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SSME FUEL PREBURNER INJECTOR CHARACTERIZATION

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SUMMARY

A project has been initiated at the Marshall Space Flight Center to determine if preburner inter- or intraelement mixture ratio maldistributions are the cause of temperature variations in The Space Shuttle Main Engine (SSME) High Pressure Fuel Turbopump (HPFTP) turbine inlet region. Temperature nonuniformity may contribute to the many problems experienced in this region. The project will involve high pressure cold-flow testing and Computational Fluid Dynamics (CFD) modeling.

INTRODUCTION

Since the beginning of the Space Shuttle program, the Space Shuttle Main Engine (SSME) has experienced a variety of problems in the high pressure fuel turbopump (HPFTP) turbine inlets. These problems include turbine blade cracks, blade erosion, and sheet metal cracks. The problems may be caused from the severe environment that is generated during start-up and shut-down or to temperature striations that exist during nominal operation. Recent studies have also suggested that the sheet metal cracking may be the result from mechanical vibrations during steady-state operation. In order to properly analyze these problems the thermal environment must be known. It has been shown that temperature striations due to distributions of mixture ratio during steady-state operations persist into the turbine. In a series of recent tests at the Marshall Space Flight Center (MSFC) temperature measurements were taken at various locations along the turbine inlet. Figure 1 shows the locations of the temperature measurements and the measured temperatures of a representative test. A measurement of the temperature of the suction side of a nozzle blade measured above 2300 degrees Rankine, several hundred degrees higher than expected. In general, it is expected that the upstream nozzle temperatures would be higher at the midspan and lower on the edges due to film cooling and Augmented Spark Igniter(ASI) flow. The data showed that the temperatures along the inner diameter were higher than those at the midspan. Thermocouples directly downstream of the baffles did not show temperatures that were notably cooler than those at other circumferential locations. The measurements made on the outer diameter edge of the nozzle blade tended to read lower, showing the effects of the film coolant, but the readings were inconsistent with circumferential variations of over 200 degrees. The thermocouples were placed in some degree of contact with cooled metal surfaces and the amount of cooling at each point is not well known. If it is assumed that the thermocouple does not lose significant heat to the hardware and that the thermocouples are accurate and properly calibrated, the temperatures measured represent the adiabatic wall temperature, which is close to the freestream stagnation temperature. Variations in the freestream stagnation temperature are caused from variations in the upstream mixture ratio. Variations in upstream mixture ratio are caused from the ASI flow, the coolant flow, and the baffles, but these variations follow particular patterns that do not explain the seemingly random variations in the data. Another source of mixture ratio variation are inter and intraelement mass flow variations. Interelement variations result from in manifold pressures and variations in flow resistance in the element due to geometric variations within design tolerances. Intraelement is the variation in mixture ratio across an element streamtube due to incomplete mixing. A study is being conducted to determine if either of these effects is the cause of the temperature nonumiformity. If intraelement effects are found to be important, possible design modifications will be examined.

APPROACH

The SSME uses liquid oxygen (LOX) and gaseous hydrogen (GH2) as its propellants. These propellants enter the preburner through shear coaxial injector elements (Figure 2). The LOX flows through a central tube that exits into a cup region where it is shrouded by a coaxial flow of high velocity GH2. An alternative design that is sometimes employed with LOX/GH2 is the swirl coaxial element in which the central LOX flow enters the element with angular momentum giving the flow a radial component at the element exit to enhance mixing. The objective of this study is to assess the mixture ratio variation that should be expected from the current preburner element and to assess the possible benefits that a swirl element would offer.

In order to isolate the injector effects and to simplify the experiment, it is common practice to characterize injector performance with cold-flow tests using simulants for the fuel and oxidizer. However, most of these tests have been conducted with the elements flowing to open air. It is not possible to simulate realistic conditions unless a high back pressure is imposed at the element exit. Because of this, the ambient back pressure testing may be misleading. Specifically the SSME preburner element has been compared to a swirl element[Ref 1]. Under these test conditions the, the swirl element produced a superior liquid mass distribution. It is not possible to scale this data to the expected hot-fire conditions because unrealistically high mach numbers are required to produce mass flows that are comparable to the hot-fire conditions. In order to obtain a truly realistic comparison, the experiments need to be repeated at a back pressure of at least 560 psig.

Currently, two high pressure cold-flow chambers are available for use at MSFC. These chambers were designed for another test program and will require some modification. A new manifold system has already been developed in-house to accommodate the SSME preburner element and a comparable swirl element. When tested at ambient back pressure the swirl element generates a far superior liquid mass distribution to that of the shear element. However, at high pressure conditions, it is not known how the elements will compare. Based on the characteristics of their operation, it is expected that the shear element performance will improve and swirl element performance will degrade at high pressure. The shear element relies on the momentum of the gas to break-up and disperse the liquid stream. At high pressure, the density of the gas increases, allowing high momentum to be achieved at a low mach number. The swirl element uses radial momentum to disperse the liquid. At high pressure, the increase in gas momentum retards the effect of the radial liquid momentum. However, the gas momentum will enhance the liquid break-up. Basically, the difference in mixing efficiency of the two element types will not be as drastic at high pressure. However, it is expected that the difference still be quite significant. A temperature striation of 200 degrees Rankine only requires a mixture ratio variation of approximately 0.13 from a nominal 0.893 value.

Typically, at ambient back pressure the mixing of the liquid propellant is measured directly using a mechanical patternator, which is simply an array of capture tubes positioned downstream of the injector element exit to measure the mass flux distribution. High back pressure tests require a closed pressure chamber. Mechanical patternation is very difficult to integrate into a pressure chamber. Recently, optical methods of measuring mass distribution have been applied with good success [ref. 2].

