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The Survey of Space Shuttle

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Abstract: ***The Space Shuttle was a spacecraft which was used by the American National Aeronautics and Space Administration, or NASA. Space Shuttles were used to carry astronauts and cargo into space. Cargo such as satellites, parts of a space station or scientific instruments were taken up into space by the space shuttle. The Space Shuttle design was remarkable. The idea of "wings in orbit" took concrete shape in the brilliant minds of NASA engineers, and the result was the most innovative, elegant, versatile, and highly functional vehicle of its time. The shuttle was indeed an engineering marvel on many counts. Accomplishing these feats required the design of a very complex system.It was a new kind of spacecraft because it could be used again and again. In this paper we summarize the development of space shuttle including assembly, inspection and maintenance.***

Keywords: Astronauts, Satellites, Space Station, Scientific Instruments

1. Objectives

1) To understand the concept of Space Shuttle.
2) Familiarize yourself with parts of shuttle.
3) To know the working of space shuttle.

2. Introduction

The **Space Shuttle** was a partially **reusable low Earth orbital spacecraft system** operated by the U.S. National Aeronautics and Space Administration (NASA) as part of the Space Shuttle program. Its official program name was Space Transportation System (STS), taken from a 1969 plan for a system of reusable spacecraft of which it was the only item funded for development.The first of four orbital test flights occurred in 1981, leading to operational flights beginning in 1982. In addition to the prototype whose completion was cancelled, five complete Shuttle systems were built and used on a total of 135 missions from 1981 to 2011, launched from the Kennedy Space Center (KSC) in Florida. Operational missions launched numerous satellites, interplanetary probes, and the Hubble Space Telescope (HST); conducted science experiments in orbit; and participated in construction and servicing of the International Space Station. The Shuttle fleet's total mission time was 1322 days, 19 hours, 21 minutes and 23 seconds.

Shuttle components included the Orbiter Vehicle (OV) with three clustered Rocket dyne RS-25 main engines, a pair of recoverable solid rocket boosters (SRBs), and the expendable external tank (ET) containing liquid hydrogen and liquid oxygen. The Space Shuttle was launched vertically, like a conventional rocket, with the two SRBs operating in parallel with the OV's three main engines, which were fueled from the ET. The SRBs were jettisoned before the vehicle reached orbit, and the ET was jettisoned just before orbit insertion, which used the orbiter's two Orbital Maneuvering System (OMS) engines. At the conclusion of the mission, the orbiter fired its OMS to de-orbit and re-enter the atmosphere. The orbiter then glided as a spaceplane to a runway landing, usually to the Shuttle Landing Facility at Kennedy Space Center, Florida or Rogers Dry Lake in Edwards Air Force Base, California. After landing at Edwards, the orbiter was flown back to the KSC on the Shuttle Carrier Aircraft, a specially modified Boeing 747.

3. Components of Space Shuttle

1) External Tank.
2) Orbiter.
3) Solid Rocket Booster.
4) Main Engine.

