SPACE SHUTTLE MAIN ENGINE
THE FIRST TEN YEARS

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Part 9 – The Goals, First Flight

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The DVS program (see The Requirements) was planned to verify all design requirements in a logical fashion, using certain key task completions as benchmark control points or gates constraining the continuation of the program for some of the more critical activities [12]. Superimposed on that program were other significant milestones that were established by various NASA and other government agencies as an aid in tracking the general health of the SSME and shuttle program. These generally fell into one of three categories: design reviews, test progress, and formal demonstrations.

A preliminary design review (PDR) was conducted by the NASA with each of the three competing contractors during the SSME contract competition phase in 1970. Immediately after the establishment of a definitive contract, the official PDR was conducted with the Rocketdyne design. The major emphasis in this review involved technical concerns and issues that were too sensitive to discuss during the competition. The purpose of the PDR was to establish confidence in the design concepts and agree to further actions to pursue in areas of insufficient confidence. The PDR was concluded in September 1972 with the agreed-to actions and schedules. The next major step, a critical design review (CDR), was scheduled to be conducted in the first quarter of 1976; however, during the program realignment in 1974, the CDR was rescheduled and was actually completed in September 1976.

The primary purpose of the CDR was to demonstrate that the design was sufficiently mature to allow fabrication of the first deliverable flight engines to commence. The review was organized by MSFC under four separate teams headed up by MSFC task managers Carlyle Smith, John McCarty, Walt Mitchell and Zack Thompson. Weaknesses, questions, required design changes and other requested actions were documented as review item dispositions (RIDs) and approved by the team leaders to be dispositioned by the CDR board. A pre-board review was held with Jerry Thomson, MSFC chief engineer for SSME, as pre-board chairman. Recommendations by the pre-board were dispositioned by the full CDR board which was chaired by Bob Thompson, SSME project manager. In all, 105 RIDs were dispositioned with 86 of then requiring additional action to be performed by Rocketdyne. At the conclusion of the CDR, on September 27, 1976, the SSME design was baselined so that any future design changes would be subject to formal configuration control. Fabrication of the first set of flight engines was allowed to proceed.

Early in 1979, the NASA conducted an Orbital Flight Test Design Certification Review (OFT DCR) of all the Space Shuttle elements. The SSME portion of the OFT DCR was organized much the same as the CDR, with Joe Lombardo as the pre-board chairman and Bob Thompson as the SSME board chairman. The purpose of the DCR was to review the verification status of all design requirements and to certify to NASA Headquarters that the engine design was sufficiently mature as to be considered flight worthy. The SSME portion of the DCR was completed in April 1979 and approved by Bob Lindstrom, manager, Shuttle Projects Office, MSFC. The Space Shuttle DCR results and certifications were then presented to John Yardley, associate administrator for space transportation systems.

Test progress milestones were established for six individual "first tests" [12]. One of them was the first ISTB ignition test discussed in a previous section. The last one was the first SSME "all-up" throttling test which was accomplished on March 16, 1977, on

Engine 0002 Test 902-056. The most significant test milestone was established in terms of total accumulated test duration of the single engine ground test program (excluding MPTA). A goal of 65,000 seconds was set by John Yardley as representing a sufficient level of development maturity to consider the engine flight worthy. NASA Headquarters considered the achievement of this goal to be a flight constraint. The goal of 65,000 seconds was reached on March 24, 1980 during a test on Engine 2004. Figure 27 shows the growth of the accumulated test time over the years and also the annual improvement in average test duration that made it possible to reach the goal in that time period. The dramatic increase in average test duration was possible because the development problems were being solved and increasing confidence allowed more longer duration tests to be scheduled.

The original SSME Program Plan included a Preliminary Flight Certification (PFC) demonstration test program to be conducted prior to the first flight. Specific requirements for the PFC evolved gradually during the program with the final requirements being established in early 1980 [40]. The PFC was defined in terms of a unit of tests that were called cycles. Each cycle consisted of 13 tests and 5,000 seconds of test exposure which included simulations of normal and abort mode flight profiles. It was required to conduct two PFC cycles on each of two engines of the flight configuration in order to certify that configuration for 10 shuttle missions. The PFC demonstration required 100 percent successful tests. If any test were shut down because of an engine problem, the PFC cycle did not count and had to be started over from zero.

Other PFC cycles were added to the program for the purpose of overstress testing and flight abort simulation. Eventually eight PFC cycles were completed prior to the first flight. A summary of the PFC cycles with their completion dates is given in Figure 28. At the time of the first flight, the SSME test program had accumulated 110,253 seconds during 726 tests.

