SPACE SHUTTLE MAIN ENGINE THE FIRST TEN YEARS

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Part 8 – Fuel Preburner Burn Through

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On August 27, 1977, Engine 0004 Test 901-133 was prematurely terminated by the primary observer because of an external fire. Hardware inspections after the test revealed that a hole had been burned completely through the FPB liner and outer body, allowing significant leakage of the hot gas to the outside. A simple design change was made that eliminated the specific failure mode; however, almost three years later, another failure occurred with the same result. MPTA Test SF1001, on July 12, 1980, experienced a major fire in the aft compartment. It was determined that Engine 0006 FPB had a hole burned through the FPB liner and outer wall very similar to the incident on Engine 0004.

The FPB (Figure 25) provides the turbine drive gas for the HPFTP. It consists of two propellant manifolds, a centrally located ASI, an injector and a short combustor section welded together into the major hot gas manifold that also includes the oxidizer preburner, the high pressure turbine exhaust gas flow path and the injector for the main combustor. The FPB injector is a coaxial element injector with each element having low

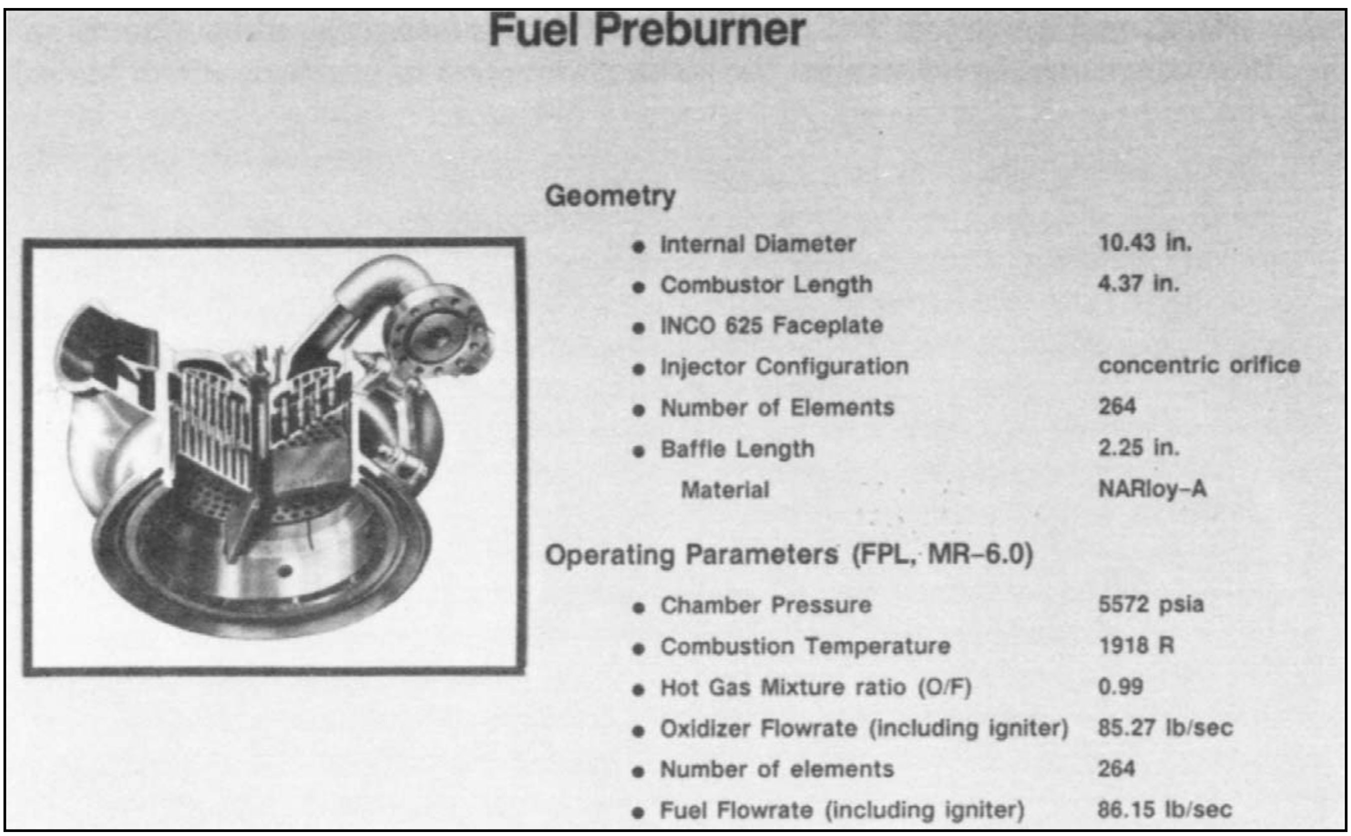

Figure 25 Fuel Preburner (Photo SC89c-4-1020)

