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Saturn V Booster - The F-1 Engine

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On December 20, 1964, NASA announced, "The F-1 Rocket Engine, the most powerful being developed by the United States, has completed its flight rating test, and is now ready for cluster firings and actual flight.

The engine that completed FRT consists of a single thrust chamber, injector and dome, a single direct drive turbopump, a single gas generator, two each fuel pump discharge lines and control valves and also lox pump discharge lines and control valves, and a single start valve. The start valve is the only major engine part requiring electrical energy as a control device. Instrumentation to monitor engine operation during flight also requires electrical energy but is independent of engine operation. This engine system is in accordance with the reliability design concept that highest overall engine reliability is achieved by using the minimum number of parts. The FRT engine resulted from this concept combined with previous Rocketdyne engine experience and advanced metallurgy.

The F-1 thrust chamber design provides a tubular wall. Regeneratively cooled thrust chamber with a gas-cooled extension, a double inlet oxidizer dome, and a high performance flat face injector incorporating features that make it dynamically stable. That means that if the engine system is disturbed from any source, it will quickly damp out the resulting oscillations.

The thrust chamber extension is designed to carry the expansion area ratio from the cooled chamber area of 10 to 1 up to the exhaust ratio of 16/1. Cooling from the 5000 degrees F. chamber gas to a 1200 degrees F. wall temperature is accomplished by passing the turbine exhaust gas through the double wall of the skirt. The primary consideration in selection of the turbopump design was to attain reliability by using a minimum number of parts and proved design concepts. The direct drive design includes a two stage velocity compounded turbine consisting of two rotating impulse wheels separated by a set of stationary impulse stators driving the two main centrifugal pump elements, each preceded by inducer or partial axial stages operating at high suction specific speeds. Overall pump diameter was reduced as much as possible by using double volutes rather than single volute discharges. The fuel pump is located on the shaft between the oxidizer pump and the turbine to separate the elements having the greatest temperature extremes.

To drive the turbine, the F-1 engine uses a gas generator burning engine propellants, burned at a fuel-rich mixture ratio.

In the selection of the fuel and oxidizer valves, the advantages of single, large components were weighed against multiple smaller valves. Two fuel and two oxidizer valves were selected. The actuators for the main oxidizer and gas generator valves utilize engine fuel as the hydraulic fluid. The other major components include dual linked ball valves for the control of the gas generator and a four-way solenoid valve to control the sequencing of the engine system by controlling the fuel flow to the actuator piston of the main lox and gas generator valves. Gimballing was selected as the method of thrust vector control after extensive analysis of other means of vector control.

There were several advancements in the materials areas necessary to fabricate the FRT engine. One of these was the high strength aluminum alloy forgings rather than castings for the valve bodies. This was necessary to achieve the high proof pressure capability. The high strength heat·treated nickel alloy thrust chamber assembly was another area which required extensive development. One of these problems was the braze alloy for sealing the hundreds of tubes making up the fuel cooled chamber wall into a high temperature, high pressure vessel. The furnace cycle for brazing the tube joints was combined with the heat treat cycle for the pressure jacket and tube bands.

The high thrust vector loads of the gimbal system necessitated use of a high strength forging for the lox dome since engine thrust is transmitted through this member. The turbopump assembly also included many special alloys, heat treat and special processes such as shot peening to gain the necessary properties for this high performance assembly.

The auxiliary equipment to accomodate the engine to the Saturn V booster vehicle also posed materials and processing problems. One of these was the high strength cast interface panel for the electrical and fluid instrumentation and control lines. The panel also must support the insulation curtain between the engine boat tail and the stage structure and tanks.

The engines themselves also require insulating cocoons to protect non-cooled engine areas, such as structural members from radiant heat and hot gas circulation from adjacent engines in the booster cluster.

Launch safety requirement imposed additional requirements. One of these was to change the 28 volt initiation of the pyrotechnic igniters to high voltage systems which would not be ignited by stray energy fields.

The goals for the manned flight qualification test demonstration to be conducted by the end of 1966, include refinement of the thrust chamber injector for increased performance, and at the same time to meet more stringent dynamic combustion stability requirements. The test demonstrations will include quick recovery from test-induced instabilities in the thrust chamber. In order to maintain consistently the high reliability requirements of the Saturn V booster, a system has been developed so that each part is fabricated and processed to exact specifications. A step-by-step detailed planning system called "Assembly Operations Record" books are made up for each component. Once approved, no deviation is permitted from the A.O.R. book sequence. Similar process documents are worked out and signed off with subcontractors making critical engine parts. By this system and continued diligence and attention to each detail, Rocketdyne can assure the high reliability required for the Saturn Apollo Program.