SSME LIFETIME PREDICTION AND VERIFICATION, INTEGRATING ENVIRONMENTS, STRUCTURES, MATERIALS; THE CHALLENGE

Robert S. Ryan, Larry D. Salter, George M. Young, III, and Paul M. Munafo
Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

The planned missions for the Space Shuttle dictated a unique and technology-extending rocket engine. The high I_{SP} (performance) requirements in conjunction with a 55-mission lifetime, plus volume and weight constraints, produced unique structural design, manufacturing, and verification requirements. Operations from earth to orbit produce severe dynamic environments, which couple with the extreme pressure and thermal environments associated with the high performance, creating large low cycle loads and high cycle alternating stresses above endurance limit which result in high sensitivity to alternating stresses. Combining all of these effects resulted in the requirement for exotic materials, which are more susceptible to manufacturing problems, and the use of an all-welded structure. This paper discusses the challenge of integrating environments, dynamics, structures, and materials into a verified SSME structure to meet a 55-mission lifetime while producing unprecedented performance. Included also are the verification program and developmental flight results. Rocketdyne Division of Rockwell International Corporation, under contract to Marshall Space Flight Center, is the prime contractor for the development of the Space Shuttle Main Engine (SSME).

INTRODUCTION

The Space Shuttle mission requirements and the resulting propulsion system requirements have led to very stringent and technology-extending structural design, verification, manufacturing, and operational approaches. Being a manned vehicle, Space Shuttle dictated that the engine be of the highest possible reliability (References 1 and 2).

The Space Shuttle missions require the engine to have high performance I_{SP} of 455 seconds, a thrust of 375,000 pounds (sea level), long life (55 missions), minimum maintenance, and to be achieved within stringent weight and volumetric constraints. These concepts and requirements led to a new approach, "line replaceable units (LRU's)," that could be installed either in the field or factory. Acceptance and/or verification of LRU's are accomplished separately from the engine system (Reference 3).

In order to achieve the high performance (I_{SP}), a two-stage pump system is used in conjunction with preburners which burn the fuel rich, furnishing the power for the pumps. This extremely hot fuel rich gas feeds the main combustion, efficiently developing the engine thrust. This system results in unprecedented operating regimes of temperatures, pressures, and rotating machinery speeds. The high rotary speeds and the combustion processes create mechanical, acoustical, and fluctuating pressure environments. Figure 1 is a schematic showing typical pressures and temperatures. The volumetric and weight constraints drive the design toward a high concentration of energy and minimum structure sizing (thickness, etc.). The energy concentration can be illustrated by observing the size of the high pressure fuel pump, which generates 70,000 horsepower within an envelope 18 inches in diameter by 30 inches long and rotates at speeds up to approximately 40,000 rpm (References 1, 2, 4, 5, 6, 7, 8, and 9).

The structural design problem is further complicated by the multivaried operating regime (throttling to 65%) and the requirement to gimbal the engine ± 10 degrees at a 10 degree/second rate for vehicle control authority. The engine starts on the ground, operates in the atmosphere and then in a vacuum, and shuts down, producing large thermal and pressure cycles for each burn. Since the nozzle expansion ratio is a key parameter to high performance, a compromise between atmosphere and vacuum is required, leading to a very complex, additional set of environments during ground start.

Volumetric and weight constraints introduce designs which create additional fluctuating environments. For example, curved ducts, bellows, valves, and changing duct/valve diameter create higher velocities, unsteady flow environments, and acoustic pressures which are additive to the normal turbine fluctuating pressures and combustion induced noises.

Combining all of these environments leads to three classical design problems, (1) strength - pressures, thermal loads, and inertial loads; (2) low cycle fatigue - pressure and thermal cycles associated with each firing that is unprecedented in rocket engine design, and (3) high cycle