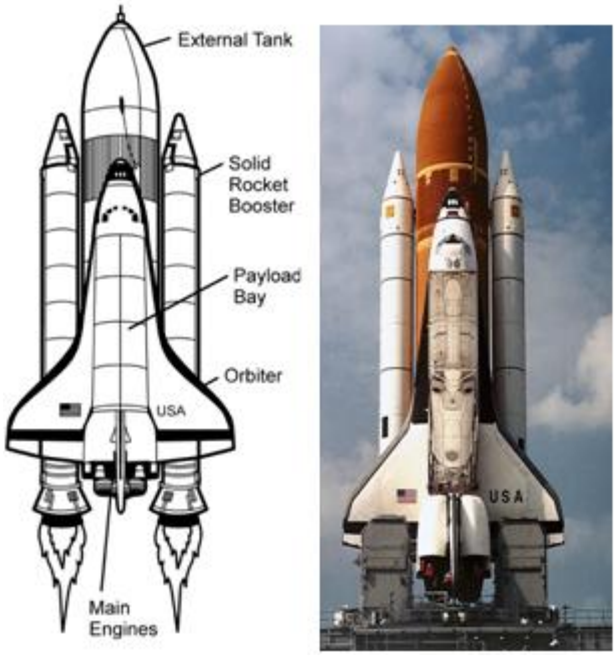

Figure 2.1: Space shuttle Configuration

External Tank

A **Space Shuttle external tank** (**ET**) was the component of the Space Shuttle launch vehicle that contained the liquid hydrogen fuel and liquid oxygen oxidizer. During lift-off and ascent it supplied the fuel and oxidizer under pressure to the three Space Shuttle Maine Engines (SSME) in the orbiter. The ET was jettisoned just over 10 seconds after MECO (Main Engine Cut Off), where the SSMEs were shut down, and re-entered the Earth's atmosphere. Unlike the Solid Rocket Boosters, external tanks were not re-used. They broke up before impact in the Indian Ocean (or Pacific Ocean in the case of direct-insertion launch trajectories), away from shipping lanes and were not recovered.

The ET was the largest element of the space shuttle, and when loaded, it was also the heaviest. It consisted of three major components:

- The forward liquid oxygen (LOX) tank
- An unpressurized inter tank that contains most of the electrical components
- The aft liquid hydrogen (LH_2) tank; this was the largest part, but it was relatively light, due to liquid hydrogen's very low density.

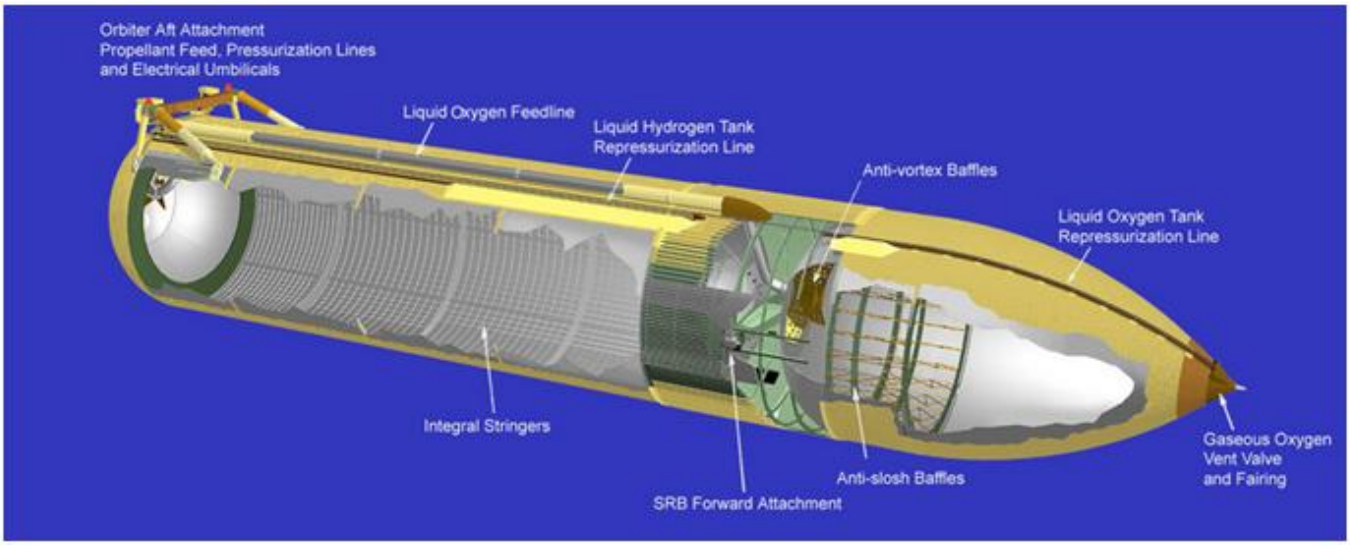

Figure 2.2: External Tank

Over the years, NASA worked to reduce the weight of the ET to increase overall efficiency. For each pound of weight reduction, the cargo-carrying capability of the shuttle spacecraft was increased almost one pound.

Versions of ET

Table 2.1: Wight of tank

Standard Weight Tank	35,000 kg (77,000 lb.)
Light weight Tank	30,000 kg (66,000 lb.)
Super lightweight Tank	26,000 kg (58,500 lb.)

Orbiter

An orbiter is a space plane that goes into orbit around the earth. The Space Shuttle orbiter was the size of a small jet airliner, and is still by far the largest spacecraft ever launched into orbit. Its main engines were used only during launch.

