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SPACE SHUTTLE ORBITER: COUNTDOWN

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ABSTRACT

The launch of Space Shuttle into low earth orbit late this year will herald a new era in space transportation. As a transporter and as an experimental platform, the Shuttle will make possible low cost development of space manufacturing processes, products, scientific opportunities, and large scale public services. And, as the Shuttle becomes operational, its role in the military space mission will gain added importance.

Timelines in the completion of each increment of development of the first Orbital Flight Vehicle - successfully achieved to date - becomes increasingly crucial as the scheduled launch date approaches. Concurrent with the testing and finalization of this vehicle's software and hardware construction are the preliminary developmental stages of future Shuttle Orbiters.

The status of each Shuttle Orbiter is - and will continue to be - of particular interest as the Space Shuttle becomes the key in the operation of the space transportation system.

INTRODUCTION

The second Orbiter, designated the "Columbia," has successfully moved through final assembly, functional checkout, and rollout preparatory to integrated testing and orbital flight missions. The on-schedule, within cost delivery of the Columbia to KSC in March represented a significant research and development program accomplishment as we proceed to attain the driving goal of providing an operational manned system capable of economically placing payloads in orbit.

With a length of 122 feet and a wing span of 78 feet, the Orbiter is about the size of a DC-9. The Orbiter is designed to accomplish over 100 missions with minor refurbishment, and is capable of transporting 65,000 pound payloads to earth orbit and providing on-orbit support and refurbishment services to space emplaced satellites as required. The Orbiter is designed to accommodate a wide range of payload missions and flexibility is increased with extra-vehicular activity capabilities and mission extension kits.

Development and qualification testing of major Orbiter system elements, subsystems, and components has proceeded with few "surprises" to date. The first Orbiter was seen by many viewers in 1977, when the approach and landing tests at Edwards Air Force Base were performed. During this test phase, through which the Orbiter's flight capabilities within the atmosphere were assessed, the vehicle was carried 25,000 feet into the sky atop a Boeing 747, then released. The Orbiter flight characteristics were proven to be outstanding, and system operation/hardware problems were minor.

MAJOR STRUCTURE ELEMENTS

The mid fuselage is the Orbiter's primary load-carrying structure, accommodating a 60 by 15 foot payload bay. The upper half of the mid fuselage supports the payload bay doors, hinged along the side. Horizontal frame assemblies of the mid fuselage consist of machined flanges with boron/

aluminum tubular struts.

Four constant-contour panels comprise the graphite/epoxy payload bay doors which open at the upper centerline to provide access to the payload bay. Panel testing has successfully demonstrated service life, the capability of withstanding maximum decibel pressures, and ultimate structural loadings.

The aft fuselage thrust structure consists primarily of diffusion bonded titanium and boron/epoxy reinforcement construction. This method of construction provides the lightest weight structure that will accept the extremely high loads applied by the Orbiter main engines. The majority of the remaining aft fuselage structure consists of machined aluminum construction with titanium reinforcement in highly loaded areas.

The use of boron/aluminum, graphite/epoxy and the titanium boron/epoxy composite materials significantly reduced the weight of the vehicle, maximizing the Orbiter's cargo carrying capability.

The wing structure assembly of the Orbiter, constructed of conventional aluminum material, is approximately 60 feet long at the fuselage intersection, with a maximum thickness of over 5 feet. Two-piece elevons are individually controlled by linear hydraulic actuators.

The vertical tail, with an area of 413 square feet, is designed to provide fixed and movable aerodynamic control and to operate as a speed brake during atmospheric flight. The tail and rudder/speed brakes are operated by four large rotary actuators.

The forward fuselage is constructed of 2024 aluminum alloy skin/stringer panels, frames, and bulkheads. The forward fuselage provides support for the nose gear and supports the crew module at only four attach points, thus minimizing thermal conductivity. The crew module is a conical, pressurized vessel, made of 2219 aluminum alloy plates and designed to provide a shirtsleeve environment. This three-level crew module consists of the flight deck, the mid section which includes avionics bays, and the lower section that provides for the environmental control and life support system.

The structural test article (STA) airframe was moved into Lockheed-Palmdale's test facility in 1978 and the STA test program was initiated in October with influence coefficient testing, which verified close agreement with the structural math models used for the initial vehicle design. The structural qualification tests are underway, and will assure that the Orbiter structure meets all operating and environmental requirements for the first manned orbital flight (STS-1). These qualification tests consist of limit-plus tests used to verify internal load distributions and the structural integrity of the airframe, and thermal tests which assess the effects of thermal gradients, both singularly and when combined with a static load. Additional structural, strength, and fracture tests will be performed on special components to fully qualify the Orbiter structure for operational flights.

SUBSYSTEM AND COMPONENT DEVELOPMENT

The orbital maneuvering engines provide the thrust to perform the Shuttle's orbit insertion, maneuvering and de-orbit. Following completion of a successful development test program in December 1978, qualification tests of the orbital maneuvering system (OMS) commenced in February 1979. This test series will qualify the OMS for the first manned orbital flight.

The Orbiter's reaction control system (RCS) consists of 38 bipropellant primary thrusters and six vernier thrusters. The aft RCS qualification test program supporting the first orbital flight was initiated in December 1978. Several of the fifteen scheduled hot fire tests have been successfully completed in verification of mission requirements. Forward RCS testing began in March 1979 with acoustic testing, which will be followed with hot fire testing at the White Sands Test Facility. The RCS qualification testing supporting STS-1 will be completed in September 1979.

The Orbiter's environmental control and life support system (ECLSS) provides the atmospheric environment for the crew and thermal environment for electronics; provides cooking, hygiene, and other life support functions; maintains subsystems and components within specified temperature limits; provides via the payload door radiator panels active heat rejection to protect payloads; and provides an airlock support subsystem.

All of the ECLSS qualification tests have been initiated with over half of the tests successfully completed. Remaining tests are scheduled to be completed by the end of June 1979. It is not anticipated that there will be any constraints on the first manned orbital flight.

The electrical power subsystem functionally consists of a fuel cell power plant subsystem and a power reactant storage and distribution subsystem. There are three fuel cell power plants to supply the primary in-flight electrical power used by the Shuttle, generated through the chemical combination and conversion of cryogenic oxygen and hydrogen.

Qualification testing of the fuel cells, which began in December 1978, is proceeding with good results. Vibration tests are complete and vacuum testing is under way to verify functional operation through a 168 hour mission. Qualification testing for the first manned orbital flight will be complete by the end of June. Additional operating life tests will demonstrate life cycle durability, performance, and compatibility with flight environment requirements. A total of 2000 operating hours and 50 start cycles will be accumulated throughout the qualification tests.

The Orbiter hydraulic system includes three independent systems which generate and distribute hydraulic power to operate aerosurfaces, deploy landing gear, and operate the landing/deceleration system. Each hydraulic system is powered by an independent auxiliary power unit (APU) located in the Orbiter's aft fuselage.

Qualification testing of the auxiliary power unit and its controller were initiated in February 1979. Tests results thus far confirm that flight operations requirements will be met. The qualification program, scheduled for completion in July, will certify the APU and controller for STS-1 and subsequent flights.

The Space Shuttle avionics system employs five general-purpose computers to operate the control surfaces, telemetry and displays, perform guidance and navigation and flight control calculations; and monitor the vehicle's performance status. Each computer is capable of performing up to 400,000 operations per second, and in terms of weight, power, and volume, it represents the state-of-the-art in computer technology. Within the vehicle's avionics, attitude, and incremental velocity change, information is provided by three inertial measurement units. Automatic and manual controls of the total vehicle through all phases of flight are provided by means of the flight-control subsystem in conjunction with the Orbiter's general purpose computers. Flight control elements include rate-gyro assemblies and accelerometer assemblies and control drivers.

The Flight Systems Laboratory (FSL), in Rockwell International's Downey facility, is being effectively employed for verification testing of Orbiter hardware/software for the entry to roll-out mission phases, while the Shuttle Avionics Integration Laboratory (SAIL) facility at JSC is testing the ascent and on-orbit mission phases. Hardware is complete at both facilities, and the capability has been established for flight software/flight hardware verification testing.

