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Toward Lift-off

Introduction

This booklet was published by the Marshall Space Flight Center as part of its celebration of the 20th Anniversary of the first launch of the Space Shuttle on April 12, 1981. The text is based on information originally published in 1985 in a special Marshall Center 25th Anniversary Report. Special thanks to the current and retired Marshall Center Shuttle engineers who assisted in this booklet.

Toward Lift-off

A Brief History and Chronology of the Marshall Space Flight Center's Role
in Designing, Developing, and Testing the Space Shuttle Propulsion Elements for STS–1

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Liftoff of STS–1

Sunday Morning, April 12, 1981

In Huntsville, Alabama, like in other places, Sunday morning often means time to enjoy the Sunday paper or prepare for church. But Sunday morning April 12, 1981, dawned different in Huntsville as well as all over the world. Dawn brought the launch of Columbia, America's first Space Shuttle—a goal that people at Huntsville's Marshall Space Flight Center and at other NASA locations had dedicated themselves to for more than 10 years.

As lift-off approached, Marshall engineers monitored consoles in Huntsville while others from Huntsville participated at the launch site in Florida. Their job was to give the green light to the Shuttle propulsion elements that Marshall engineers and contractors had spent a decade perfecting. At 3 seconds after 6:00 a.m. CST, the mission designated STS–1, lifted off from Pad A of Kennedy Space Center's Launch Complex 39. "Now we can breathe," said Jack Lee, who served as Deputy Director of the Marshall Center in the 1980s and as Director in the early 1990s.

Rising on a pillar of orange flame and white steam, the Shuttle cleared its 348-foot-high launch tower in 6 seconds and reached Earth orbit in about 12 minutes. "It was a beautiful happening," Lee said. The solid rocket boosters and external tank had been shed prior to orbit. "Man, that was one fantastic ride," later exclaimed STS–1 Pilot Robert Crippen. "Engineering data says that the Space Shuttle main engines, solid rocket motors, and external tank worked in an outstanding manner," STS–1 Commander John Young said later regarding the Marshall-provided propulsion elements. "We got a smooth push out of the launch stand," added Crippen.

Dr. William R. Lucas, then serving as Director of the Marshall Center, referred to STS–1 as the start of "a new chapter in the continuing account of man's exploration and use of space." STS–1 was the first American-crewed space flight in nearly six years. Huntsville, along with the rest of the Nation, was captivated by the first flight of the Space Shuttle, a craft unlike anything America had previously launched. An estimated 80,000 people gathered at the Kennedy launch site, and upwards of one million people viewed it from nearby east central Florida. Although Columbia did not carry a payload during the 54½-hour flight, it did carry plenty of instrumentation to monitor the system's performance. The mission ended with a perfect landing at Edwards Air Force Base in California.

The story of the vital role that the Marshall Center played in designing, developing, and testing the propulsion elements for the Space Shuttle represented an entirely new chapter in the Center's history. It was a chapter that ushered in a new era in human space flight.

The Marshall Space Flight Center, a field installation of the National Aeronautics and Space Administration, was established in 1960 and named in honor of General George C. Marshall, the Army Chief of Staff during World War II, Secretary of State, and Nobel Prize Winner for his world-renowned "Marshall Plan." The Center was activated on July 1, 1960, with the transfer of buildings, land, space projects, property, and personnel from the U.S. Army. Dr. Wernher von Braun became the Center's first director and is credited by many for establishing the foundation for human space exploration in the 20th century. "Dr. von Braun, if he could be here, would feel this was another step forward," Dr. Eberhard Rees told a reporter for the *Birmingham Post Herald* following the launch of STS–1. Rees, who followed von Braun as Director of the Marshall Center in 1970, added, "And I think he (von Braun) would have been a little bit tense as I was because… it is quite a bit of complicated machinery."

In 1961, Marshall's Mercury-Redstone vehicle boosted America's first astronaut, Alan B. Shepard, on a suborbital flight. The Marshall Center's first major program was development of the Saturn rockets, the largest of which boosted humans to the Moon in 1969. The Center also developed the lunar roving vehicle for transporting astronauts on the lunar surface and Skylab, the United States' first crewed orbiting space station. During the 1960s, the Marshall Center devoted every available resource to developing the Saturn V Moon rocket to meet the goal that President Kennedy set in 1961 to land a human on the Moon before the end of the decade.

