SPACE SHUTTLE MAIN ENGINE
THE FIRST TEN YEARS

Robert E. Biggs

Part 2 – The Obstacles

Getting Started, Component Testing, Engine Testing, Problem Management

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GETTING STARTED

Engine development testing was planned to be conducted at the NASA rocket test site in Mississippi and to begin late in 1974. The Mississippi Test Facility (MTF) had been used for static testing the Saturn (Apollo) launch vehicle stages, and the Saturn test facilities were modified, at NASA direction, to accommodate the SSME. (MTF was later renamed the National Space Technology Laboratory [NSTL] and more recently, the Stennis Space Center [SSC].) In the meantime, component and subsystem testing was also planned for the Coca area of the Rocketdyne Santa Susana Field Laboratory (SSFL) at Chatsworth, California. Existing test facilities were to undergo major modifications to accommodate the turbopumps and combustion devices and various combinations of components arranged in subsystems. During 1973 and early 1974, unforeseen difficulties were encountered with the Coca construction project that eventually led to a schedule slip of about six months. At the same time, procurement delays, weight reduction design changes and required structural improvements caused the fabrication of major components to fall behind schedule. [14]

In the summer of 1974, the SSME program was realigned under the leadership of Bob (J.R.) Thompson as the MSFC SSME project manager and Norm Reuel as the Rocketdyne vice president and program manager. The program schedules were adjusted by about six months and increased management emphasis was provided to assure timely completion of the remaining development tasks. The most significant of these involved the Integrated Subsystem Test Bed (ISTB).

The ISTB was originally planned as a "bobtail" engine. It was to be made up of the four turbopumps and two preburners with associated plumbing and controls, but without a thrust chamber assembly (TCA). (The TCA consists of the main injector, the main combustion chamber and the nozzle). The control system included all the required valves and actuators; however, the controller was a remotely located, laboratory-type, rack-mounted computer operating in "single string" (no redundancy). This configuration was one of the subsystems originally planned for subsystem testing; however, during the fact-finding negotiations of July 1971, it was agreed that a shortened version of the TCA would be added to the ISTB. The shortened TCA was to have an area ratio (throat area divided by exit area) of 35 to 1 rather than the flight configuration of 77.5 to 1. The ISTB, then, became essentially an engine assembly which, because of the area ratio reduction, could throttle to 50 percent power level without requiring a vacuum chamber.

With the program realignment, the activation of the ISTB test facility planned for Coca test area (Coca-lC) was deferred in favor of testing the ISTB at NSTL, with the first test scheduled for May 1975. A special management team was formed to determine and implement system and operational changes that would ensure achievement of this very key objective. The team was headed by Dom Sanchini as associate program manager and included Ted Benham as the manufacturing project manager and Dr. Ed Larson as the engineering project manager. The team investigated in detail the production release and fabrication system being used. With the concurrence and help of MSFC Project Management, Quality and Engineering, changes were made to simplify paperwork and provide quick turnaround for hardware modifications without sacrificing quality or configuration control. This was achieved largely due to the assignment of 25 top design engineers to on-the-floor manufacturing support with authority for on-the-spot approval of material review dispositions and design change rework modifications [15]. The chief engine designer, Bob Crain, supervised the ISTB assembly.

The ISTB first full-up ignition test date had been selected by the Management and Budget Office of the White House as one of the major Space Shuttle program milestones by which that office would monitor the program progress and health. This very important milestone was achieved on schedule. The ISTB was installed in NSTL test stand A-1 (Figure 6) and a countdown demonstration test (Test 901-001) was conducted on 19 May, 1975. After five

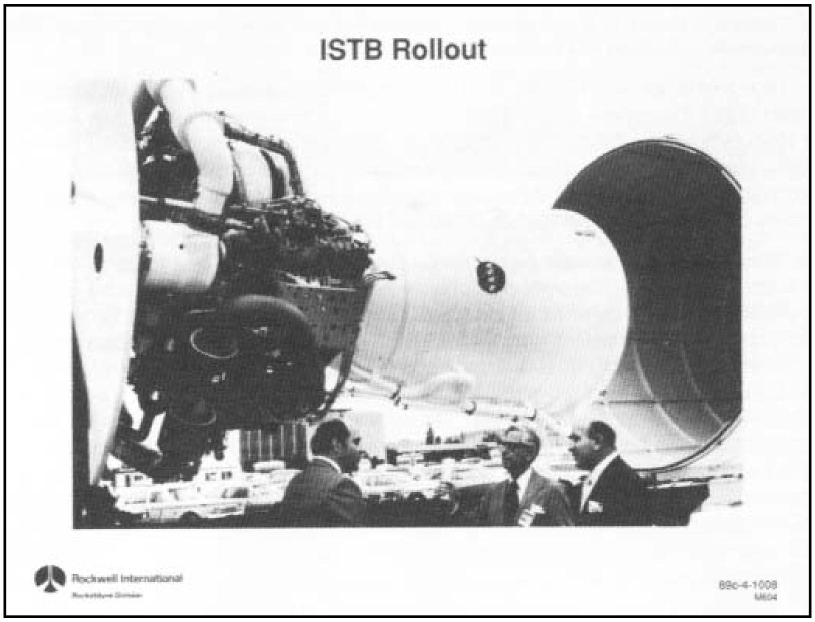

Figure 6. The Integrated Subsystem Test Bed (Photo No. 89c-4-1008)

short exploratory ignition tests, the full thrust chamber ignition test was conducted on 23 June, 1975. The engine development test program was underway.