The technique involves doping the liquid simulant with a small amount of fluorescing dye which is then excited using a laser sheet and mapping the fluorescence. This method will be used and work is ongoing to address the gas phase mixing with nonintrusive measurements

The variation in the element resistance can be measured by simple water flow tests. However, because it is impossible to insure that the LOX post is positioned exactly in the center of the fuel annulus, circumferential variation in mixture ratios occur. Mixing measurements will be made in the high pressure chamber with the LOX post canted to measure the resulting mixture ratio nonuniformity as well as the variation in the overall flow resistance of the element.

An attempt will be made to use the data generated on this program along with the hot-fire data generated at The Pennsylvania State University to anchor CFD models which will allow an overall prediction to be made of the downstream intraelement mixing effect.

References

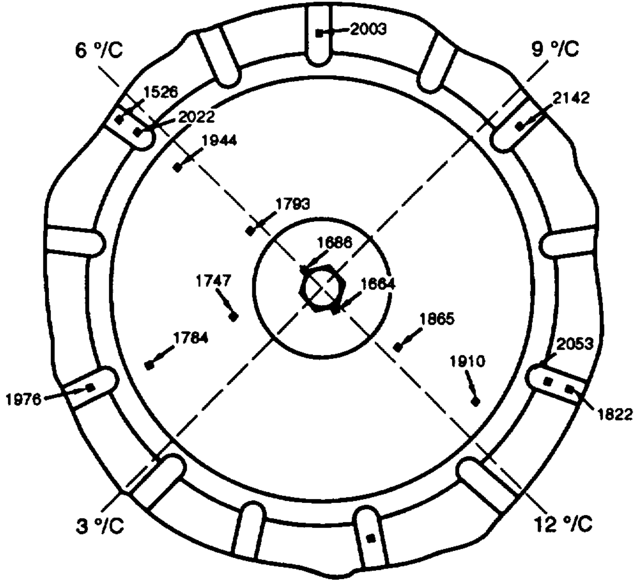
[1] Cox, G.B., "Rocket Engine Injection Element Characterization" , AIAA/SAE/ASME/ASEE 24th Joint Propulsion Conference, Boston , July 1988.

[2] Hartfield, R. J. and Eskridge, R., "Experimental Investigation of a Simulated LOX Injector Flow Field," AIAA/SAE/ASME/ASEE, 29th Joint Propulsion Conference, Monterey, June 1993.

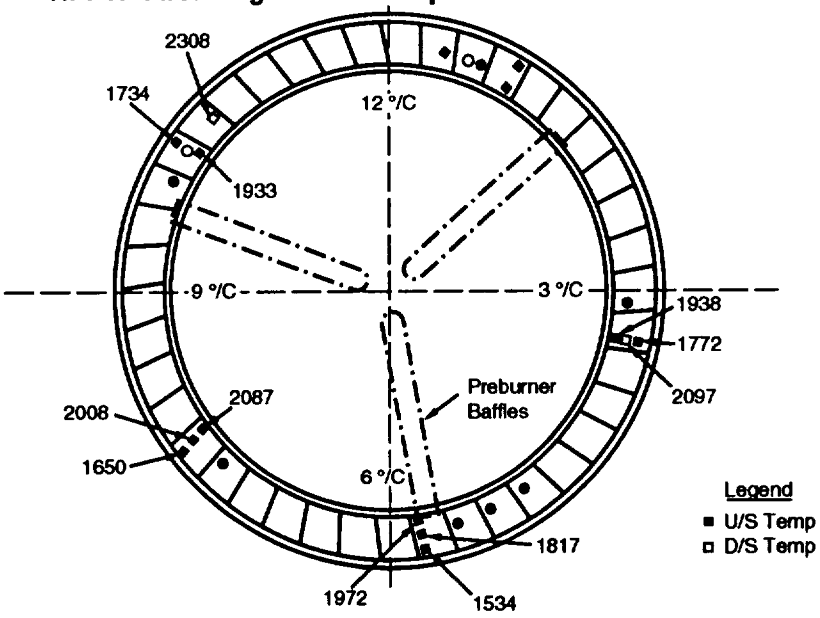
[3] Pal, S., Moser,M.D., Ryan,H.M., Foust, M.J., and Santoro,R.J., "Flowfield Characteristics In a Liquid Propellant Rocket", AIAA/SAE/ASME/ASEE, 29th Joint Propulsion Conference, Monterey, June 1993.

Figure 1

HPFTP Turbine Inlet Dome and Strut Temperature Measurements



HPFTP First Stage Nozzle Temperature Measurements



Preburner Injector Element

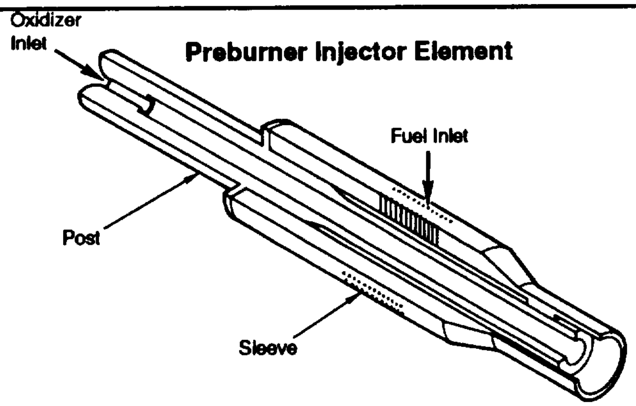


Figure 2