Impressive and powerful though they were, the Saturns had one disadvantage—they were expendable. Used only once, they were expensive to manufacture, stock in inventory, and use. When the Agency began looking ahead to a crewed space station as the next step beyond lunar exploration, alternatives to expendable rockets were considered. The concept of a reusable Space Shuttle was particularly appealing as a vehicle to ferry people and supplies to and from orbit. With its expertise in large launch vehicles and propulsion systems, it was only natural that the Marshall Center should play a major role in the Space Shuttle program.

By 1970, NASA initiated Space Shuttle development activity. At first, Marshall was heavily involved in the program definition phase leading to the initial Shuttle configuration. In addition, Marshall played a vital role in the development of the launch vehicle system having been chosen by NASA to co-chair two major integration working groups with personnel from Johnson Space Center. These were the ascent flight integration working group and the propulsion systems integration working group. When the final concept was selected, the Center was given the responsibility for the development of the advanced propulsion systems. Of the principal Shuttle elements—the orbiter, main engines, external tank, and solid rocket boosters—all but the orbiter were developed under Marshall Center management.

Much of the Shuttle effort at Marshall was performed by the same personnel and in the same facilities that had served the Saturn program so well. As Saturn activity subsided, these resources were mustered for the Space Shuttle effort. Necessary administrative and physical changes occurred to accommodate the Shuttle program, but in general the Center continued its proven practices in the development of large propulsion systems.

The Shuttle posed a number of technical challenges to Marshall engineers. Serving as both a passenger and cargo vehicle, the orbiter required highly efficient propulsion systems. How could that capability best be achieved? By integral engines? By external boosters? By a combination of both? How could enough fuel be provided for lift-off without burdening the orbiter with empty tanks in flight? How could fuel efficiency be improved to get the most energy from every gallon?

For Saturn vehicles, the answer to these questions was expendable booster stages that provided thrust and then were discarded. The Shuttle, however, had to meet a new requirement—reusability—and that introduced a host of new questions. What sort of rocket engine could withstand repeated use? How much of the propulsion system could be recycled and reused on successive flights? What materials could survive the rigors of repeated launches and reentries? For each of the propulsion elements, the Marshall Center developed unique solutions. The end product was a totally new launch vehicle.

Test firing of a Space Shuttle main engine.

The Space Shuttle Main Engine

The Space Shuttle main engines became the most advanced cryogenic liquid-fueled rocket engines ever built. From the outset, it was recognized that the main engines required the greatest technological advances of any element in the Shuttle program. The three high-pressure engines clustered in the tail of the orbiter would each provide almost a half million pounds of thrust, for a total thrust equal to that of the eight-engine Saturn I first stage. Unlike Saturn engines, the Shuttle main engines were designed to be throttled over a range of 65 percent to 109 percent of their rated power. Thus, the engine thrust could be adjusted to meet different mission needs. The initial design goal for each engine was multiple starts and a total firing lifetime of 7½ hours, as compared to the Saturn J–2 engine's lifetime of about 8 minutes. The engines were also designed to be gimballed so they could be used to steer the Shuttle as well as boost it into orbit.

To get very high performance from an engine compact enough that it would not encumber the orbiter or diminish its desired payload capability, Marshall worked closely with its prime contractor, the Rocketdyne Division of Rockwell International. The greatest problem was to develop the combustion devices and complex turbomachinery—the pumps, turbines, seals, and bearings—that could contain and deliver propellants to the engines at pressures several times greater than in the Saturn engines.

The Shuttle engine components would have to endure more severe internal environments than any rocket engine ever built. Working out the details of this new high-pressure system was difficult and time consuming, but the resultant engines represented a significant advance in the state of the art.

The Shuttle main engine would also become the first propulsion system with a computer mounted directly on the engine to control its operation. This digital computer was designed to accept commands from the orbiter for start preparation, engine start, thrust level changes, and shutdown. The controller was also designed to monitor

STS–1 Commander John Young in orbit.

engine operation and automatically make corrective adjustments or shut down the engine safely. Advances in electronic circuitry were required for the addition of this unit to a rocket engine. Because it would operate in a severe environment, special attention was paid to the design and packaging of the electronics during an extensive design verification program.