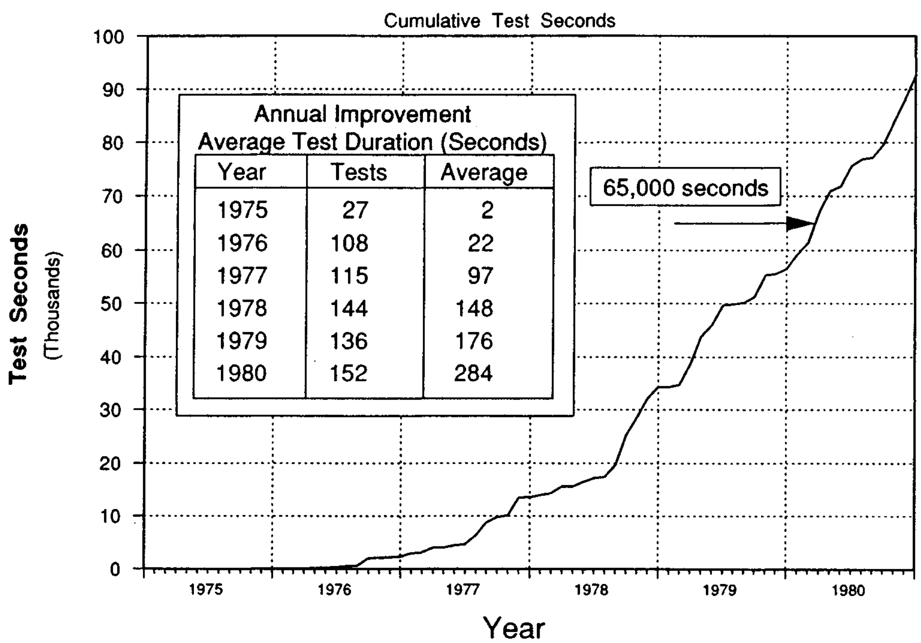

Figure 27 Single Engine Test History (Photo No. 89C-4-1018)

RATED POWER LEVEL (100%)
CERTIFICATION SUMMARY FOR STS-1

CERTIFICATION OBJECTIVES	CERTIFICATION CYCLE REQUIREMENTS	ENGINE 2004				ENGINE 0009		ENG 2008	ENG 0008
		1ST CYCLE	2ND CYCLE	100/109% ABORT	102% CYCLE	1ST CYCLE	102% CYCLE	102% CYCLE	100/109% ABORT
TOTAL TESTS	13	16	17	7	4	21	13	16	5
STARTS TO RATED POWER LEVEL	13	14	15	7	4	15	13	14	5
TOTAL DURATION (SEC)	5000	5246	5098	2406	1298	5608	5041	5881	2540
TIME AT RATED POWER LEVEL	3000	3568	3643	1316	258	4078	31	479	1032
TIME ABOVE RATED POWER LEVEL	425	425 (102%)	425 (102%)	1090 (109%)	880 (102%)	427 (102%)	4070 423 (104%)	4363 433 (104%)	1440 (107% & 109%)
MISSION DURATIONS	6	8	8	3 (610 SEC)	2	9	8	9	4 (610 SEC)
NOMINAL MISSIONS (520 SEC)	4	5	6	–	2	7	6	7	–
ABORT TO ORBIT (665 SEC)	1	1	1	–	–	1	1	1	–
RETURN TO LAUNCH SITE ABORT (823 SEC)	1	2	1	–	–	1	1	1	–
	DATE COMPLETED	6 79	2 80	4 80	7·80	9 80	12 80	1·81	3 81

Figure 28 Summary for STS-1 (Photo No. 309-654Q)

THE FIRST FLIGHT

The first four flight configuration engines were assembled and acceptance tested in the first half of 1979. Engine acceptance testing included a 1.5-second start verification, a 100-second calibration firing and a 520 second flight mission demonstration test. Engine 2004 was allocated to the PFC demonstration program and Engines 2005, 2006 and 2007 were installed in the orbiter Columbia for the initial Space Shuttle flight. Several shuttle program problems (such as orbiter tile replacement) ensued which caused the first flight to be delayed. During this time significant changes were made to the three flight engines as a result of the test problems previously discussed. Because of the number and complexity of the changes, it was decided to repeat the final engine acceptance test. Engines 2005, 2006 and 2007 were removed from the orbiter and shipped to the engine test site at NSTL. In June 1980, all three engines successfully completed a 520 second flight mission demonstration test and were subsequently reinstalled in the orbiter Columbia.

A successful 20 second Flight Readiness Firing (FRF) was conducted on February 20, 1981. All three main engines were operated simultaneously at RPL with the entire, Space Shuttle, including the solid rocket booster (SRB), on the launch pad in the launch attitude. The normal launch sequence was used including starting the main engines at T minus 6.6 seconds (staggered by 0.120 seconds). Liftoff was precluded by not igniting the SRB (normally at T minus zero). The FRF had been planned as the final “all-up” verification that the engines and all interfacing systems were capable of satisfactory operation. Engine performance was within expected limits; and post-test hardware inspections, leak tests and other required checkouts were satisfactorily completed The engines were ready for flight.

