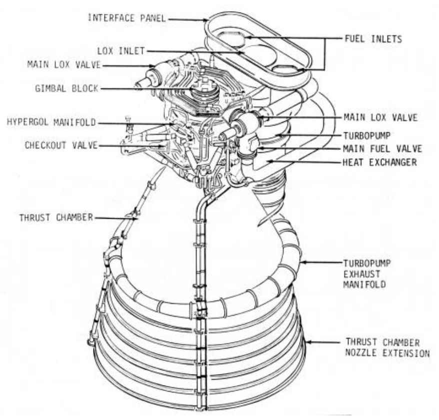
F-1 Engine - Propulsion of the Saturn V Moon Rocket



NASA provides this drawing of the F-1 engine (five of these lifted the Saturn V rocket from Apollo 11's launch pad) and describes how the F-1 operates:

The F-1 engine has a complex ignition sequence which will be described here. First, a description of the engine.

A large combustion chamber and bell have an injector plate at the top, through which RP-1 fuel and LOX are injected at high pressure. Above the injector is the LOX dome which also transmits the force of the thrust from the engine to the rocket's structure. A single-shaft turbopump is mounted beside the combustion chamber.

The turbine is at the bottom and is driven by the exhaust gas from burning RP-1 and LOX in a fuel-rich mixture in a gas generator. After powering the turbine, the exhaust gases pass through a heat exchanger, then to a wrap-around exhaust manifold which feeds it into the periphery of the engine bell.

The final task for these hot gases is to cool and protect the nozzle extension from the far hotter exhaust of the main engine itself. Above the turbine, on the same shaft, is the fuel pump with two inlets from the fuel tank and two outlets going, via shut-off valves, to the injector plate. A line from one of these 'feeds' supplies the gas generator with fuel.

Fuel is also used within the engine as a lubricant and as a hydraulic working fluid, though before launch, RJ-1 ramjet fuel is supplied from the ground for this purpose.

At the top of the turbopump shaft is the LOX pump with a single, large inlet in-line with the turboshaft axis. This pump also has two outlet lines, with valves, to feed the injector plate. One line also supplies LOX to the gas generator.

The interior lining of the combustion chamber and engine bell consists of a myriad of pipework through which a large portion of the fuel supply is fed. This cools the chamber and bell structure while also pre-warming the fuel.

Lastly, an igniter, containing a cartridge of hypergolic fluid with burst diaphragms at either end, is in the high pressure fuel circuit and has its own inject point in the combustion chamber. This fluid is triethylboron with 10-15% triethylaluminium.

At T minus 8.9 seconds, a signal from the automatic sequencer fires four pyrotechnic devices. Two of them cause the fuel-rich turbine exhaust gas to ignite when it enters the engine bell. Another begins combustion within the gas generator while the fourth ignites the exhaust from the turbine.

Links are burned away by these igniters to generate an electrical signal to move the start solenoid. The start solenoid directs hydraulic pressure from the ground supply to open the main LOX valves.

LOX begins to flow through the LOX pump, starting it to rotate, then into the combustion chamber. The opening of both LOX valves also causes a valve to allow fuel and LOX into the gas generator, where they ignite and accelerate the turbine.

Fuel and LOX pressures rise as the turbine gains speed. The fuel-rich exhaust from the gas generator ignites in the engine bell to prevent backfiring and burping of the engine. The increasing pressure in the fuel lines opens a valve, the igniter fuel valve, letting fuel pressure *reach the hypergol cartridge which promptly ruptures.*

Hypergolic fluid, followed by fuel, enters the chamber through its port where it spontaneously ignites on contact with the LOX already in the chamber.

Rising combustion-induced pressure on the injector plate actuates the ignition monitor valve, directing hydraulic fluid to open the main fuel valves. These are the valves in the fuel lines between the turbopump and the injector plate.

The fuel flushes out ethylene glycol which had been preloaded into the cooling pipework around the combustion chamber and nozzle. The heavy load of ethylene glycol mixed with the first injection of fuel slows the build-up of thrust, giving a gentler start.

Fluid pressure through calibrated orifices completes the opening of the fuel valves and fuel enters the combustion chamber where it burns in the already flaming gases. The exact time that the main fuel valves open is sequenced across the five engines to spread the rise in applied force that the structure of the rocket must withstand.

The thrust [rises] during the start-up of each engine. It takes two seconds for full performance to be attained on all engines once the first has begun increasing. The engines are started in a staggered 1-2-2 sequence so that the rocket's structure would be spared a single large load increase, with the centre engine being the first to start.

The outboard engines exhibit a hiccup in their build-up due to the ingestion of helium from the pogo suppression system installed in each one. The centre engine does not have this installed.

As the flow of fuel and LOX rises to maximum, the chamber pressure, and therefore thrust, is monitored to confirm that the required force has been achieved. With the turbopump at full speed, fuel pressure exceeds hydraulic pressure supplied from ground equipment. Check valves switch the engine's hydraulic supply to be fed from the rocket's fuel instead of from the ground.

Click on the image for a much larger view.

Credits:

Drawing and quoted passage from Apollo 11's Flight Journal. Online, courtesy NASA.

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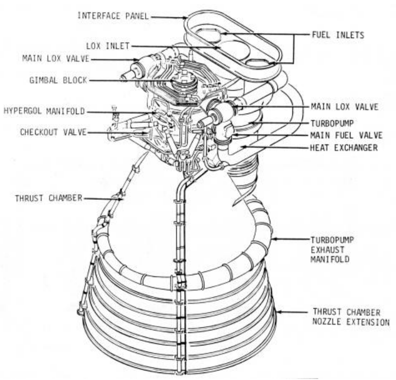

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