Six orbiters were built for flight: Enterprise, Columbia, Challenger, Discovery, Atlantis, and Endeavour. All were built in Palmdale, California, by the Pittsburgh, Pennsylvania-based Rockwell International company. The first orbiter, Enterprise, made its maiden flight in 1977. An unpowered glider, it was carried by a modified Boeing 747 airliner called the Shuttle Carrier Aircraft and released for a series of atmospheric test flights and landings.

Enterprise was partially disassembled and retired after completion of critical testing. The remaining orbiters were fully operational spacecraft, and were launched vertically as part of the Space Shuttle stack.

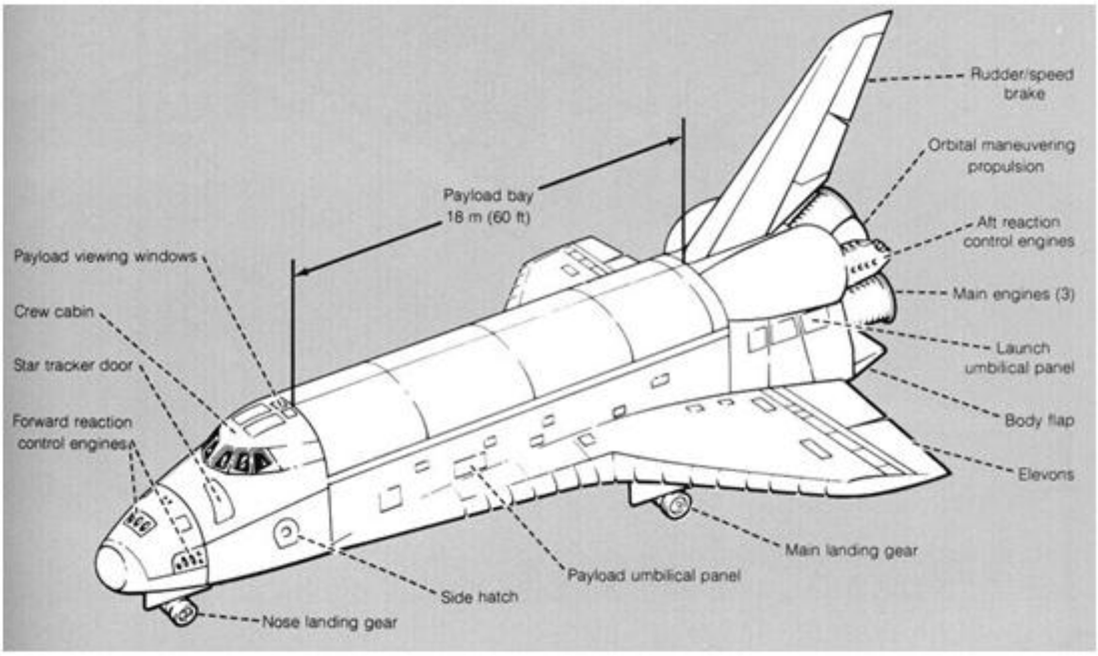

Figure 2.3: Orbiter

Table 2.2: Orbiters Profile

Name	OVD	First flight	Last flight	Status
Atlantis	OV-104	Oct 3-7, 1985	July 8-21, 2011	Retired
Challenger	OV-099	April 4-9, 1983	Jan 28, 1986	Destroyed
Columbia	OV-102	April 12-14, 1981	Jan 16, 2003	Destroyed
Discovery	OV-103	Aug 30, 1984	Feb 24, 2011	Retired
Endeavour	OV-105	May 7, 1992	May 16, 2011	Retired