To verify the Orbiter's hydraulic system, tests are conducted utilizing the Flight Control Hydraulic Laboratory in Downey, integrated with the Flight System Laboratory for end-to-end flight control system verification. This facility verifies flight-control operations during real-time simulated mission segments, using hydraulic system components with simulated actuator mounts and aerosurfaces within a rigid structural test fixture, providing mass inertia with simulated real-time aerodynamic loading capability.

The Orbiter's thermal protection system (TPS) utilizes approximately 32,000 tiles made of silica fibre-based quartz for thermal insulation during re-entry. These tiles are numerically milled and are essentially non-conductors that prevent the passage of heat into the structure, maintaining backface temperatures below 350°F. The nose cap and most of the wing leading edges are covered with a reinforced carbon-carbon composite that will withstand surface temperatures in excess of 2300°F.

The certification of the TPS system for flight is based upon qualification tests in which the system is exposed to simulated launch, on-orbit, and re-entry environments. The test program consists of plasma-arc testing, which simulates the re-entry aerodynamic heating environment; acoustic tests, which simulate both launch and re-entry acoustic environments; cold soak tests simulating on-orbit conditions; and applied loads tests, which simulate the aerodynamic loads on the TPS. The TPS test program for STS missions 1 through 6 is currently over 75 percent complete, and will be finalized by mid-September 1979. Additional life testing in support of operational flights is planned for completion prior to STS-7.

READINESS FOR LAUNCH

Prior to its delivery to KSC, the Columbia's final assembly and checkout flow progressed very effectively at Palmdale. Detailed subassembly and subsystem checkouts, together with functional checks and combined systems checkout operations, verified system parameters.

In July 1979, integrated testing of the vehicle will begin at KSC. During this testing, the Space Shuttle vehicle subsystems will be operated in combinations and modes that will be exercised during a mission, in order to assess systems actions/reactions and to verify the vehicle's functional capability.

Late in 1979 the Space Shuttle vehicle will be ready for the first orbital flight. Excellent design and development progress, the highest standards of quality workmanship, coupled with intensive qualification testing, in-depth ground test programs, and rigorous checkout processes, have confirmed our confidence in the flightworthiness of the world's only reuseable spacecraft.

FOLLOW-ON ORBITERS

The current Shuttle program involves a fleet of four orbiters. The Orbiter follow-on contract, ratified in January, authorizes the modification of two existing orbiters to meet operational requirements and the manufacture of two additional vehicles. The structural test article, named the Challenger, will be delivered to Rockwell's Palmdale final assembly and checkout facility in the latter part of 1979, upon completion of testing at Lockheed. At that time, installation of subsystems will begin in support of the scheduled delivery to KSC in late 1981.

After performing the six initial orbital flights, the Columbia will undergo modifications which will make it a fully operational vehicle. Development of the modification kits which will expedite this process is currently underway.

Incorporated into the development of Orbiters 103 and 104 will be several weight economizing design modifications. The utilization of weight saving materials in the wing, the vertical tail and the mid fuselage will trim the Orbiter weight by 5200 pounds.

Orbiter 103, the Discovery, is scheduled for delivery in December 1982. Detail work was begun on the aft fuselage in August 1977 and assembly of the crew module is scheduled to commence in August 1979.

Long lead detail fabrication of Orbiter 104 aft fuselage is scheduled to begin in August 1979, and the crew module assembly is scheduled to start a year later. This vehicle, named the Atlantis, is scheduled for delivery in December 1983.

CONCLUSION

The President's space policy embraces the Shuttle as the major new technical capability upon which American space endeavors will rely, and our next immediate concern is to step into the Space Shuttle operational phase in 1981. From there we will progress into extended duration missions, leading to earth orbiting production and public service facilities.

It is incumbent upon us as a nation to expand our frontiers into the unique space environment to help solve some of the major problems on earth. But in recent years, our hopes and aspirations have not been matched by a correspondingly high commitment of resources. Indeed, real federal outlays for space have steadily declined since the Apollo era. In GFY 1979, only 0.8 percent of all federal outlays is committed to space. The irony of those trends is that our space program has spawned a steady stream of technological advancements now being used for a broad range of day-to-day applications.

Over the next two decades, an acceleration of private and public support will be essential to our taking full advantage of the capabilities of the space transportation system. But the benefits will far exceed the costs. Man's inquisitive nature will drive him to explore this last frontier, and his exploitive nature will cause him to take maximum advantage of space for defense, industrial, and scientific projects. The Space Shuttle will herald a new era, with the promise of answers to problems and needs of mankind. We cannot afford to miss the opportunity.

STATUS OF SPACE SHUTTLE
EXTERNAL TANK
SOLID ROCKET BOOSTER
and
MAIN ENGINE

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ABSTRACT

The paper will cover the current status of three major propulsion elements for the Space Transportation System: the Space Shuttle Main Engine (SSME), the External Tank (ET) and the Solid Rocket Booster (SRB). Presented will be the Test and Manufacturing experience in the last year, the Test and Manufacturing plans for the coming year and the current status of hardware to support the first manned orbital flight.

INTRODUCTION

The responsibility for developing, manufacturing and testing three of the four major elements of the Space Transportation System's Space Shuttle vehicle is assigned to the Marshall Space Flight Center (Figure 1). These elements are the Space Shuttle Main Engine, the External Tank, and the Solid Rocket Booster. Together these three elements form the Space Shuttle's major propulsion system providing the power to place the Orbiter in earth orbit. Development of the Orbiter, which is the lander as well as the crew and payload carrying element of the Space Shuttle, is under the cognizance of the Johnson Space Center.

The Space Shuttle Main Engine, which represents the most significant technological advancement of the Space Shuttle Program, is a high performance, reusable engine with variable thrust. Three of these engines, mounted in the Orbiter's aft fuselage, will power the Orbiter from launch to just short of orbital insertion. The External Tank carries the propellants for the Space Shuttle Main Engines and serves as the structural link for the other Shuttle elements. Since the tank is the Shuttle's only expendable element, achieving the design unit weight and cost is extremely critical to program success. The Solid Rocket Booster, whose recovery and reusability make the Space Shuttle economically feasible, provides the additional power necessary to boost the Shuttle off the launch pad towards orbit.

EXTERNAL TANK

The External Tank is that element of the Space Shuttle that carries the liquid hydrogen and liquid oxygen propellants consumed by the Space Shuttle Main Engines. Illustrated in Figure 2 the thermally insulated tank is 154.2 feet long and 27.5 feet in diameter, approximating the size of the first stage of the Saturn V. Loaded the tank weighs 1.6 million pounds and empty 75,000 pounds. Basically the External Tank consists of three structures: the Liquid Oxygen Tank, the Liquid Hydrogen Tank, connected by the intertank, a short hollow cylinder which also houses the instrumentation. The thermal insulation is a nominal one-inch-thick coating of polyurethane type foam. Besides preventing loss of the cryogenic propellants, the insulation also prevents ice from forming on the tank after the propellants are loaded. Ice formation would not only significantly increase lift-off weight, but also in shedding would pose a hazard to the thermal protection system of the parallel-mounted Orbiter.

In addition to carrying the propellants, the External Tank is also the structural backbone of the Space Shuttle, with the Orbiter and the Solid Rocket Boosters attached to it in the launch configuration. At lift-off the tank absorbs about 6.9 million pounds of thrust.

The External Tank's support systems include a propellant feed system to supply the propellants through 17-inch diameter lines to the Orbiter engines, a pressurization and vent system to regulate the tank pressure and assure a minimum impact area by inducing tumbling by the tank after separation, an environmental conditioning system to regulate the temperature and humidity in the Intertank area primarily by purging the area with dry gaseous nitrogen, and an electrical system to distribute power and instrumentation signals and to provide lightning protection. Since the tank is the only expendable element of the Space Shuttle all fluid controls and valves for engine operation, except the valves in the vent system are located in the Orbiter.

The prime contractor for the External Tank is Martin Marietta Aerospace at Marshall Space Flight Center's Michoud Assembly Facility, New Orleans, LA.

Testing

During the past year the major thrust of testing in the External Tank Project has been in two areas: structural and qualification. The schedules for these are shown in Figures 3 and 4. Steady progress has been made in qualifying the various components of the tank. In the main the actual component testing has been performed by the subcontractors and vendors producing the items. While some problems have been encountered, they have been relatively minor and readily resolved. At the present time about 90% of the qualification testing has been completed.

