PART III. SPACE SHUTTLE MAIN ENGINE

Introduction

The Space Shuttle Main Engine (SSME) was the first and only fully reusable, high performance, liquid rocket engine in the world rated for human spaceflight. The staged combustion engine burned a mixture of LO2 and LH2 to lift the vehicle into space. The ET provided the fuel and oxidizer for the three SSMEs, which worked in tandem with the twin SRBs during the first two minutes of powered flight. The engines operated for an approximate total eight-and-one-half minutes from ignition to MECO, and burned over 1.6 million pounds (approximately 528,000 gallons) of propellant. The SSMEs powered the Shuttle with more than 1.2 million pounds of thrust.

The SSME staged combustion cycle burned the fuel in a two-step process. First, the dual preburners burned most of the hydrogen and part of the oxygen from the turbopumps, producing hydrogen-rich gas at high pressure and limited temperature. The flow of hot gas drove the turbines in the high-pressure turbopumps. The turbine exhaust flowed into the main combustion chamber, where the fuel was completely burned, producing hydrogen-rich gas at high pressure and high temperature. The exhaust from the main combustion chamber expanded through the nozzle to produce thrust. At sea level, the propellants provided each engine thrust levels of approximately 380,000 pounds at rated power level (RPL) or 100 percent thrust; 390,000 pounds nominal power level (NPL) or 104.5 percent RPL; and 420,000 pounds at full power level (FPL) or 109 percent RPL (or approximately 470,000 pounds, 490,000 pounds, and 512,000 pounds, respectively, in a vacuum).

The engines were throttleable in one-percent increments over a thrust range of 67 to 109 percent RPL. All three main engines received the same throttle command at the same time. This provided for a high thrust level during liftoff and initial ascent, but allowed thrust to be reduced during the final ascent phase. The engines were gimbaled to control pitch, yaw and roll during the ascent.

The SSME operated at greater temperature extremes than any mechanical system in common use today. Before ignition, the LH2, the second coldest liquid on Earth, was minus 423 degrees F. The combustion chamber reached 6,000 degrees F following ignition, which was hotter than the boiling point of iron. To meet the demands of the severe operating environments, exotic alloys were developed, such as NARloy-Z (Rocketdyne) and Inconel Alloy 718 (Special Metals Corporation).[1036] The latter, a nickel-based superalloy, was used in approximately 1,500 engine components and comprised roughly 51 percent of the SSME, by weight.

[1036] R.P. Jewett and J.A. Halchak, "The Use of Alloy 718 in the Space Shuttle Main Engine," in *Superalloys 718, 625 and Various Derivatives*, ed. Edward A. Loria (The Minerals, Metals & Materials Society, 1991), 749-760.

The three engines, almost interchangeable in the launch position, were referred to as the center (Engine 1), left (Engine 2), and right (Engine 3). The only difference among the three positions on the orbiter was that different areas of the nozzles required thermal protection from the external environment depending on orbiter position.[1037]

The nozzle, main combustion chamber, powerhead, low-pressure turbopumps, valve assemblies, and ducts were manufactured by Pratt & Whitney Rocketdyne[1038] in Canoga Park, California. The high-pressure turbomachinery for the last engine configuration flown on the Shuttle, the Block II SSME, was produced at the Pratt & Whitney Rocketdyne facility in West Palm Beach, Florida. The first flight for the high-pressure liquid oxidizer turbopumps occurred in 1995, and in 2001 for the high-pressure fuel turbopumps. Major SSME subcontractors were HR Textron (also known as Woodward HR Textron and Hydraulic Research, Inc.) in Valencia, California, for engine valve actuators and Honeywell, Inc. in Clearwater, Florida, for the main engine controller. Historically, more than thirty-five subcontractors in about twelve states contributed to the SSME project.[1039]

The SSME program was managed by NASA's Space Shuttle Project Office located at MSFC. Engines and engine components were tested at NASA's SSC in Mississippi. Over the course of the SSP, the SSMEs accumulated more than fifty-seven hours of flight time and another 246.7 hours of ground testing.[1040] Originally, the main engines were designed for fifty-five starts and 27,000 seconds of run time before needing replacement.[1041]

Reporting on the SSME program status as of October 1992, in response to a request from the House of Representatives' Committee on Science, Space and Technology, the SSME Assessment Team concluded that, "By all accounts, the SSME is a marvel of engineering achievement."[1042]

[1037] Katherine P. VanHooser, personal communication with James M. Ellis, MSFC, August 23, 2011.

[1038] Pratt & Whitney Rocketdyne, headquartered in Canoga Park, California, is a division of Pratt & Whitney, a wholly owned subsidiary of the United Technologies Corporation. The company was formed by North American Aviation (NAA). In 1967, NAA and Rocketdyne merged with the Rockwell Corporation to form North American Rockwell, later part of Rockwell International. The aerospace entities of Rockwell International, including the former NAA, and Rocketdyne, were sold to Boeing in 1996. In 2005, Boeing sold what was then called Rocketdyne Propulsion and Power to United Technologies Corporation, which they subsequently combined with their Pratt & Whitney Space Propulsion Division. The name of the corporate entity at the time of the relevant historical event is used throughout this section of the narrative.

[1039] NASA MSFC, Transition Project Office, "STS Stack" Recordation Data Package, June 15, 2009, Tab D: MSFC STS Element Major Hardware Suppliers.

[1040] Pratt & Whitney, "Pratt & Whitney Rocketdyne's Space Shuttle Main Engines Power Final Flight to International Space Station," P&W Press Release, July 8, 2011, http://www.pw.utc.com/media_center/ press_release/2011/ 07_jul/7-8-2011_00001.asp.

[1041] Originally, the main engines were contractually required to operate for 27,000 seconds consisting of fifty-five starts at eight minutes per flight. Jenkins, *Space Shuttle*, 412.

[1042] NASA, *Report of the SSME Assessment Team*, January 1993, i, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930012456.pdf.