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"LIQUID HYDROGEN TECHNOLOGY, J-2 ENGINE"

Good afternoon, my name is Paul Fuller, and I represent North American Aviation's Rocketdyne Division. The subject of my talk with you today will be the application of oxygen/hydrogen technology to the J-2 engine system.

To put the use of this engine in proper perspective, let me describe the vehicles in which it will be used. The Saturn IB will be the first to utilize the J-2. As you may know, the Saturn IB is a two-stage vehicle consisting of the Chrysler-built S-1 first stage and the Douglas S-IVB second stage. One J-2 is used in the S-IVB stage. Principle missions for this vehicle are: the development of earth orbital systems, Apollo earth orbit training, and unmanned deep space probes. The major vehicle for which the J-2 was developed is the Saturn V. The Saturn V is a three staged vehicle utilizing the Boeing S-IC first stage, North American Space and Information Division S-II second stage, and the Douglas S-IVB as a third stage. Five J-2's are used on the S-II stage. The mission of this vehicle is the injection of the Apollo system into a lunar trajectory. To accomplish such a trajectory the S-IVB stage will have the requirement of initial orbital injection, coast, and a second burn to accomplish the required escape ΔV.

Now let us look at the J-2 rocket engine in more detail.

The J-2 engine is assembled around the high performance thrust chamber which serves as a mount for all components. The thrust chamber has an altitude expansion ratio of 27.5:1 while retaining the capability of firing under sea level environment. This capability permits the engine and the vehicle to be developed without the use of complex and expensive altitude simulation equipment.

The chamber is regeneratively cooled by use of hydrogen flowing through the tubular bundle. The chamber is fabricated from .012" stainless steel tubes and the design was selected for structural strength, known fabrication techniques, and afforded excellent heat transfer characteristics.

Liquid hydrogen is delivered at more than 1000 psi to the inlet manifold and is heated from -423°F to -260°F. Coolant velocity within the tube varies from 60 ft/sec to 1000 ft/sec at the throat. The combustion chamber temperature ranges to 5500°F and the thrust chamber develops a nominal thrust of 200,000 lbs.

The injector, as well as the thrust chamber, has made full use of the unique heat-transfer properties of hydrogen and is designed for concentric injection, promoting stable and controlled burning. Oxygen is injected into the chamber through a number of tubular orifices extending to the injector face. Ninety-five percent of the hydrogen flows into the combustion chamber through annular orifices and 5% flows through the porous injector face for cooling and to reduce thermal stresses.

Propellants are provided to the thrust chamber at high pressures by means of dual, direct-drive turbopumps mounted on the thrust chamber. Each turbopump is a single-shaft unit, with the bearings cooled by the propellant being pumped. The oxygen pump requires 20 gpm coolant flow and the hydrogen pump requires 10 gpm. The bearing coolant flow is returned to the inlet of each pump, thereby eliminating any loss of propellant.

The oxygen pump is a single stage centrifugal type, operating at a speed of 8000 RPM and requiring a net positive suction head of 25 feet. The hydrogen pump is a seven stage, axial flow type, operating at 25,800 RPM and requiring 130 feet net positive suction head.

The power to drive these two turbopumps is provided by a gas generator which is integrally mounted to the turbine manifold of the fuel pump. The gas generator receives oxygen and hydrogen through feed lines from the main propellant ducts and burns fuel rich to provide a reasonably hot, but highly efficient, low-molecular-weight gas. This gas passes first through the two stages of the hydrogen pump turbine and then is directed to the oxygen pump turbine and finally is injected into the thrust chamber nozzle. Typical temperatures are 1200°F to the fuel turbine, 800°F to oxygen turbine, and 700°F to exhaust. The power balance between these two turbopumps is provided by a bypass duct around the oxygen pump turbine.