Figure 2.4: Shuttle launches Profile

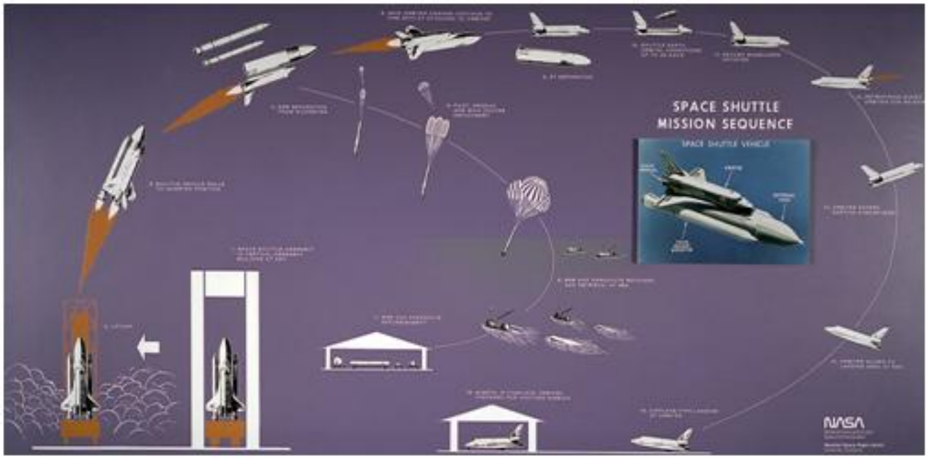

Figure 2.5: Typical flight Profile

Solid Rocket Booster

Solid-fuel rocket boosters (SRBs) are large solid propellant motors used to provide thrust in spacecraft launches from initial launch through the first ascent stage. Many launch vehicles, including the Ariane 5, Atlas V,and the NASA Space Shuttle, have used SRBs to give launch vehicles much of the thrust required to place the vehicle into orbit. The NASA Space Shuttle used two Space Shuttle SRBs, which were the largest solid propellant motors ever built and the first designed for recovery and reuse.] The propellant for each solid rocket motor on the Space Shuttle weighed approximately 500,000 kilograms