In the structural test area, more than satisfactory progress has been maintained. Because of its size the External Tank is being tested by major structures; that is, Liquid Oxygen Tank, Liquid Hydrogen Tank, and Intertank. The facilities being used to conduct the tests are located at the Marshall Space Flight Center. General objectives are to confirm structural analyses and to verify the structural design.

The pace of the structural test program was set in 1977 with the successful completion of the Intertank testing, which revealed only minor problems which were quickly resolved.

By the end of the first quarter of 1978, the Liquid Oxygen Tank and Liquid Hydrogen Tank Structural Test Articles and supporting test equipment had arrived at the Marshall Space Flight Center, and preparation for the respective test programs begun. During the same time period the External Tank for the Mated Vertical Ground Vibration Test also arrived at Marshall. This test program, successfully completed at the Marshall Space Flight Center, was to determine the interaction between the four major Shuttle elements during the various flight phases, beginning with launch, progressing through Solid Rocket Motor burnout, and ending with the final flight phase of the Orbiter and External Tank (Figure 5).

During the spring of 1978 the Liquid Hydrogen Tank Structural Test Article and supporting hardware, an Intertank and Liquid Oxygen Tank Simulator were installed in the test stand (Figure 6), which is the modified Saturn V First Stage Test Stand. The test program started during the summer and involved six different test conditions. The first two conditions involved the tank empty, the next three required the tank to be loaded with liquid hydrogen and the sixth again with the tank empty. The entire series has been just recently completed very satisfactorily with only minor problems of the type to be expected.

The Liquid Oxygen Tank Structural Test Article and its support hardware are being used in two separate test series, the Modal Survey Test and the Structural Test. The objective of the Modal Survey Test, the first series performed, is to determine the effect of vibrations on the tank loaded to various levels. The tests were completed during the fall with successful results (Figure 7).

Preparation for the structural test series has nearly been completed, and the actual testing will begin in May. At this time no major problems are expected to devolve for this series.

Manufacturing

The fact that the External Tank is the only expendable item in the Space Shuttle stack, played a major role in the design and development of the manufacturing process. Two aspects were paramount; first, maintain unit cost as low as possible and second, allow a relatively high production rate, particularly when compared with previous programs. For example, during the Saturn V program about 15 first stage flight tanks were manufactured over about five years. During the next 12 years almost 500 External Tanks will be produced.

One of the prime methods for achieving the goals was the development of a series of sophisticated tools and techniques as opposed to maintaining a large highly skilled work force. As an example the components for the Liquid Hydrogen Tank are assembled in a weld fixture that has been called one of the largest "lathe" type tools in the free world. It is approximately 150 feet long and 40 feet in width. It also makes two circumferential welds at the same time (Figure 8). The tools for producing the Liquid Oxygen Tank are equally sophisticated.

Another manufacturing technique developed to obtain low unit cost and high production rate is to mechanically spray on the tank insulation rather than using the hand application methods of earlier programs. Two different types of insulation are used with the External Tank. One is a spray-on foam insulation (SOFI), applied over the bare tank, which provides the basic thermal protection. The other is an ablator material applied in specific areas for additional protection against aerodynamic heating and plume impingement from the separation rockets and the Space Shuttle Main Engine. The application process is different from previous programs in that the tank skin and spray environment must be controlled within specific temperature and humidity limits. The large size of the facility required to perform this spray technique coupled with the varying tank skin thickness posed a significant engineering challenge. This has been met by providing humidity control for the spray area and passing heated air through the tank to maintain a constant temperature. During the application the tank is rotated in a vertical position as the computer-controlled spray gun transverses a track in the vertical wall of the spray facility.

Following the completion of the manufacturing of test articles early in 1978 a smooth transition was achieved into the fabrication of flight External Tanks. The weld and assembly of the major components for the first flight tank proceeded extremely well (Figure 9), verifying the procedures and techniques developed during the test article fabrication phase. Not unexpectedly, however, application of the thermal protection system to this tank is proceeding somewhat more slowly than projected since it was the first-time full-scale use of the facility. The problems basically involve spray gun operation and environmental control in the spray cell. However, the basic causes were quickly identified, and appropriate procedural changes and facility modifications were enacted correcting the anomalies.

The major components for the External Tank for the first Space Transportation System Launch have been completed, and the item is in final assembly. It will go into final checkout this month (April) and be shipped to the Kennedy Space Center in May. The succeeding flight stages are in various phases of assembly. Following manufacturing of the first six flight tanks, scheduled for development test flights, fabrication of the operational flight tanks will begin. The delivery schedule for External Tanks through Fiscal Year 1981 is shown in Figure 10.

Future Outlook

During the remainder of 1979, the following major activities are planned:

a. Delivery of the first two flight External Tanks to the Kennedy Space Center.
b. Completion of the External Tank Structural Test Program.
c. Completion of the qualification test program.
d. Certification of the External Tank for flight.
e. Initiation of fabrication and assembly of development phase flight tanks.
f. Issuances of contract authority to proceed on the fabrication and assembly of 27 operational External Tanks.
g. Initiation of fabrication and assembly of the first operational flight tank.

SOLID ROCKET BOOSTER (SRB)

The Solid Rocket Booster (SRB), in pairs, provide primary first stage thrust for the Space Shuttle from launch until about two minutes into the flight. At this time the burned-out Boosters are separated and lowered to the ocean by a parachute recovery system. Retrieved from the ocean the boosters are returned to the launch site for refurbishment and reuse. Achieving these last two mentioned features, recovery and reusability, is a key program objective, since these will make the Space Shuttle economically feasible.

The Booster, illustrated in Figure 11, is 150 feet in length and 146 inches in diameter. Operational lift-off weight of each is about 1.3 million pounds, with a propellant weight slightly in excess of 1.1 million pounds. The sea level thrust for each is about 2.65 million pounds. The Solid Rocket Booster is made up of six subsystems: the solid rocket motor, the structural subsystem, the thrust vector control subsystem, the separation subsystem, the recovery subsystem, and the electrical subsystem.

The Solid Rocket Motor subsystem is the primary propulsive element providing thrust for ignition to burnout. It consists of a lined, insulated, segmented rocket motor case loaded with solid propellant, an ignition system with electromechanical safe and arm device, initiators, and loaded igniter; a movable nozzle; raceway bracketry; instrumentation and the necessary integration hardware.

All of the components and subsystems are physically interchangeable and replaceable.

The Structural subsystem provides the necessary structural support for the Shuttle vehicle on the launch pad, transfers thrust loads to the Orbiter and External Tank, and provides housing, structural support, and bracketry needed for the recovery system, the electrical components, the separation motors, and the Thrust Vector Control components. The subsystem consists of the nose assembly; the forward ordnance ring; the forward skirt, including the forward External Tank attach ring and attach struts; the aft skirt including the heat shield; and the systems tunnel and structure for mounting the other subsystems' components. In addition, frustum floatation, weighing, hoisting and towing provisions, and structural thermal protection are provided.

The Thrust Vector Control subsystem by moving the Solid Rocket Motor nozzle, provides pitch, roll, and yaw vehicle movements as directed by the Orbiter Command System. The subsystem, mounted in the aft skirt, consists of two hydraulic power supplies and two servoactuators.

The Separation Subsystem is designed to ensure safe separation of the Sold Rocket Boosters from the External Tank. The separation subsystem consists of a release system, sensors, and separation bolts located in the forward attach fitting and in each of the aft attach structs, and eight solid booster separation motors, four mounted in the nose frustum and four mounted externally on the aft skirt. The aft motors are located unsymmetrically, which imparts a small roll to the Solid Rocket Booster at separation.

The Recovery subsystem provides the necessary hardware to control the Solid Rocket Booster final descent velocity and attitude after separation. The subsystem includes parachutes, methods of sequencing and deploying the parachutes, parachute separation components, and location aids that help in finding and retrieving the expended booster and parachutes.

The Electrical subsystem for operational flights consists of two major systems dedicated to two specific portions of the Solid Rocket Booster flight. The Ascent system is operational from prelaunch until separation; the Recovery system is operational from just prior to separation until Solid Rocket Booster splashdown. The Ascent system consists of components necessary to respond to Orbiter commands for controlling Booster prelaunch functions, ignition, powered flight, and separation. The Recovery system consists of the components necessary to successfully recover the Booster after burnout and separation. It initiates severance of the nozzle extension, deployment of the drogue and main parachutes, power to the location aides, and severance of the main parachute at water impact.

