTC.

UTC -- Coordinated Universal Time, the world-wide scientific standard of timekeeping. It is based upon carefully maintained atomic clocks and is highly stable. Its rate does not change by more than about 100 picoseconds per day. The addition or subtraction of leap seconds, as necessary, at two opportunities every year adjusts UTC for irregularities in Earth's rotation.

UV -- Ultraviolet (meaning "above violet") radiation. Electromagnetic radiation in the neighborhood of 100 nanometers wavelength.

V

Velocity -- A vector quantity whose magnitude is a body's speed and whose direction is the body's direction of motion.

W

W -- Watt, a measure of electrical power equal to potential in volts times current in amps.

Walking orbit -- A spacecraft orbit that precesses, wherein the location of periapsis changes with respect to the planet's surface in a useful way.

Wavelength -- The distance that a wave from a single oscillation of electromagnetic radiation will propagate during the time required for one oscillation.

Weight -- The gravitational force exerted on an object of a certain mass. The weight of mass m is mg Newtons, where g is the local acceleration due to a body's gravity.

WWW -- World-Wide Web.

X

X-band -- A range of microwave radio frequencies in the neighborhood of 8 to 12

GHz. X-ray -- Electromagnetic radiation in the neighborhood of 100 picometer

wavelength.

Z

Z -- Zulu in the phonetic alphabet, stands for UT, Universal Time.

Zenith -- The point on the celestial sphere directly above the observer. Opposite the nadir.

References

"How Space Shuttles Works" by Craig Freudenrich, Ph.D.
http://science.howstuffworks.com/space-shuttle1.htm

"NSTS 1988 Reference Manual" National Aeronautics and Space Administration
http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/stsref-toc.html

"Orbiter" by Martin Schweiger, Ph.D.
http://orbit.medphys.ucl.ac.uk

"Space Shuttle Operating Systems" by National Aeronautics and Space Administration"
http://science.ksc.nasa.gov/shuttle

"Space Technology and Engineering project" by Peter Carafano, RN, M.Ed.
http://stem21id.wikispaces.com/file/.../Project+Abstract+and+Summary2.do

"The Basics of Flight" by Jet Propulsion Laboratory, California Institute of Technology
http://www2.jpl.nasa.gov/basics/