Improved fuel efficiency was achieved by an ingenious staged combustion cycle never before used in rocket engines. This two-stage process called for exhaust gases to be recycled for greater combustion efficiency. Part of the fuel was combusted in preburners to drive the turbines. After which, the exhaust gases would be channeled into the main combustion chamber for full combustion at higher temperatures with the balance of the propellants. The rapid mixing of propellants under high pressure was designed to be so complete that a 99-percent combustion efficiency could be attained.

"During the testing of the three engines used on Columbia, we made a significant number of changes as our knowledge of the engines matured," said Boyce Mix, who worked for 15 years at the Resident Office at Marshall's Mississippi test site, where he played a key role in the acceptance testing of the Space Shuttle main engines. The changes were necessary for an engine of extreme complexity designed to fire not once, but over and over again. "We felt very confident the engines would perform well and they did," Mix added.

George Hopson, who now works as manager of the Space Shuttle Main Engine Project Office at Marshall, recalled work on the engine in the 1970s. "I remember one particular problem we encountered on the main oxidizer valve," Hopson said. "It took us almost a year to solve it. Every time we tested the engine, we took a chance of burning it up. I can't recall any other Space Shuttle main engine development problem that even approached that one in difficulty. That was the biggest obstacle to enabling NASA to launch the first Shuttle on schedule."

Rollout of a new external tank at the Michoud Assembly Facility.