The design, development, test and integration of the Booster is being approached uniquely by the Marshall Space Flight Center. With the exception of the Solid Rocket Motor, the Center is performing the integration and development of the subsystems in-house, with the fabrication being accomplished by various subcontractors. Development and test of the Solid Rocket Motors is being performed by the Thiokol Corporation, Wasatch Division, Brigham City, Utah. The development plan for the Motor is shown in Figure 12.

An effort is being made to reduce the weight of the Solid Rocket Booster. A very active effort is presently being conducted with the goal of reducing Booster weight to the point where 700 pounds of additional payload weight will be available.

Testing

During the past year significant progress has been made in all test programs for the entire Solid Rocket Booster. More than satisfactory progress has been achieved in the developmental static firing tests of the Solid Rocket Motor, being conducted by Thiokol at the corporate test site near Brigham City, Utah. Following the first static firing in 1977, the second and third static firings were successfully conducted in February and October 1978. The third firing represented a major milestone in the motor development program because it was the first time the motor had been mated and tested with an SRB Aft Structural Skirt and Thrust Vector Control System. The fourth and final development firing was successfully conducted during February (Figure 13). This thoroughly successful test series demonstrated the repeatable performance of the motor and has provided the basis for proceeding with the manufacture of the motors for the first Space Transportation System Launch.

The second phase of Solid Rocket Motor static firing tests, also being conducted by Thiokol at the Brigham City test site, will begin this month (April) with the firing of the first of three qualification motors. The objective of this test series, which will be completed in September, is to verify the motor design and demonstrate performance repeatability.

The SRB Recovery Subsystem Test program was also successfully completed during 1978. The Recovery Subsystem basically consists of a pilot, a drogue, and three main parachutes; location aids; and associated hardware. The total package weighs nearly 6,000 pounds. The test program consisted of six tests in which the recovery system was attached to a simulated Solid Rocket Booster and dropped from an altitude of over 17,000 feet. These tests were conducted at the National Parachute Test Range, El Centro, California. Several sled tests were also performed successfully to verify the separation of the frustum from the Recovery Subsystem.

Structural tests of the Booster, initiated during the early part of 1978, are continuing successfully with completion expected by September 1979. The test series is being conducted at the Marshall Space Flight Center using the former Saturn IB Test Stand which has been modified (Figure 14). To reduce cost and improve handling, the Structural Test Article is shorter than the flight article. Four of the seven segments which compose the motor portion of the Booster are not present; however, this does not affect the test results. The general objectives of the tests are to verify structural design and confirm structural analysis. To date the ascent loads testing have been completed successfully with data verifying that the desired structural margins exist and indicating that no major problem should be expected in the water impact testing.

Qualification testing of the other Solid Rocket Booster Subsystems is progressing satisfactorily. Typical hardware design and test fixture problems have been experienced; however, these have been resolved and no impedement is foreseen in the successful conclusion of the qualification test programs.

Manufacturing

During the past year all of the Solid Rocket Booster's subassembly manufacturing efforts have continued satisfactorily, with problems being encountered and resolved. An example is the problem of reproducible fracture toughness in the D6AC steel used to manufacture the Solid Rocket Motor case. It was a challenging problem since it is difficult to obtain in D6AC steel a high toughness concurrently with reasonable yield and ultimate strengths. The resolution was the development of a double tempering process during the case heat treatment, which was achieved by Thiokol in conjunction with the case vendor. Case hardware can now be selectively tempered so that the desired fracture toughness (with the required yield strength) can be reproduced.

Following completion of the production of the test articles, the manufacturing effort flowed into flight hardware. Except for the Solid Rocket Motor, all of the subsystems for the first Space Transportation System have been delivered to the Kennedy Space Center. There, since the delivery of the first flight subsystem in the fall of 1978, the Booster Assembly Contractor, United Space Boosters, Inc., have been conducting assembly and checkout. The final Solid Rocket Motor segment will be shipped to Kennedy in May to complete the delivery of the subsystems for the first flight Solid Rocket Boosters.

Future Outlook

During the remainder of 1979, the following major activities are planned:

a. Complete Solid Rocket Motor qualification firings.
b. Manufacture and deliver to the Kennedy Space Center the Solid Rocket Motors for the first Space Transportation System launch.
c. Complete Solid Rocket Booster structural and qualification tests.
d. Complete assembly of the Boosters for the first Space Transportation System launch and initiate assembly of the Boosters for the next two launches.

SPACE SHUTTLE MAIN ENGINE

The Space Shuttle Main Engine Project (SSME) encompasses the design, manufacture and test of the Space Shuttle Main Engine (Figure 15), a high performance reusable engine with variable thrust. Three of these engines, each developing a rated thrust of 470,000 pounds, are located in the Shuttle Orbiter's aft fuselage and will power the Orbiter from launch to just short of orbital velocity. The Marshall Space Flight Center manages the SSME Project and has contracted development of the engine to the Rocketdyne Division of Rockwell International.

Testing

Development of the SSME has progressed significantly during the past year with extended engine operation at the rated thrust conditions. During the past 12 months the engine development program has accumulated approximately 20,000 seconds of operation. The total accumulated engine operation time is currently (February 28) 34, 743 seconds with 10,400 seconds conducted at rated thrust conditions (Figure 16). Several major engine component failures occurred however during the year and will be discussed. A significant highlight and milestone of the past year was the successful series of tests at flight rated thrust conditions conducted on Engines 2002 and 0005. Both engines incorporated substantially the modifications and basic design planned for the Preliminary Flight Certification and early flight engines. The sustained high performance and endurance demonstrated on Engine 0005 was particularly impressive since the test series was similar to that planned for the Preliminary Flight Certification Program. This engine accumulated in excess of 5,000 seconds of operation, requiring minimal component replacement, with 4,680 seconds at rated thrust, or above, during a series of 13 engine tests. Disassembly and inspection of the turbomachinery provided both assurance of the basic design integrity and insight into areas of further needed improvement. Subsequent to this test series, Engine 0005 testing was extended to 12,000 seconds, and the engine was subjected to extensive teardown disassembly and inspection.

Four areas of engine development receiving major emphasis during the past year due to prior failures or deficiencies were: 1) the mechanical integrity of the high pressure oxidizer turbopump rotor and related dynamic characteristics, 2) expected life and cause of prior failures of main injector oxidizer post elements, 3) cycle life and endurance limits of the high pressure fuel turbopump turbine blades, and 4) suction performance capability of the high pressure turbomachinery. Significant progress has been made in each of these areas, and the first flight requirements have been demonstrated.

Three major test failures occurred during the past year resulting in liquid oxygen fires and extensive damage to three separate development engines. The first failure involved a non-flight instrument incorporated in the high pressure oxidizer pump to measure relative shaft displacement for bearing load verification. Since the instrument was a test article the failure did not reflect adversely on the design. The second failure was the result of inadvertent damage to the liquid oxygen heat exchanger during a post manufacture modification. As a result of this failure, inspection control of similar rework operations have been strengthened and all heat exchangers will be proof tested after modification operations in the liquid oxygen side of the powerhead. The third failure was caused by metallic fretting in the main oxidizer valve between the flow liner and bellows assembly. As a result of this failure, all liquid oxygen system valves have been modified to preclude fretting.

As a result of a Congressional request for a review of the Project development status, one of the more significant findings of the National Academy of Science and Engineering was a recommendation to activate the engine test stand initially planned in the program at Santa Susana. NASA Management concurred in this recommendation, and the Project initiated this activity in April 1978. This test stand, now active, is supporting the total test program.

Relative to overall project schedules, major emphasis is directed toward: 1) delivery of the Main Propulsion Test Article engines for continued vehicle testing, 2) Certification Testing for the Design, Development, Test & Evaluation (DDT&E) flights, and 3) delivery of the first flight engine set to the Kennedy Space Center (KSC).

The engines for the Main Propulsion Test are updated engines with a 100% rated power level capability and will be used for the second series of tests. This test program, using a flight-type External Tank, a simulated Orbiter mid-fuselage, and a flight-weight aft fuselage with three Space Shuttle Main Engines, is being conducted, under Marshall management, to obtain verification data on the Shuttle Main Propulsion system during actual operation. The first series of four static firings was successfully completed last July at the National Space Technology Laboratories (Figure 17).