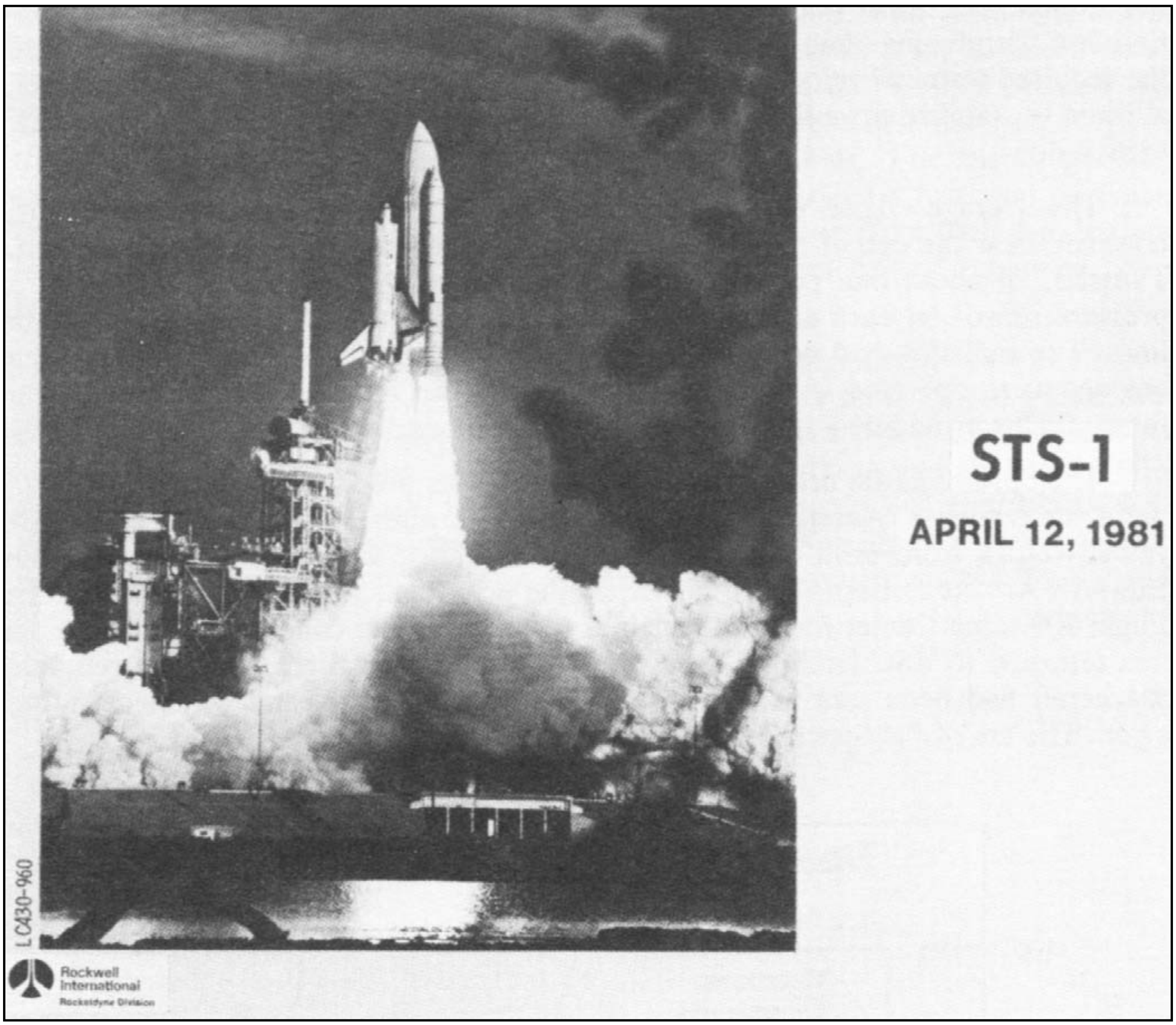

Figure 29 The First Space Shuttle Flight - STS-1 (Photo No. LC430-960)

The countdown for the launch of STS-1 was initiated on April 5, 1981. This initial attempt was aborted at T minus nine minutes because of a problem with the orbiter computer systems. The computer problem was resolved by reloading the software, and the countdown was resumed on April 11. This time the countdown was successful with liftoff occurring at 7:00 a.m. on April 12, 1981 (Figure 29). Engine operation was flawless throughout the flight, maintaining a constant mixture ratio while responding to the power level commands issued by the orbiter guidance and control (G&C) computers. Figure 30 is a plot of actual power level for all three engines, and it shows how close to the same performance the three engines were. The start command was given at T minus 6.6 seconds, and all three engines were stabilized at RPL prior to liftoff at T minus zero. Less than a minute into the flight, all three engines were commanded to throttle down to 65 percent power level to reduce the vehicle acceleration during the time of maximum external aerodynamic loading. After about fifteen seconds at 65 percent, the engines were returned to RPL, where they remained until the vehicle acceleration approached its design limit of three g's. The G&C computers then gradually throttled the engines so that the reduction in thrust would match the mass, reduction due to propellant consumption and thereby maintain a constant safe acceleration. As the vehicle approached the required terminal velocity, the engines were throttled to 65 percent power level, allowed to stabilize for a little over five seconds and then commanded by the G&C to shut down.