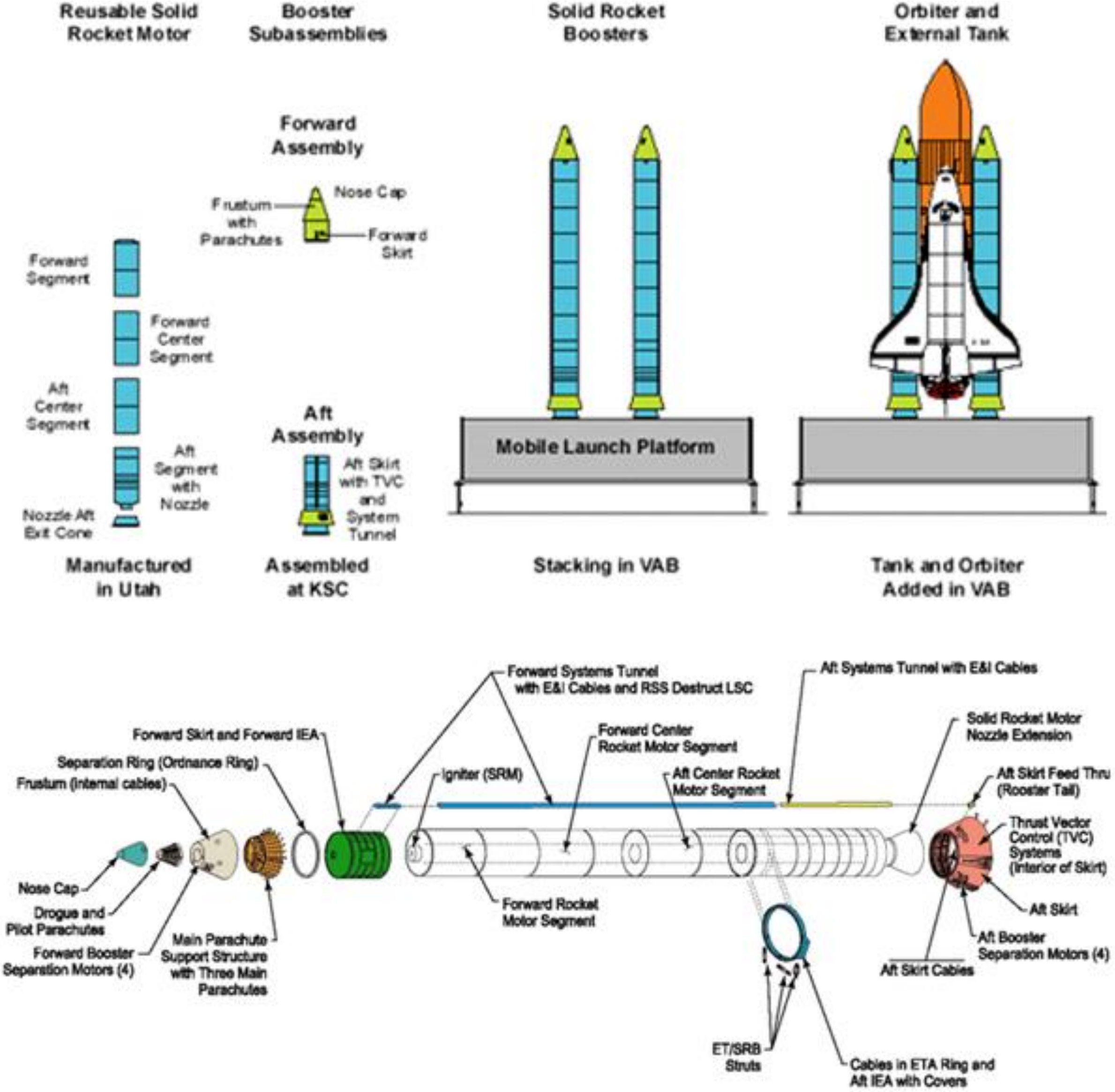

Figure 3.1: Rocket Booster

Main Engine

The Aerojet Rocket dyne RS-25, otherwise known as the Space Shuttle main engine (SSME), is a liquid-fuel cryogenic rocket engine that was used on NASA's Space Shuttle and is planned to be used on its successor, the Space Launch System.Designed and manufactured in the United States by Rocketdyne (later known as Pratt & Whitney Rocket dyne and Aerojet Rocket dyne), the RS-25 burns cryogenic liquid hydrogen and liquid oxygen propellants, with each engine producing 1,859 kN (418,000 lb$_f$) of thrust at liftoff. Although the RS-25 can trace its heritage back to the 1960s, concerted development of the engine began in the 1970s, with the first flight, STS-1, occurring on April 12, 1981. The RS-25 has undergone several upgrades over its operational history to improve the engine's reliability, safety, and maintenance load. Subsequently, the RS-25D is the most efficient liquid fuel rocket engine currently in use.The engine produces a specific impulse (I_{sp}) of 452 seconds (4.43 km/s) in a vacuum, or 366 seconds (3.59 km/s) at sea level, has a mass of approximately 3.5 tones (7,700 pounds), and is capable of throttling between 67% and 109% of its rated power level in one-percent increments. The RS-25 operates at temperatures ranging from −253 °C (−423 °F) to 3300 °C (6000 °F).