Certification testing for DDT&E flights was begun with Engine 2004, a flight equivalent engine. Completion of test series requires the accumulation of 5,000 seconds of operation and a minimum of 13 tests. Included in this test series is operation of the engine at 102% of rated thrust for overstress testing, and test durations extending to 823 seconds during a single firing to simulate one of the vehicle abort modes. Both of these test conditions have been previously demonstrated successfully on Engine 0005. Subsequent to successfully completing the certification duty cycle, critical components will be disassembled and inspected prior to a planned second Certification duty cycle for added flight confidence.

Manufacturing

Eleven complete engine assemblies have been manufactured at this time in addition to other development test components. Seven of the engine assemblies were assigned to the development program, three were delivered for the main propulsion cluster test series and one engine is being readied for the Preliminary Flight Certification test series. Three additional deliverable engine assemblies are in final build at this time for delivery to the launch site in May for the first launch in November 1979.

The Project continues to place emphasis on engine weight control. With make-work changes now forecast, it is expected that the Final Flight Certification weight will exceed the specification weight by as much as 200 pounds or approximately 3%. Some of this weight could be recovered in subsequent years, or offset by some performance uprating, although this is not being addressed at this time.

Future Outlook

Delivery of the first flight engine set to KSC is scheduled for May 15, 1979. Incremental engine deliveries after each acceptance test series and post test functional checkout are planned to be completed in May 1979. Figure 18 shows a photograph of the first flight engine in final engine assembly. The engine maintenance requirements have been released for incorporation with the Orbiter propulsion system documentation. Launch support planning has been completed for the Rocketdyne launch team and MSFC technical support at KSC and the MSFC Huntsville Operations Support Center (HOSC).

CONCLUSION

During the past year the Space Shuttle Projects under the cognizance of the Marshall Space Flight Center have made satisfactory progress in testing and manufacturing. While there have been problems, they have been basically the type to be expected at this point of a major space program. These anomalies have undergone detailed examination, and their basic causes are understood. They are being rapidly resolved, and there is every reason to believe that the required tests will be successfully completed and fully operational hardware shipped to the Kennedy Space Center as scheduled to support the latest firing date for the first Space Transportation System launch.

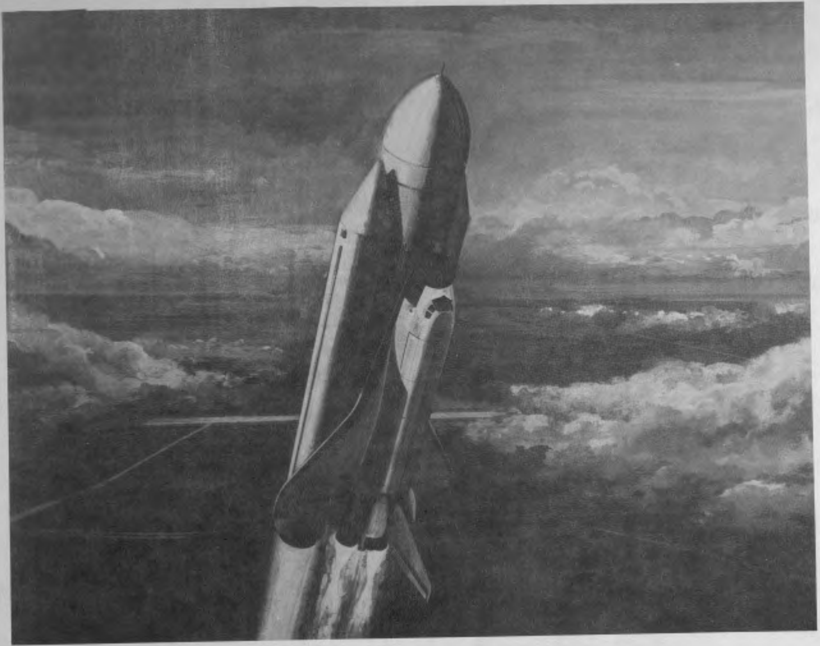
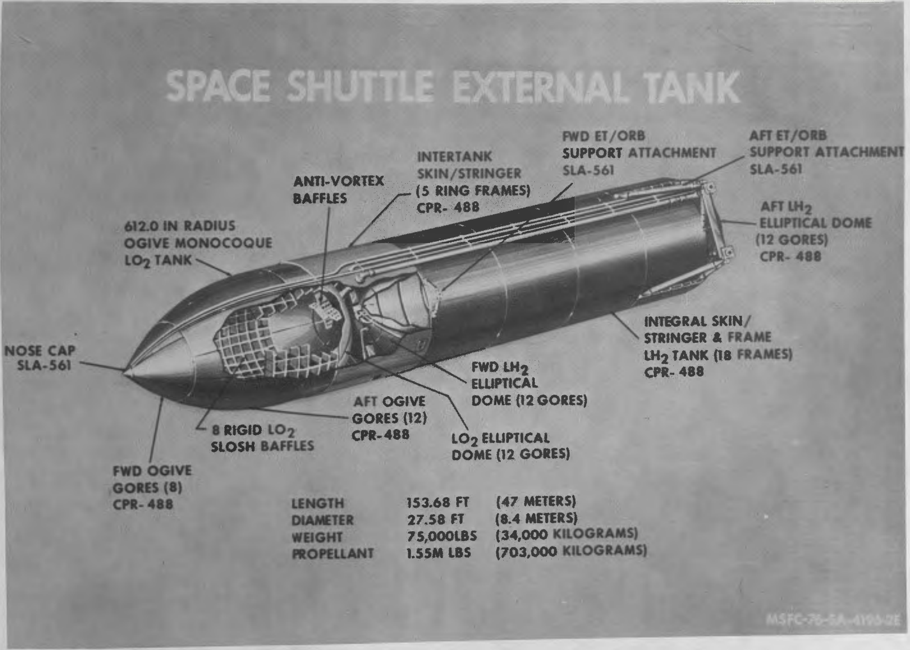


Figure 1. Space Shuttle



LENGTH	153.68 FT	(47 METERS)
DIAMETER	27.58 FT	(8.4 METERS)
WEIGHT	75,000LBS	(34,000 KILOGRAMS)
PROPELLANT	1.55M LBS	(703,000 KILOGRAMS)

Figure 2. External Tank

SA31–5564

EXTERNAL TANK STRUCTURAL TEST PLAN

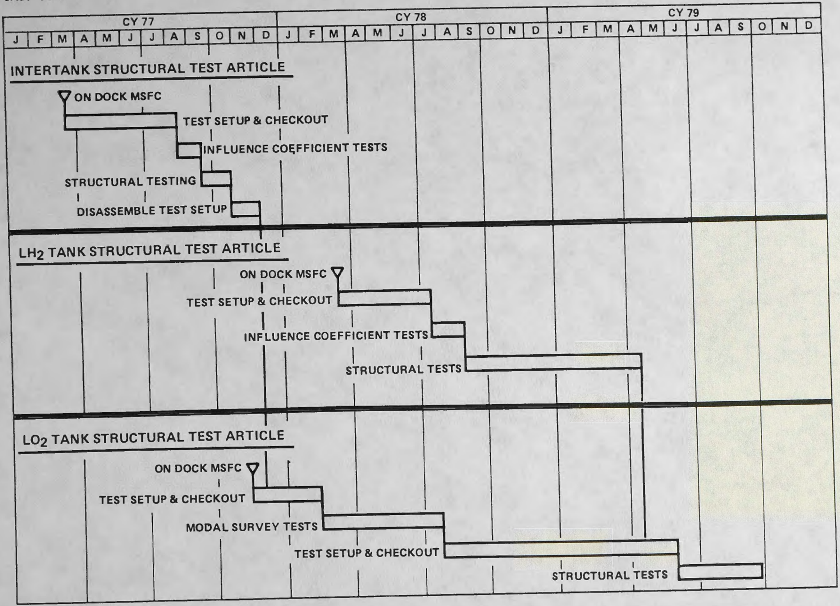


Figure 3.