The average engine performance was well within specification requirements; however, near the end of the flight, a small drift in mixture ratio was observed [41]. The shift of about one percent was found to be caused by radiant beating of a pressure sensor on each engine, located near the warm HPOTP turbine seal drain lines. The radiation had no effect during ground testing or even in flight until the engines were operated in the vacuum -of space. The anomaly was eliminated on future flights by adding a small amount of insulation and a radiation shield.

The Space Shuttle orbiter Columbia achieved its predicted orbit and remained there for two days. Americans were back in space after an absence of almost six years. Return from orbit occurred on April 14, 1981, with a safe landing at the Edwards Air Force Base, California. After the post-flight inspections at the Dryden Flight Research Center found the engines to be in perfect condition, the Columbia was returned to KSC an April 28 to prepare for the next flight. The first reusable spacecraft had been sent to space, safely returned to earth, and was ready to go again. The era of the Space Shuttle had begun.

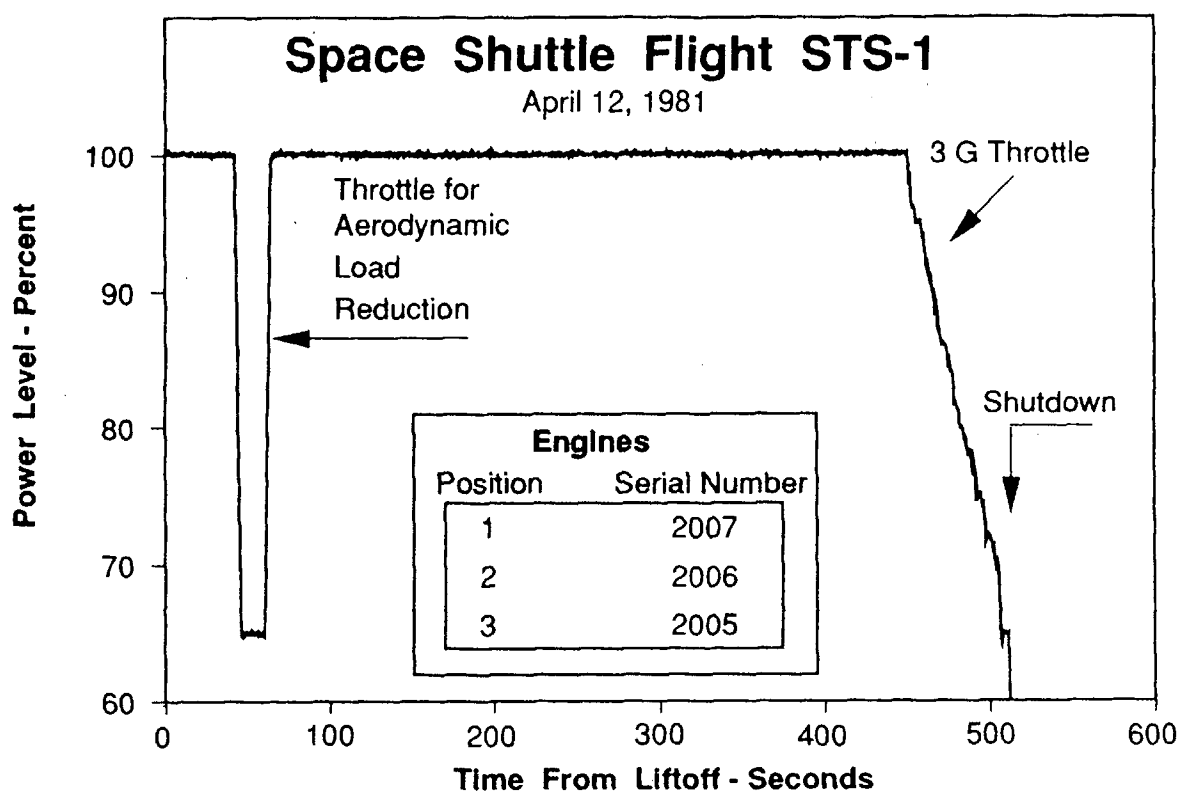

Figure 30 STS-1 Engine Performance (Photo No. 89c-4-1028)