velocity LOX flowing in a center post, with high velocity gaseous hydrogen in a surrounding annulus to promote uniform mixing. Combustion takes place below the INCO 625 faceplate in three compartments which are separated by 2.25-inch-long copper alloy baffles to prevent tangential modes of instability. The baffles and the faceplate are cooled by hydrogen flowing through drilled holes into the combustion chamber. The outer structural body of the combustor is cooled by the use of a concentric cylindrical liner with hydrogen flowing between the liner and the combustor wall. This same hydrogen is used to cool the HPFTP turbine bellows by the utilization of a welded-in liner extension.

The failure that occurred on Engine 0004 in 1977 happened during a test series wherein the problem of generalized overheating of the FPB body was already being studied by the use of externally mounted thermocouples. The through hole was in line with a LOX post at the outer raw comer of a baffle compartment. It had started by eroding through a small dead-end compartment called an acoustic cavity, which was attached to the inside of the liner. It then progressed though the liner and finally burned through the half-inch thick outer combustor wall. It was concluded that the burning was caused by a localized recirculation of LOX from the corner element, causing, burning of the nearby acoustic cavity, which acted as fuel to propagate the burning. Two design changes were adopted immediately. The acoustic cavities were eliminated, and all six of the outer row baffle comer LOX posts were deactivated (plugged). The hole in the preburner was repaired by welding and testing was resumed five days after the incident.

The second failure, in 1980, was located six elements away from a baffle (Figure 26) and was determined to be caused by a different mechanism [39]. Inspection of the preburner elements showed no evidence of contamination which could have caused fuel blockage; however, it was discovered that the individual element LOX posts were not concentric with the fuel annuli, causing a fuel restriction on the outboard side of the outer row elements. Further inspection showed that the lack of concentricity was caused by a deformity of the face plate in which it was bowed outward almost a tenth of an inch, half way between the center and the outer row. The investigating team [39] concluded from the inspection of all other preburners that the bowed condition was unique to the failed unit. In addition, a review of historical problem reports disclosed that this FPB had experienced more reported cases of overheating or minor erosion than all other preburners combined. The cause of the deformity was never identified; however, periodic inspections were added for all preburners to verify outer row element concentricity in the future.