COMPONENT, TESTING

This history of the SSME contains a review of the major problems encountered during engine testing from the first test of the ISTB to the first flight of the Space Shuttle and, as such, does not go into detail concerning the component and subsystem test program. The history, however, would be incomplete without at least a summary of this important part of the SSME development.

Within the program realignment of 1974, it was decided that the first article of each major component would be allocated to the ISTB. This action would accelerate engine testing and the discovery of any potential major system problems, but would delay the beginning of the component test program until after the second article had been assembled. The component test program began in the same month as the engine test program (May 1975) with the low pressure turbopumps (LPOTP and LPFIFP). The two high pressure turbopumps (HPOTP and HPFTP began testing three months later, in August 1975. The combustion devices test program actually began during Phase B in 1971. The test program planned for the Coca area, however, began with ignition system tests and progressed to preburners and then preburners with the MCC, and finally, culminated with the TCA (MCC with a 35 to 1 nozzle) in August 1975.

As mentioned before, component tests were used to great advantage in the design verification program delineated in the DVSs. Most of the problems that were encountered, however, were due to the complexity of the test facilities rather than the discovery of component failure modes. The test facilities were designed to accept various combinations of components arranged in subsystems and used facility devices (usually servo-controlled valves) to simulate the engine environment. The turbopump test stand had approximately 2,000 valves including 24 which were servo-operated. Preburner propellants were supplied from a 14,000 psi system with valves weighing as much as five tons. One of the more significant problems occurred on Coca-1A early in 1976. The oxidizer subsystem, which consisted of a LPOTP, HPOTP and OPB (actually a half powerhead which included the preburner) was being tested. At 19 seconds into Test 740-007, a facility rotary flowmeter failed, releasing flowmeter blades into the LOX flow stream. The blades initiated a fire at a downstream throttle valve which burned, causing a decrease in flow resistance. The decrease in flow resistance caused enough of a change in the operation of the HPOTP that it cavitated, lost axial thrust control and began to rub internally. This resulted in a major fire which caused significant damage to the components and the facility [16]. A similar failure occurred on a fuel subsystem test on Coca-1B the following year. Test 745-018 experienced a major fire beginning with a fire in a facility throttle valve caused by cavitation-induced erosion [17].

With the advent of engine and component testing and its attendant loss of hardware, it soon became evident that the planned hardware was inadequate to support the scheduled test program and keep up with the attrition realized from the development problems. This deficiency was to remain with the program for many years. The component test program, if pursued as originally planned, would have drained valuable resources from the engine test program to develop the complicated test facilities. The NASA administrator, Dr Robert Frosch, stated in testimony to the Senate Subcommittee on Science, Technology and Space, that "...we have found that the best and truest test bed for all major components, and especially turbopumps, is the engine itself." [18] Largely due to the lack of sufficient resources to pursue an aggressive component test program in addition to the engine test program, the Coca area test facilities were gradually phased out from November 1976 to September 1977.

ENGINE TESTING

The engine test program is summarized in Figure 7. It shows the number of engine tests as a function of calendar time from the first test in May 1975 to the first flight in April 1981. Also shown are the total test seconds and the test seconds at rated power level. Superimposed on the accumulated tests plot are indicators showing the initial dates of the major engine problems that are to be discussed in the following chapters. The eight problems listed were chosen as being the most significant as they relate to flight safety; and, even though some other problems also caused loss of resources during the program, the recovery effort for these eight was judged to be the most difficult in terms of what had to be done to allow program continuation and to assure a safe first flight.

PROBLEM MANAGEMENT

Before continuing into the discussion of development problems encountered during the engine test program, it seems appropriate to summarize the management techniques employed by the SSME program to expedite the solution of these problems. The two consistent management devices were, the “special team” and the “5 o’clock meeting.” Although not unique to Rocketdyne or the SSME, both devices proved to be quite valuable in aiding the timely solution of these problems.

For every significant problem, a special team was formed under an autonomous team leader to whom appropriate organizational authority was delegated. Sometimes a separate MSFC team was formed and other times the Rocketdyne and MSFC teams were combined. Full time dedicated team members were assigned to each team, representing all the technical disciplines required to solve the problem and return the program to normalcy. Team members were usually technical managers and included such specialties as structural analysis, dynamics, materials, thermodynamics, metallurgy, systems, quality control, data handling, component design and test planning. The teams were charged with the multiple tasks of identifying the problem cause, establishing problem control sufficiently to enable safe resumption of testing, determining and implementing the ultimate redesign or other action to prevent further recurrence of the problem, and providing proof to Rockwell and NASA management that the problem was eliminated or controlled. The team leader was chosen for each problem as it occurred and was usually the engineering director with the most appropriate background and expertise. Of the first 20 special teams formed, Ed Larson, director, Design Technology, was assigned as team leader for half of them. It is likely that he would have been assigned to others except for the fact that he had not yet concluded an investigation of a previous problem.

