 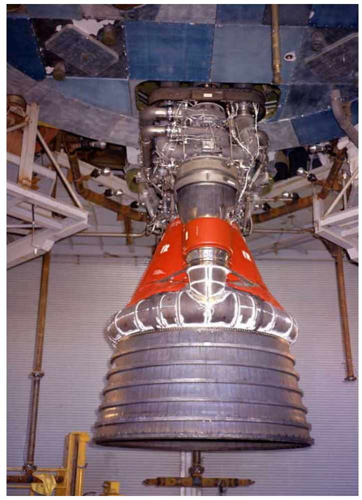 

SATURN V F-1 ENGINE

The F-1 is a rocket engine developed by Rocketdyne and used in the Saturn V. Five F-1 engines were used in the S-IC first stage of each Saturn V, which served as the main launch vehicle in the Apollo program. The F-1 is still the most powerful liquid-fueled rocket engine developed.

The F-1 was originally developed by Rocketdyne to meet a 1955 US Air Force requirement for a very large rocket engine. The eventual result of that requirement was two different engines, the E-1 and the much larger F-1. The E-1, although successfully tested in static firing, was quickly seen as a technological dead-end and was abandoned for the larger, more powerful F-1. The USAF eventually halted development of the F-1 because of a perceived lack of requirement for such a large engine. However, the recently created NASA appreciated the usefulness of an engine with so much power and contracted Rocketdyne to complete its development. Test firings of F-1 components had been performed as early as 1957. The first static firing of a full stage developmental F-1 was performed in March 1959.

For seven years of development F-1 tests revealed serious combustion instability problems which would sometimes cause catastrophic failure.[2] Progress on this problem was initially slow, as the problem onset was intermittent and unpredictable. Eventually engineers developed a technique of detonating small explosive charges (which they called "bombs") inside the combustion chamber while the engine was firing, which allowed them to determine exactly how the running chamber responded to variations in pressure. The designers could then quickly experiment with different fuel-injector designs to obtain the one most resistant to instability. These problems were addressed from 1959 through 1961. Eventually the engine's combustion was so stable it would self-damp artificially induced instability within about 1/10th of a second.

The Rocketdyne-developed F-1 engine is the most powerful single-nozzle liquid fueled rocket engine ever used in service (the M-1 rocket engine was designed to have more thrust, and was ground tested, but was never put into service) . The F-1 was a liquid-fueled rocket motor, burning RP-1 (kerosene) as fuel, and using liquid oxygen (LOX) as the oxidizer. A turbopump was used to inject fuel and oxygen into the combustion chamber.

The heart of the engine was the thrust chamber, which mixed and burned the fuel and oxidizer to produce thrust. A domed chamber at the top of the engine served as a manifold supplying liquid oxygen to the injectors, and also served as a mount for the gimbal bearing which transmitted the thrust to the body of the rocket. Below this dome were the injectors, which directed fuel and oxidizer into the thrust chamber in a way designed to promote mixing and combustion. Fuel was supplied to the injectors from a separate manifold; some of the fuel first travelled in 178 tubes down the length of the thrust chamber — which formed approximately the upper half of the exhaust nozzle — and back in order to cool it.

A gas-generator was used to drive a turbine which in turn drove separate fuel and oxygen pumps, each feeding the thrust chamber assembly. The turbine was driven at 5,500 RPM by the gas generator, producing 55,000 brake horsepower (41 MW). The fuel pump produced 15,471 gallons (58,564 litres) of RP-1 per minute while the oxidizer pump delivered 24,811 gal (93,920 l) of liquid oxygen per minute. Environmentally, the turbopump was required to withstand temperatures ranging from input gas at 1,500 °F (816 °C), to liquid oxygen at -300 °F (-184 °C). Structurally, fuel was used to lubricate and cool the turbine bearings.

Below the thrust chamber was the nozzle extension, roughly half the length of the engine. This extension increased the expansion ratio of the engine from 10:1 to 16:1. The exhaust from the turbopump was fed into the nozzle extension by a large, tapered manifold; this relatively cool gas formed a film which protected the nozzle extension from the hot (5,800 °F, 3,200 °C) exhaust gas.

The F-1 burned 3,945 pounds (1,789 kg) of liquid oxygen and 1,738 pounds (788 kg) of RP-1 each second, generating 1,500,000 pounds-force (6.7 MN) of thrust. This equated to a flow rate of 413.5 US gallons (1,565 l) of LOX and 257.9 US gallons (976 l) RP-1 per second. During their two and a half minutes of operation, the five F-1s propelled the Saturn V vehicle to a height of 42 miles (68 km) and a speed of 6,164 miles per hour (9,920 km/h). The combined propellant flow rate of the five F-1s in the Saturn V was 3,357 US gallons (12,710 l) per second, which would empty a 30,000 US gallons (110,000 l) swimming pool in 8.9 seconds. Each F-1 engine had more thrust than all three space shuttle main engines combined.

F-1 thrust and efficiency were improved between Apollo 8 (SA-503) and Apollo 17 (SA-512). This was necessary for Saturn V payload capacity to meet the increasing demands of the later Apollo missions. There were small performance variations between engines on a given mission, and variations in average thrust between missions. For Apollo 15, F-1 performance was:

- Thrust (average, per engine, sea level liftoff): 1,553,200 lbf (6.909 MN)
- Burn time: 159 s
- Specific impulse: 264.72 s
- Mixture ratio: 2.2674
- S-IC total sea level liftoff thrust: 7,766,000 lbf (34.55 MN)

Measuring and making comparisons of rocket engine thrust is more complicated than first appears. Based on actual measurement the liftoff thrust of Apollo 15 was 7.823 million lbf (34.8 MN), which equates to an average F-1 thrust of 1.565 million lbf (6.962 MN), which is significantly more than the specified value. For more information, see S-IC thrust comparisons

There was an uprating redevelopment of the F-1 undertaken by Rocketdyne during the 1960s which resulted in a new engine specification known as the F-1A. While outwardly very similar to the F-1, the F-1A was actually lighter yet significantly more powerful (9.1 MN compared to F-1's 6.7 MN) and would have been used on future Saturn V vehicles in the post-Apollo era. However, the Saturn V production line was closed prior to the end of Project Apollo and no F-1A engine ever flew on a launch vehicle.

There were proposals to use eight F-1 engines on the first stage of the Nova rocket. Numerous proposals have been made from the 1970s on to the present day to develop new expendable boosters based around the F-1 engine design, but none have proceeded beyond the initial study phase.

The F-1 remained the most powerful liquid-fuel rocket engine at 6.7 MN of thrust at sea level until overshadowed by RD-170 from the Soviet Union. The RD-170 is actually a cluster of four separate combustion chambers and nozzles driven by a single turbopump. It visually appears to be and is considered by some a cluster of four engines, not a single engine. Viewed as a single engine it is the most powerful liquid-fuel rocket engine ever developed. The F-1 still holds the crown of largest single-chamber, single-nozzle liquid fuel engine ever flown. However among solid-fuel engines, more powerful engines exist, such as the Space Shuttle Solid Rocket Booster, with a sea-level liftoff thrust of 12.45 MN.