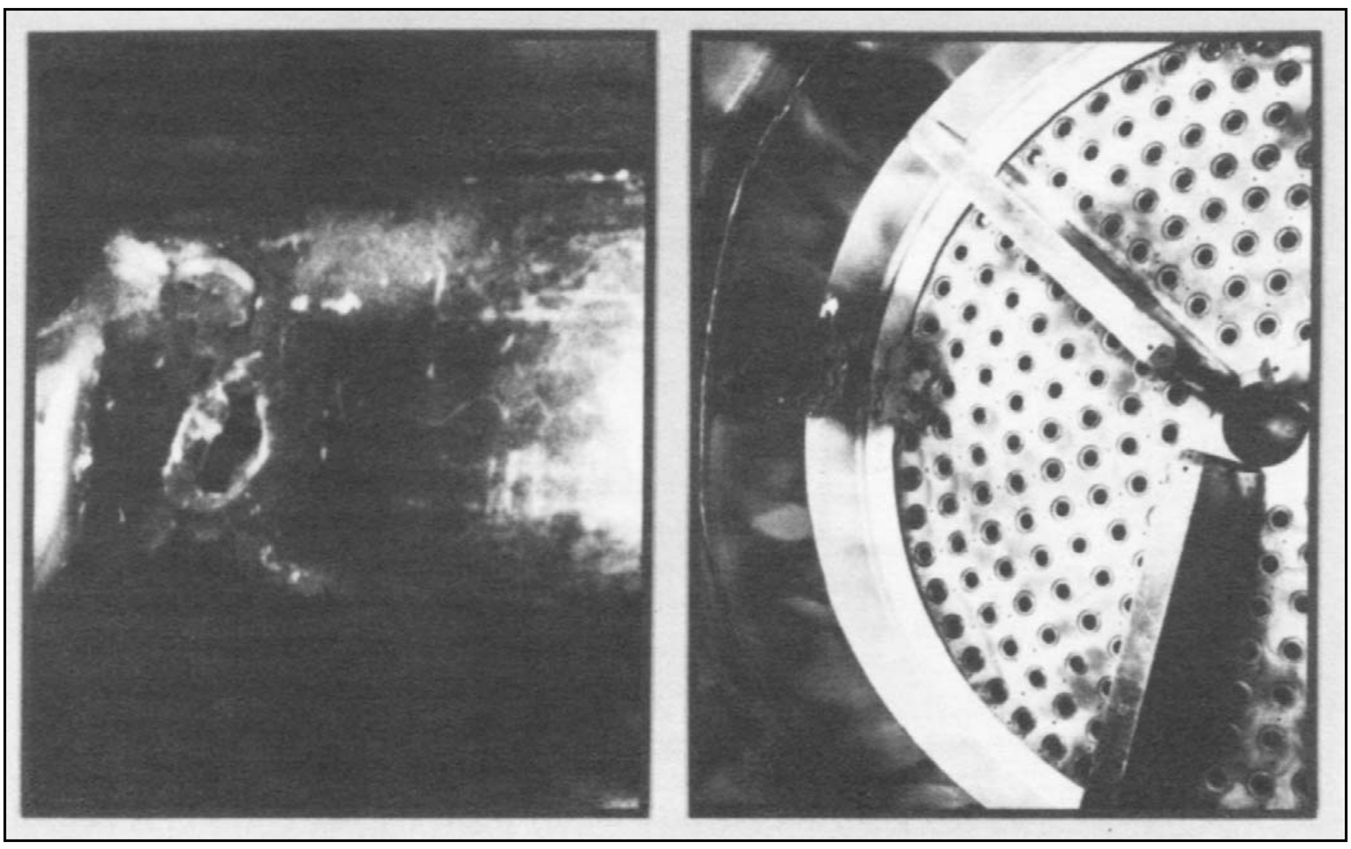

Figure 26 Engine 0006 Fuel Preburner (Photo No. SC89C-4-1013)

Even though the failure was caused by a unique hardware condition, a major effort was undertaken to preclude additional occurrences of this type of problem by' making the preburner insensitive to maldistribution of the propellants. A two dimensional, four times scale, water-flow model was constructed and tested to evaluate propellant streamlines in the outer row and along the liner wall. Two flow paths were discovered which could contribute to burning if the localized gases were at a higher mixture ratio. A recirculation field existed along the liner wall for about three inches (twelve inches on the water table) which disrupted the local boundary layer and increased the potential heat transfer. The flow path was found to be caused by the existence of an empty space along the face plate between the element and the liner. The recirculation was eliminated by the incorporation of a new liner which added a divergent section on the inside of the liner to occupy the empty space. To further reduce the potential heat transfer to the liner, the new liner was coated with zirconium oxide. Another flow path was found which would cause hot gas to flow into the coolant circuit between the liner and the FPB body. With a small axial gap between the liner and the faceplate, the fluid at the faceplate would be forced by an adverse pressure gradient to flow through the gap into the coolant circuit. The new liner included coolant flow control orifices which assure that the coolant flow pressure is always higher than the hot gas pressure. This favorable pressure gradient prevents flow through any gap and also acts as an erosion inhibitor by automatically cooling any small hole in the liner with additional hydrogen.

Tests with purposely misdirected elements were conducted to verify the effectiveness of these design changes in preventing liner erosion. It has also been shown that even if a hole were placed in the liner, hot gas would not flow into the coolant circuit. Even so, a "belt and suspenders" approach was taken with this problem by adding a thermal barrier on the inside of the FPB body which would withstand the previously experienced failure conditions for a long enough time - to complete a flight mission without failing. A ceramic thermal shield made of molybdenum and coated with disilicide was designed to be bonded to the FPB body.