COMPONENT QUALIFICATION PROGRAM

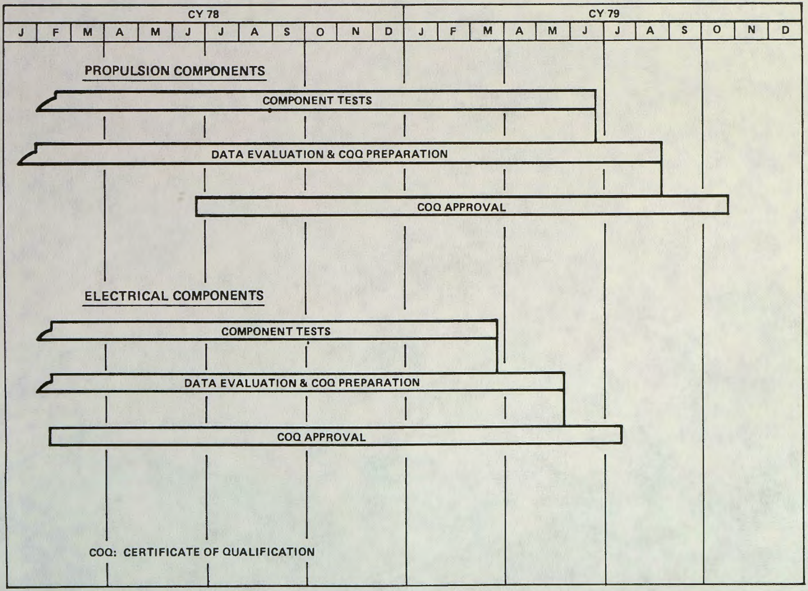


Figure 4.