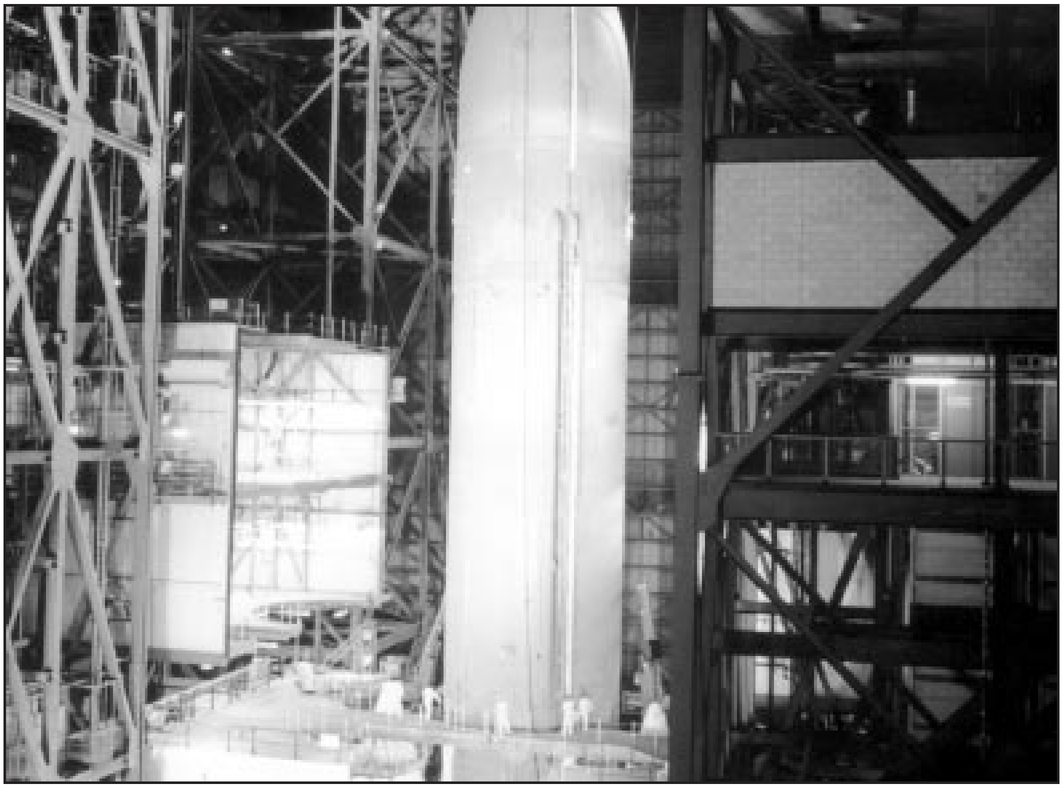
The External Tank

Even though they were designed to be extremely efficient, the three main engines would also consume a tremendous quantity of propellant. The tank was referred to as “external” as a result of discussions held when NASA was in the process of defining the Shuttle. Development costs related to developing fully reusable vehicles with “internal” tanks was avoided by using a disposable “external” tank at the expense of replacing the tank after each flight. Thus, the name “external” stuck. The tank feeding the engines was much larger than the orbiter itself. Marshall also was responsible for developing the external tank, a massive container almost as tall as the Center’s main office building. The external tank was actually designed to contain two tanks, one for liquid hydrogen and one for liquid oxygen, and included a plumbing system to supply propellants to the main engines of the orbiter.

The external tank presented a variety of technical problems, both as a fuel tank and as the structural backbone of the entire Shuttle assembly. Standing 154-feet tall with a 27-foot diameter, the external tank represented a towering structure. In its initial design, it would contain more than a half million gallons of propellant and when full weigh more than one and a half million pounds. Marshall personnel worked closely with the prime contractor, the Martin Marietta Corporation, to devise appropriate design solutions for its unusual requirements.

The Center’s prior experience on the Saturn V second stage was directly applicable to the cryogenic propellant design requirements of the external tank. To maintain the extremely low temperature necessary for the liquid hydrogen, the exterior skin of the tank was covered with about an inch of epoxy spray-on foam insulation. This thermal wall was designed to reduce heat into the tank and also reduce frost and ice formation on the tank after loading propellants. The tank was also protected in critical areas from the severe aerodynamic heating during flight by a localized ablative undercoat used to dissipate heat.

Preparing to mate the external tank and solid rocket boosters at Kennedy Space Center.



Structurally, the external tank would be attached to the orbiter and the solid rocket boosters. The load-bearing function, both on the launch pad and during lift-off and ascent, was a major design challenge. Engineers devised several solutions to make the tank as strong and as lightweight as possible. The aluminum alloy structure was designed to handle complex loads, and the problem of propellant sloshing in the tanks was solved with baffles to avoid instabilities that could affect the Shuttle's flight.

Another important design consideration was that the external tank would not be reusable. Therefore, its design had to be simple and its cost minimal. Solutions to these requirements included locating the fluid controls and valves in the orbiter and drawing power for the electronics and instrumentation from the orbiter. These economies helped to minimize expendable hardware.

Plans called for the external tank to be manufactured at the Michoud Assembly Facility by Martin Marietta under Marshall Center management. New tooling, such as a welding fixture half the span of a football field, was required to handle production of the huge tank. The barge transportation system developed to deliver Saturn stages was selected to transport external tanks to the launch sites.

"We had been up all night in the Huntsville Operations Support Center monitoring systems before the launch of Columbia," said Porter Bridwell, then deputy manager of the External Tank Project Office. "However, there was very little doubt in our minds that the external tank would perform as it should," said Bridwell, who also served as Director of the Marshall Center in the mid-1990s.

Test firing of a solid rocket motor in Utah.

Solid Rocket Boosters

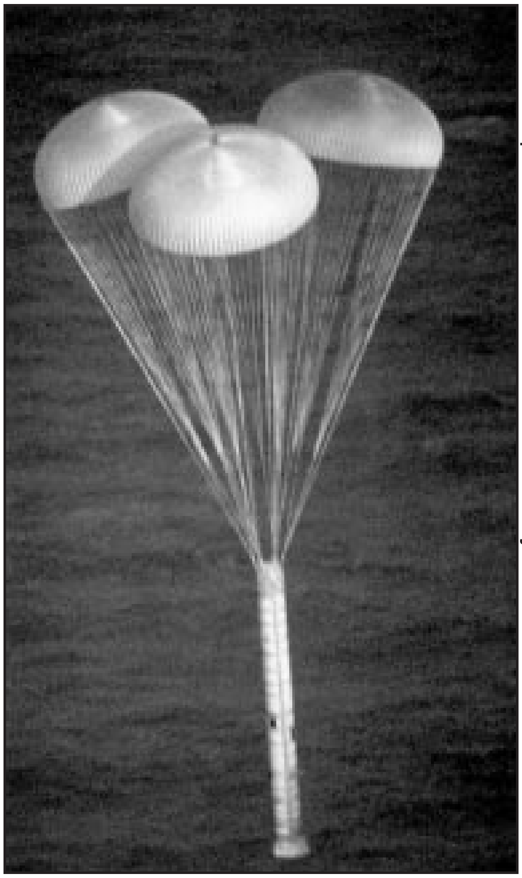
The solid rocket boosters would be the first solid propellant rockets built for a crewed space vehicle and the largest solid rockets ever flown. Designed to burn for approximately 2 minutes, each booster would produce almost three million pounds of thrust to provide 84 percent of vehicle thrust during the first two minutes of flight. The boosters were also designed to help steer the Shuttle during the critical first phase of ascent. The 11-ton booster rocket nozzle would also become the largest movable nozzle ever used.