To control the flow of propellants to the thrust chamber and gas generator, propellant valves are located in the high pressure ducts. These propellant valves require no lubrication or heating to open rapidly at speeds of 75 milliseconds. The control from these valves is provided by an electro-pneumatic system. Two solenoid valves control the flow of 400 psia helium gas to the propellant valves, with sequence events provided these solenoids by a solid state electrical system. This system not only provides the sequenced events, but also supplies high voltage for spark ignition systems located in the gas generator and thrust chamber. Both the spark ignition systems and electrical control network are redundant to insure maximum reliability for manned application. The supply of helium gas for the control system and hydrogen gas for accelerating the turbomachinery during engine starting are located in a storage tank mounted between the two turbopumps. This storage tank is unique in that it is a tank within a tank. The smaller tank, containing 1000 cubic inch, 3000 psia helium gas, is mounted internal to the larger 10,000 cubic inch, 1250 psia gaseous hydrogen tank. This tank design permits maximum utilization of space available for mounting.

The J-2 engine is not just a rocket engine supplying thrust for the vehicle, but is a fully integrated propulsion system. The engine provides functions all important to the vehicle's operation and mission capability. The first of these functions is to provide steering by means of thrust vector control. Thrust vector control, up to ten degrees, is accomplished using a gimbal bearing mounted to the thrust chamber injector. Attachments for the hydraulic actuators are provided at the thrust chamber and are located on either side of the fuel turbopump. The J-2 engine design provides flexible propellant inlet ducts, pneumatic and electrical interface systems and thus eliminates any requirement for the vehicle to provide gimbal connections. Hydraulic power is provided by a pump pad located on the oxygen pump turbine exhaust duct.

A second function provided by the J-2 is that of controlling propellant usage from the vehicle tanks through a propellant utilization system. This system can control vehicle propellant ratios by observing command signals from the vehicle and varying the engine mixture ratio to ± 10%. This mixture ratio control is accomplished by diverting oxygen flow from the oxygen pump discharge and returning it to pump inlet through an electrical control valve located on the oxygen pump discharge volute.

Another function extremely important to the vehicle is that of maintaining vehicle tank pressurization at maximum weight saving. The J-2 engine provides multiple capability in this area. For both the S-II and S-IVB applications, fuel tank pressurization is provided by extracting hydrogen gas from the thrust chamber upper fuel manifold and diverting this gas through the interface ducting to the vehicle.

Up to three lbs/sec supply is available for this purpose. For oxygen tank pressurization, a multipurpose heat exchanger is provided in the exhaust duct located below the oxygen pump turbine. For the S-II vehicle, oxygen is diverted from the oxygen high pressure duct, heated and sent to the vehicle through the interface duct system. For the S-IVB, cold helium is fed to the engine from the vehicle, heated by the heat exchanger and returned to the vehicle.

In the S-IVB vehicle, where restart missions are programmed, the engine provides self-servicing. Sufficient helium gas is provided within the engine for all assigned missions and the hydrogen gas necessary to accelerate the turbomachinery during the starting cycle is replenished by diverting two pounds of hydrogen from the fuel system which is stored in the hydrogen start tank.

In addition to these functional features of the J-2 engine, an always important requirement is that of insuring the propulsion system is performing properly during its scheduled mission. To this end, the J-2 engine provides its own complete instrumentation system. Seventy-two monitoring channels are provided by this system and are located in two assemblies mounted on the thrust chamber.

This engine design thus provides a complete propulsion package which lends itself to high reliability through complete system development. The engine is rated for a single application duration of 500 seconds, and a minimum useable service life of 3750 seconds duration. Development test experience has shown service life and duration capability in excess of these requirements. During the limited life of the J-2 engine program, over ________ test firings have been conducted, accumulating ______ seconds of operation with one engine having accumulated _____ seconds. The engine successfully passed PFRT on 23 March 1965, is currently in FRT and is scheduled to complete Qual by the end of 1965.

To support vehicle and early flight test programs, ____engines have already been delivered to the National Aeronautics and Space Administration. Delivery of engines tested at the 225,000 pound thrust level have started and development testing of the engine at thrusts in excess of 230,000 pounds is now under way.

The J-2 engine development has progressed to the vehicle testing stage. The engine has been tested to full duration capability in the single engine application of the S-IVB and in five engine cluster firings in the S-II vehicle.

As work is performed and major milestones passed, further engine improvements are made possible. Higher performance, reduced weight, greater simplicity and higher reliability beyond the 99% are continuing goals at Rocketdyne for the J-2 engine.

Thank you very much for your thoughtful attention.