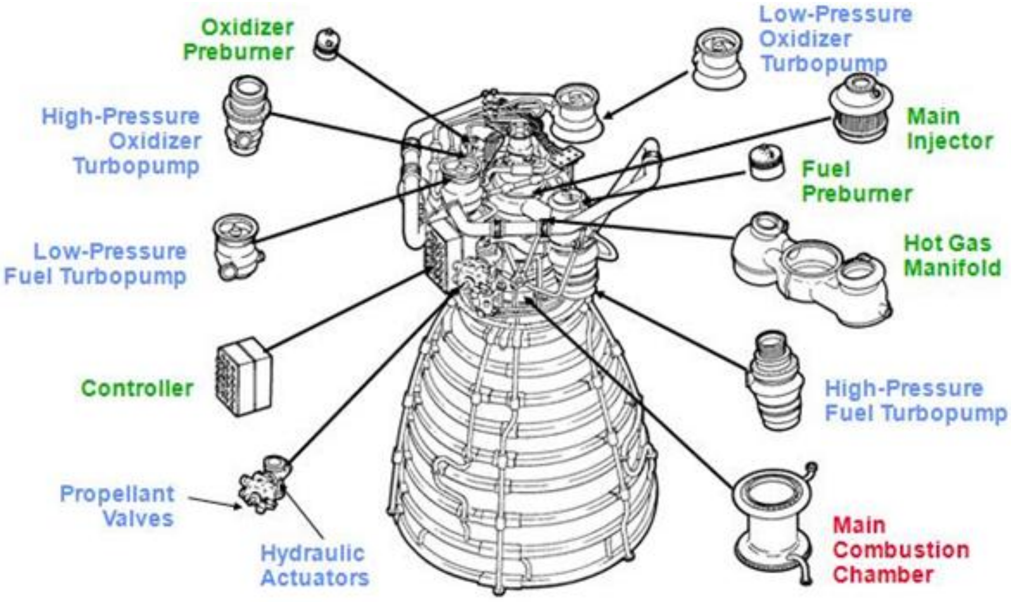

Figure 4.1: Main Engine Schematic diagram

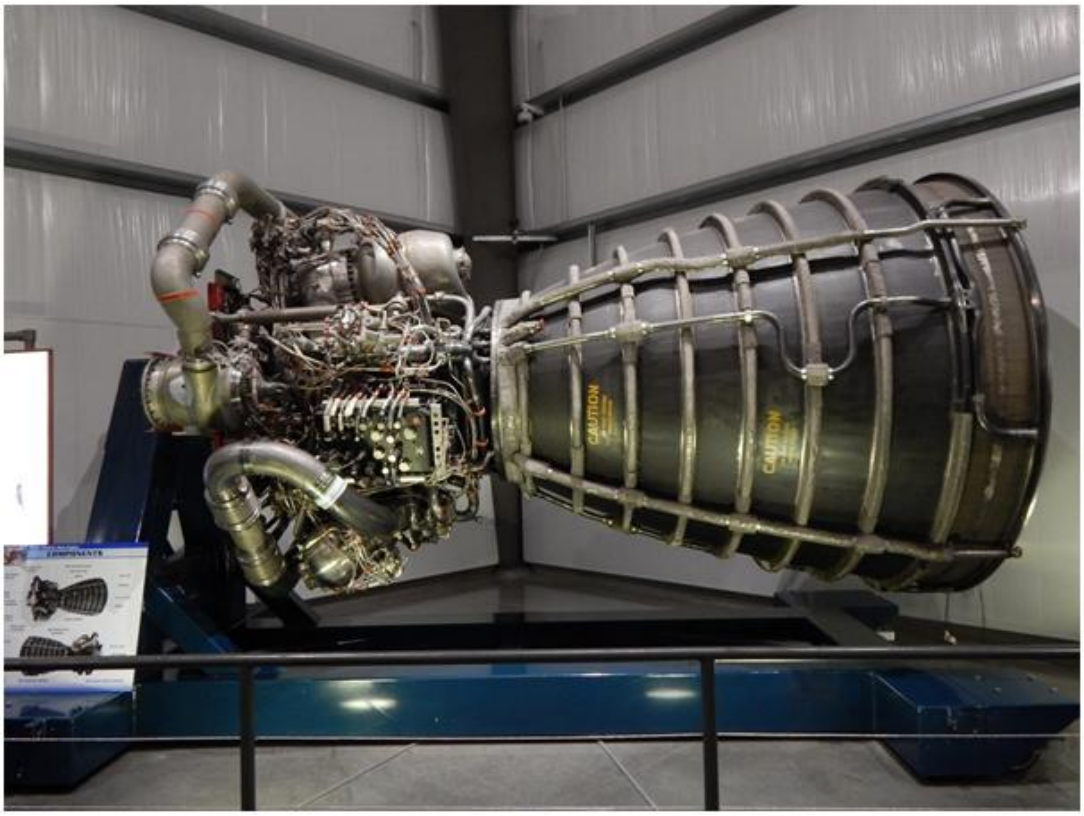

Figure 4.2: Main Engine original photograph

4. Components of Engine

a) Turbo pumps

- Oxidizer system

The low-pressure oxidizer turbopump (LPOTP) is an axial-flow pump which operates at approximately 5,150 rpm driven by a six-stage turbine powered by high-pressure liquid oxygen from the high-pressure oxidizer turbopump (HPOTP). It boosts the liquid oxygen's pressure from 0.7 to 2.9 MPa (100 to 420 psi), with the flow from the LPOTP then being supplied to the HPOTP. During engine operation, the pressure boost permits the high-pressure oxidizer turbine to operate at high speeds without cavitating. The LPOTP, which measures approximately 450 by 450 mm (18 by 18 in), is connected to the vehicle propellant ducting and supported in a fixed position by being mounted on the launch vehicle's structure