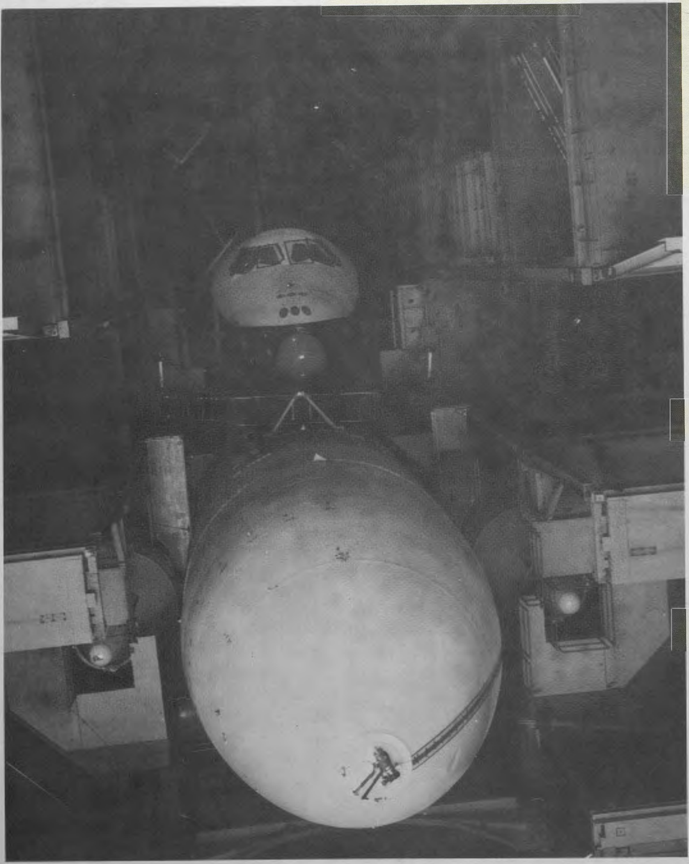


Figure 5. Space Shuttle in Mated Vertical Ground Vibration Text

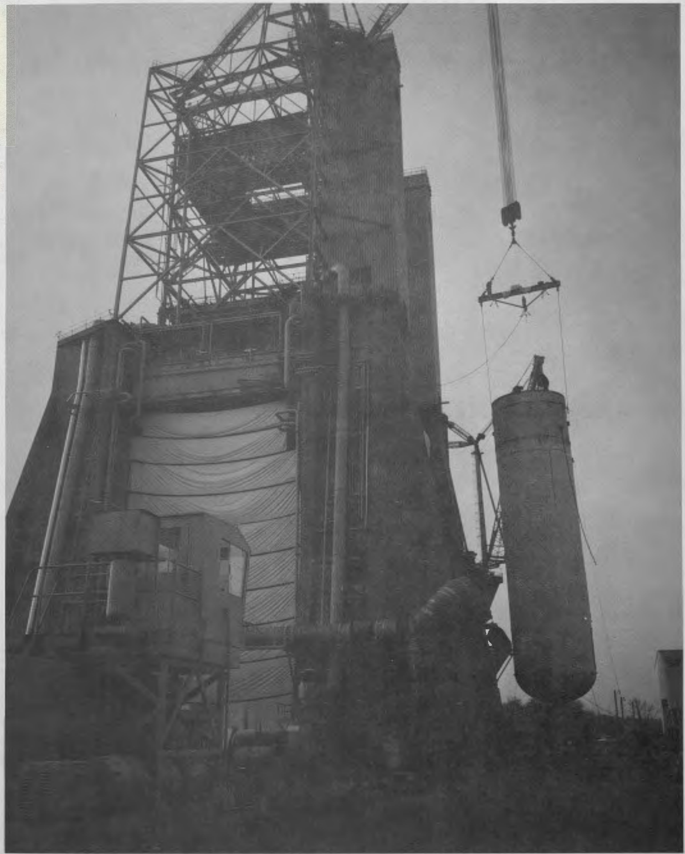


Figure 6. External Tank Liquid Hydrogen Tank going in Structural Test Stand

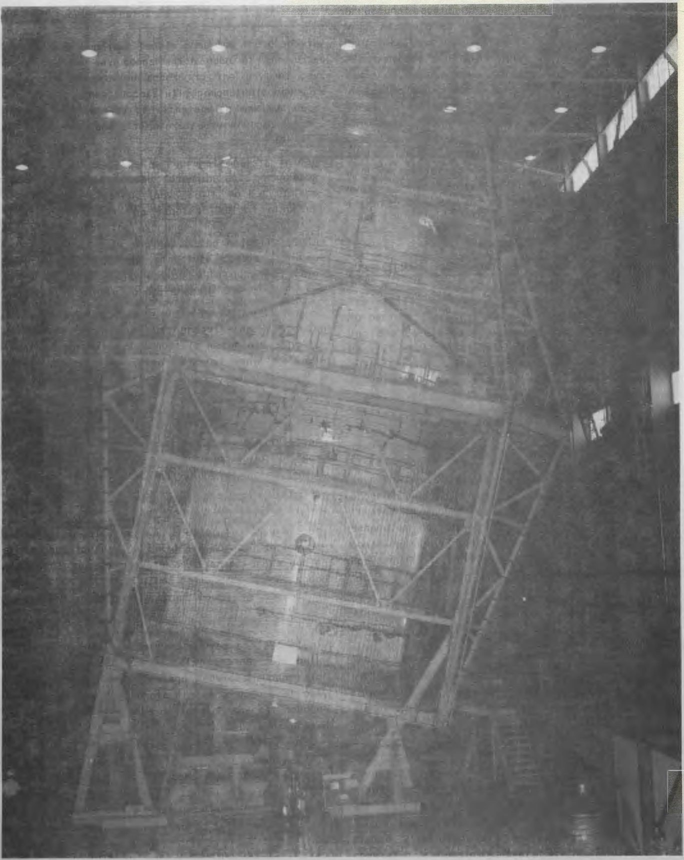


Figure 7. External Tank Liquid Oxygen Tank in Modal Survey Test

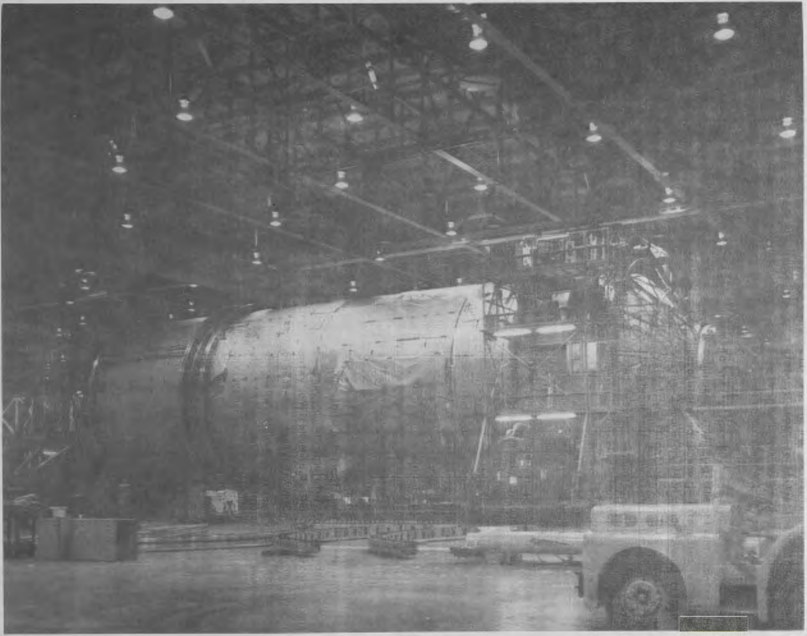


Figure 8. External Tank Liquid Hydrogen Tank Weld Fixture

Figure 9. First Flight External Tank Assembly

SA31–5563

EXTERNAL TANK FABRICATION AND ASSEMBLY SCHEDULE

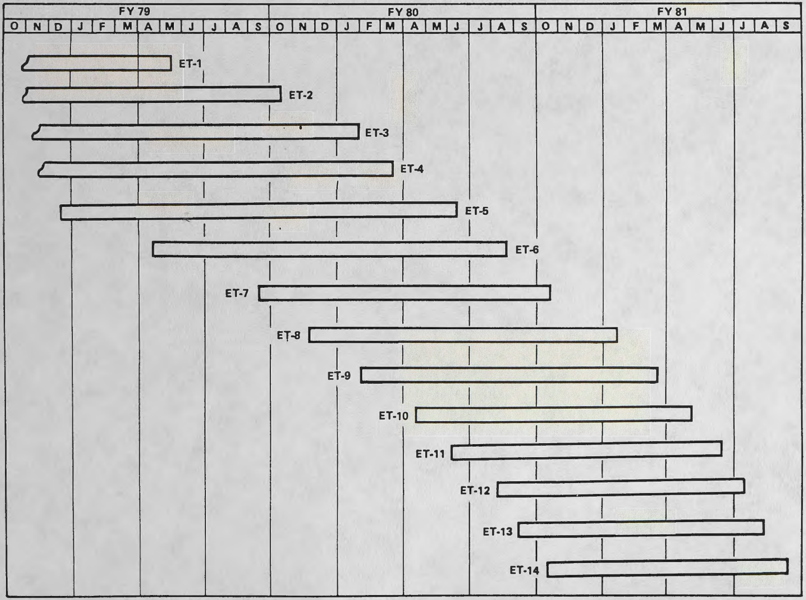


Figure 10.

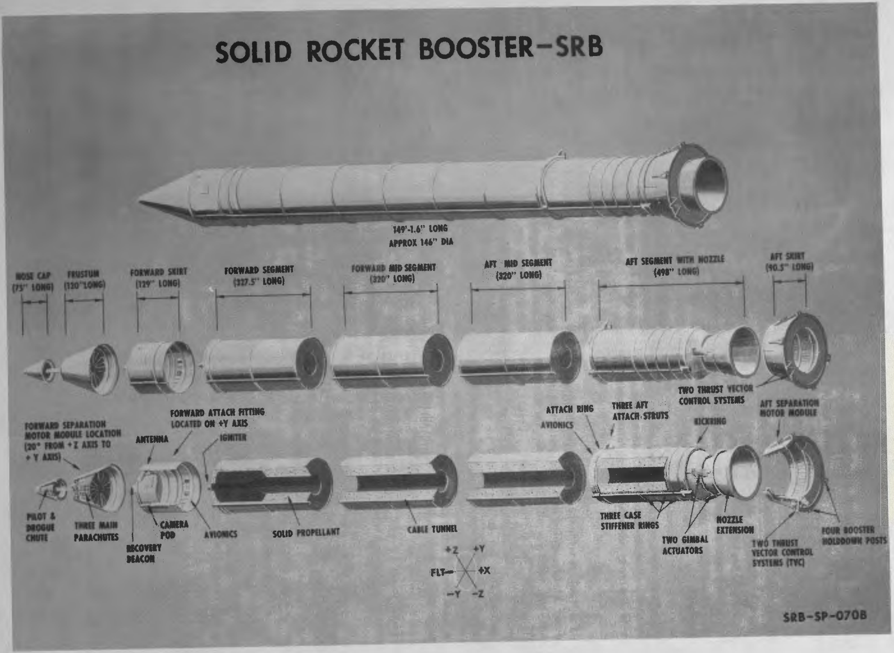

SOLID ROCKET BOOSTER—SRB
149'-1.6" LONG
APPROX 146" DIA
NOSE CAP (75" LONG)
FRUSTUM (120" LONG)
FORWARD SKIRT (129" LONG)
FORWARD SEGMENT (327.5" LONG)
FORWARD MID SEGMENT (320" LONG)
AFT MID SEGMENT (320" LONG)
AFT SEGMENT WITH NOZZLE (498" LONG)
AFT SKIRT (90.5" LONG)
TWO THRUST VECTOR CONTROL SYSTEMS
FORWARD SEPARATION MOTOR MODULE LOCATION (20° FROM +Z AXIS TO +Y AXIS)
FORWARD ATTACH FITTING LOCATED ON +Y AXIS
ANTENNA
IGNITER
PILOT & DROGUE CHUTE
THREE MAIN PARACHUTES
RECOVERY BEACON
CAMERA POD
AVIONICS
SOLID PROPELLANT
CABLE TUNNEL
ATTACH RING
AVIONICS
THREE AFT ATTACH STRUTS
KICKRING
AFT SEPARATION MOTOR MODULE
THREE CASE STIFFENER RINGS
TWO GIMBAL ACTUATORS
NOZZLE EXTENSION
TWO THRUST VECTOR CONTROL SYSTEMS (TVC)
FOUR BOOSTER HOLDDOWN POSTS
+Z
+Y
FLT
+X
−Y
−Z
SRB-SP-070B

Figure 11.

SOLID ROCKET MOTOR
DEVELOPMENT SCHEDULE

SA41–1870

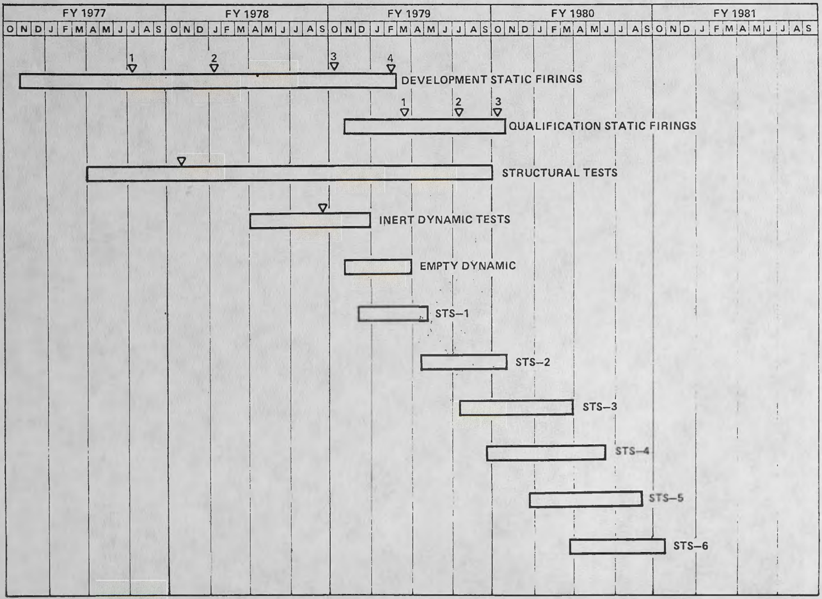


Figure 12.