From the first test until long after the first flight, the five o’clock meeting was a daily ritual set aside to recap that day’s activity and progress (or lack thereof) on the most significant current problem. Dom Sanchini, who was appointed vice president and program manager after the ISTB was delivered to NSTL for testing, conducted the meeting in his office with key members of his staff and selected individuals associated with the problem. In addition to problem team leaders, the regular attendees were; Willy Wilhelm or Paul Fuller (chief program engineer), Jerry Johnson (associate program manager, Engine systems) and Bob Biggs, chief project engineer, who was responsible for directing the engine test program. For turbomachinery problems, the meeting included Jim Hale (associate program manager, Turbomachinery) and Joe Stangeland (director, Turbomachinery). If the problem involved combustion devices, then Don Mikuni (associate program manager, Combustion Devices) and Erv Eberle (director, Combustion Devices) would attend. Quite often, the meeting would be attended by Bob Thompson who, in spite of the fact that he lived in Huntsville, Alabama, spent a lot of time in the Rocketdyne Canoga Park, California plant, and maintained a permanent office next door to Dom Sanchini.

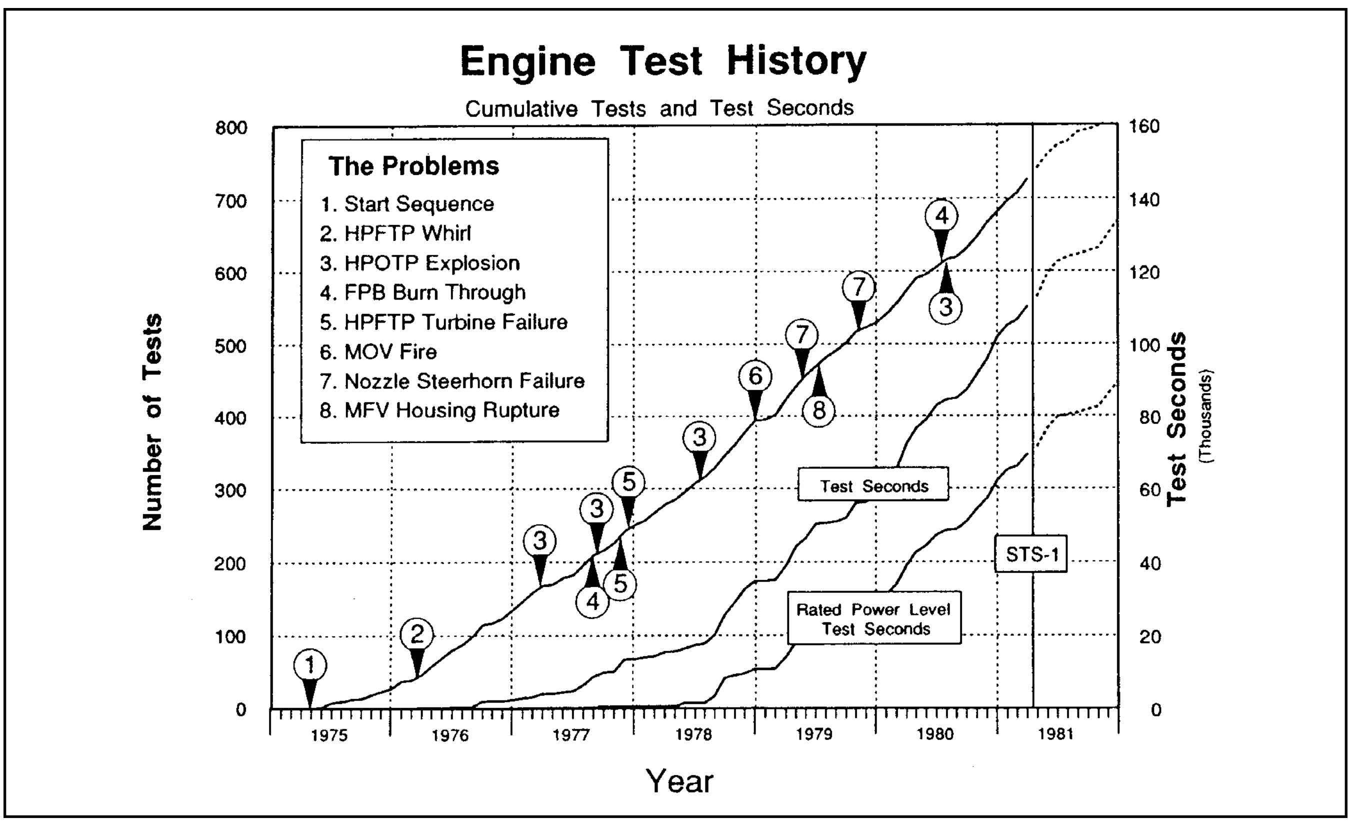

Figure 7. Engine Test Problem Summary (Photo No. 89c-4-1014)