- Fuel system

The low-pressure fuel turbopump (LPFTP) is an axial-flow pump driven by a two-stage turbine powered by gaseous hydrogen. It boosts the pressure of the liquid hydrogen from 30 to 276 psia (0.2 to 1.9 MPa) and supplies it to the high-pressure fuel turbopump (HPFTP). During engine operation, the pressure boost provided by the LPFTP permits the HPFTP to operate at high speeds without cavitating. The LPFTP operates at around 16,185 rpm, and is approximately 450 by 600 mm (18 by 24 in) in size. It is connected to the vehicle propellant ducting and is supported in a fixed position by being mounted to the launch vehicle's structure.

b) Power Head

- Preburners

The oxidizer and fuel preburners are welded to the hot-gas manifold. The fuel and oxidizer enter the preburners and are mixed so that efficient combustion can occur. The augmented spark igniter is a small combination chamber located in the center of the injector of each preburner. Two dual-redundant spark igniters are activated by the engine controller, and are used during the engine start sequence to initiate combustion in each preburner. They are turned off after approximately three seconds because the combustion process is then self-sustaining. The preburners produce the fuel-rich hot gases that pass through the turbines to generate the power needed to operate the high-pressure turbopumps. The oxidizer preburner's outflow drives a turbine that is connected to the HPOTP and to the oxidizer preburner pump. The fuel preburner's outflow drives a turbine that is connected to the HPFTP.

- Main combustion chamber

Each engine main combustion chamber (MCC) receives fuel-rich hot gas from a hot-gas manifold cooling circuit. The gaseous hydrogen and liquid oxygen enter the chamber at the injector, which mixes the propellants. Dual spark igniters in the preburner begin the combustion process. The main injector and dome assembly are welded to the hot-gas manifold, and the MCC is also bolted to the hot-gas manifold.The MCC comprises a structural shell made of Inconel 718 which is lined with a copper-silver-zirconium alloy called NARloy-Z, developed specifically for the RS-25 in the 1970s. Around 390 channels are machined into the liner wall to carry liquid hydrogen through the liner to provide MCC cooling, as the temperature in the combustion chamber reaches 3300 °C (6000 °F) during flight – higher than the boiling point of iron.

c) Nozzle

The engine's nozzle is 121 in (3.1 m) long with a diameter of 10.3 in (0.26 m) at its throat and 90.7 in (2.30 m) at its exit.The nozzle is a bell-shaped extension bolted to the main combustion chamber, referred to as a de Laval nozzle. The RS-25 nozzle has an unusually large expansion ratio (about 77.5:1) for the chamber pressure.At sea level, a nozzle of this ratio would normally undergo flow separation of the jet from the nozzle, which would cause control difficulties and could even mechanically damage the vehicle. However, to aid the engine's operation Rocket dyne engineers varied the angle of the nozzle walls from the theoretical optimum for thrust, reducing it near the exit. This raises the pressure just around the rim to an absolute pressure between 4.6 and 5.7 psi (32 and 39 kPa), and prevents flow separation. The inner part of the flow is at much lower pressure, around 2 psi (14 kPa) or less. The inner surface of each nozzle is cooled by liquid hydrogen flowing through brazed stainless steel tube wall coolant passages. On the Space Shuttle, a support ring welded to the forward end of the nozzle is the engine attaches point to the orbiter-supplied heat shield. Thermal protection is necessary because of the exposure portions of the nozzles experience during the launch, ascent, on-orbit and entry phases of a mission. The insulation consists of four layers of metallic batting covered with a metallic foil and screening.

d) Controller

Each engine is equipped with a main engine controller (MEC), an integrated computer which controls all of the engine's functions (through the use of valves) and monitors its performance. Built by Honeywell Aerospace, each MEC originally comprised two redundant Honeywell HDC-601 computers,later upgraded to a system composed of two doubly redundant Motorola 68000 (M68000) processors (for a total of four M68000s per controller).Having the controller installed on the engine itself greatly simplifies the wiring between the engine and the launch vehicle, because all the sensors and actuators are connected directly to only the controller, each MEC then being connected to the orbiter's general purpose computers(GPCs) or the SLS's avionics suite via its own engine interface unit (EIU).Using a dedicated system also simplifies the software and thus improves its reliability.