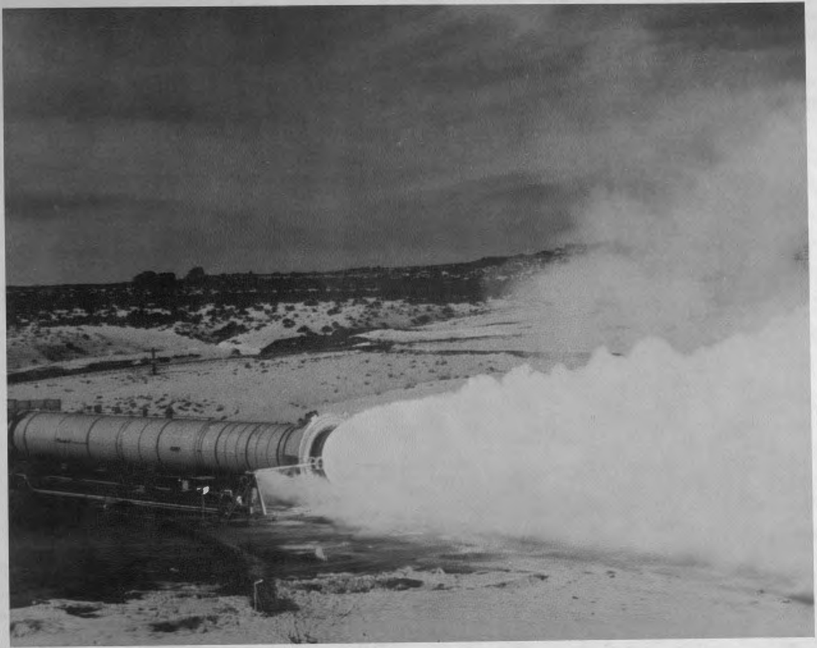


Figure 13. Solid Rocket Booster Demonstration Motor 4 Static Firing

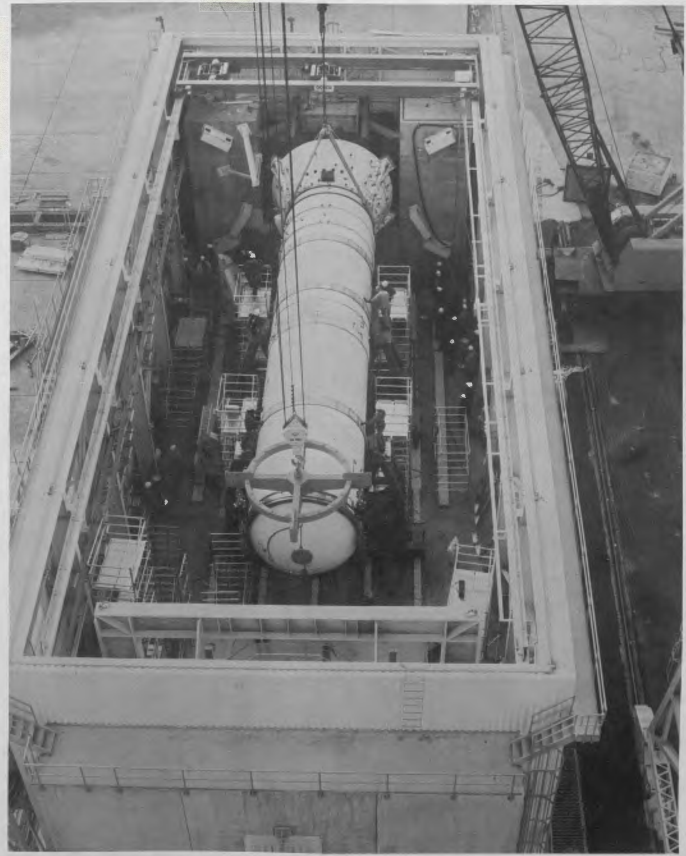
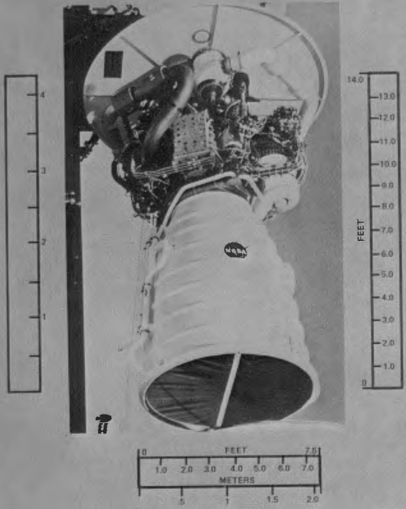


Figure 14. Solid Rocket Booster Structural Test

SPACE SHUTTLE MAIN ENGINE CHARACTERISTICS



• THRUST		
• SEA LEVEL	375K	(1,668,080 N)
• VACUUM	470K	(2,090,660 N)
• FPL	109%	109%
• CHAMBER PRESSURE	2970 PSIA	2048 N/cm^2
• AREA RATIO	77.5	77.5
• SPECIFIC IMPULSE (NOM)		
• SEA LEVEL	363.2	3562 $\frac{N\ sec}{kg}$
• VACUUM	455.2	4464 $\frac{N\ sec}{kg}$
• MIXTURE RATIO	6.0	6.0
• LENGTH	167''	424 cm
• DIAMETER		
• POWERHEAD	105'' x 95''	267 x 240 cm
• NOZZLE EXIT	94''	239 cm
• LIFE	7.5 HRS 55 STARTS:	7.5 HRS 55 STARTS

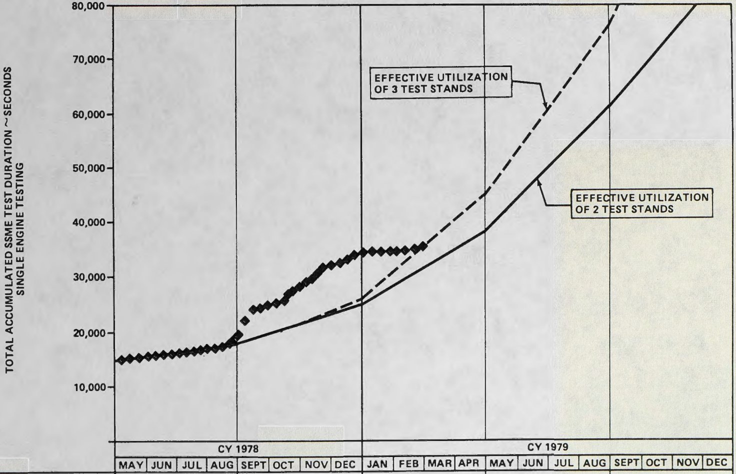
MSFC-73-SP 4144C

Figure 15.

SA51–4299

PROJECTED SSME DEVELOPMENT FORECAST

REFERENCE: SSME PROJECT ASSESSMENT TO NASA ADMINISTRATOR. 8/30/78.



PLANNED NO. TESTS DURING 4 MONTH PERIOD	32	44	60	76	76
(3 TEST STANDS)	–	65	(84)	(108)	(108)
EXPECTED AVERAGE DURATION (SECONDS) PER TEST	93	227	225	295	365

Figure 16.

Figure 17. Main Propulsion Test Static Firing

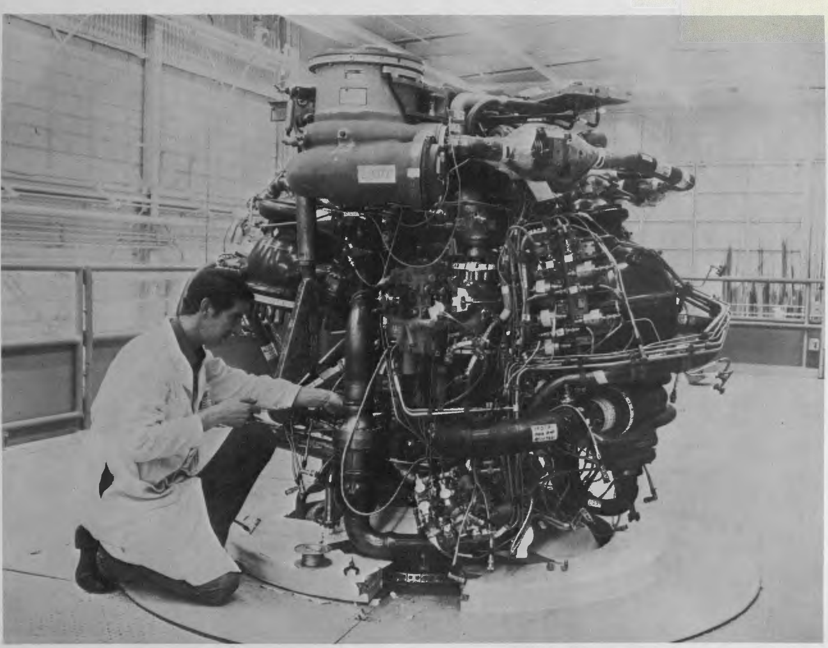


Figure 18. First Flight Engine