e) Helium System

In addition to fuel and oxidizer systems, the launch vehicle's main propulsion system is also equipped with a helium system consisting of ten storage tanks in addition to various regulators, check valves, distribution lines, and control valves. The system is used in-flight to purge the engine and provides pressure for actuating engine valves within the propellant management system and during emergency shutdowns. During entry, on the Space Shuttle, any remaining helium was used to purge the engines during reentry and for repressurization

5. Space Shuttle Launch Steps

Figure 5.1: Space shuttle before launch

T-minus 9 minutes: At several predetermined points during the launch countdown, NASA will pause the clock as part of standard procedure to give the ground teams time to resolve any unexpected issues that may crop up. At the end of these "built-in holds," the countdown clock will resume unless

NASA encounters any technical glitches. At the T-minus 9 minute mark, the clock will typically enter a 45-minute hold. Before this point, the NASA test director will perform a launch readiness poll of the shuttle launch team. Weather forecasts for the Cape Canaveral area will also be checked to verify that the conditions meet the agency's criteria for a safe launch.

During the hold, NASA officials on consoles will be polled for their "go/no go" decisions. These technicians closely monitor computer displays and gauges that show the performance of the shuttle's systems at the launch pad.

After the T-minus 9 minute built-in hold, the countdown will resume. The Ground Launch Sequencer (GLS), which is an automated program that controls all activity during the final portion of the countdown, will assume automatic control of the countdown at the T-minus 9 minute mark. This program will continue to monitor the vehicle's parameters and will be able to halt the countdown if a problem is detected. The GLS is typically started at about the T-minus 45 minute mark.

T-minus 7 minutes, 30 seconds: At this point, the command will be given to retract the orbiter access arm, which is the lowermost scaffolding arm located 147 feet (about 45 meters) above the surface of the launch pad. This structure allows people to enter the shuttle's crew compartment. The orbiter access arm remains in its extended position until seven minutes, 24 seconds before launch to serve as an emergency escape route for the flight crew.

T-minus 5 minutes: Barring any technical or weather concerns, the commander of the shuttle will be given the "go" to start the orbiter's auxiliary power units (APU), which produce pressure for the shuttle's hydraulic system. There are three separate onboard APUs, and their fuel systems are located in the aft fuselage of the orbiter.

Once the APUs are powered up, ground teams will analyze the system, and if they detect any glitches, this could halt the countdown. At the T-minus 4 minute, 30 seconds mark, the Ground Launch Sequencer program will switch the main fuel valve heaters off. As the clock ticks down, the GLS will also perform checks of the fuel and space shuttle main engines.

T-minus 2 minutes: At this point, the shuttle's commander will advise his or her crewmates to close the visors of their launch and entry suits. In these final minutes leading up to launch, the Ground Launch Sequencer is still in automatic control of the countdown.

T-minus 31 seconds: At this moment in the countdown, if there are no technical issues, the "go" command will be given for "auto sequence start," which means that the Ground Launch Sequencer will hand off primary control of the countdown to the shuttle's onboard computers.

T-minus 16 seconds: Now, the sound suppression water system at the launch pad will be activated to protect the shuttle and its payloads from being damaged by the strong acoustical energy during liftoff. Water is stored in massive tanks on the northeast side of the launch pad and is released just prior to the ignition of the shuttle's main engines. Nine seconds after liftoff, the water suppression system's peak flow rate is 900,000 gallons per minute.

T-minus 6 seconds: Just prior to this moment, if everything is functioning as it should, the command will be given to start the space shuttle's main engines. Beginning at the T-minus 6 second mark, each of the three main engines will be ignited and roar to life.

T-minus 0 seconds: The solid rocket boosters will be ignited, and the bolts that have secured the shuttle to the ground in the last six seconds of the countdown are explosively released, allowing the orbiter to rocket into the sky. Once this happens, **we have liftoff!**

6. Conclusion

In this paper we define the development of space shuttle, its various parts and their function. The Space Shuttle Program’s storied history is vast and well documented. Understanding the design and operations of this unique and complex vehicle is not confined to the study of one program, but of many. It touches on only a handful of the lessons that were learned through the various supersonic and hypersonic research programs that laid the foundation for Shuttle.

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