United Space Boosters, Inc. was the assembly and refurbishment contractor. The Morton Thiokol Corporation was selected to provide the solid rocket motors. The solid rocket boosters were designed to support the entire Shuttle assembly on the launch pad. In addition, they were designed to provide six million pounds of thrust in flight and respond to the orbiter's guidance and control computer to maintain the Shuttle's course. At burnout, the boosters would separate from the external tank and drop by parachute to the ocean for recovery and subsequent refurbishment.

The major design drivers for the solid rocket boosters were high thrust and reusability. The desired thrust was achieved by using a state-of-the-art solid propellant and by using a long cylindrical motor with a specific core design that allowed the propellant to burn in a carefully controlled manner. The requirement for reusability dictated durable materials and construction, which led to several innovations. Paints, coatings, and sealants were extensively tested and applied to surfaces of the booster structure to preclude corrosion of the hardware exposed to the harsh seawater environment. Initial specifications called for motor case segments that could be used 20 times. To achieve this durability, engineers selected a weld-free case formed by a continuous flow-forming process. Machining and heat treatment of the massive motor case segments were also major technical efforts.

Lowering solid rocket booster into Marshall structural test stand.

Reusability also meant making provisions for retrieval and refurbishment. The boosters were designed to contain a complete recovery subsystem including parachutes, beacons, lights, and tow fixtures. The 136-foot diameter main parachutes would become the largest and heaviest ribbon parachutes ever used in an operational system, and the solid rocket boosters would represent the largest and heaviest objects ever recovered by parachute. The boosters were also designed to survive water impact at almost 60 miles per hour and maintain flotation with minimal damage. “The recovery process for the solid rocket boosters was unprecedented in size and scope,” said Royce Mitchell then manager of Marshall’s booster recovery efforts.” Mitchell worked on the booster along with others like George Hardy, manager of the solid rocket booster project for Marshall in the 1970s. “Our biggest challenge was that we had no way to test the recovery system with anything near the size of the booster because we couldn’t get an aircraft to carry that much weight aloft,” Mitchell said.



Descent of spent solid rocket booster for recovery and reuse.

Arrival of Enterprise at Marshall in 1978 for yearlong series of tests.

Additional Marshall Center Support

Besides fulfilling its primary responsibilities for propulsion systems, Marshall supported many other efforts in Shuttle systems engineering and analysis. The Center's technical competence in materials science, thermal engineering, structural dynamics, aerodynamics, guidance and navigation, orbital mechanics, systems testing, and systems integration all proved valuable to the overall Shuttle development program.

Shuttle test activities were a major responsibility of the Marshall Space Flight Center for several years in the late 1970s. Both in Huntsville and at the related NASA facilities in Louisiana and Mississippi, as well as at contractor sites around the country, Marshall personnel participated in many development and qualification tests. Many worked with individual components within a laboratory. Others participated in engine static firings or dynamic tests of the mated Shuttle elements. Preparing for and coordinating the many different test programs was a significant technical challenge. Rather than build new test facilities for the massive Shuttle elements Marshall modified existing resources. Test fixtures and equipment that had stood idle since the Saturn era were revived and remodeled to support various Shuttle test efforts. In addition, special new equipment was constructed.

The busiest year was 1978. That's when Marshall Center employees conducted the external tank structural and vibration tests, solid rocket booster structural tests, and mated vertical ground vibration tests. Meanwhile, single engine tests and main propulsion system cluster firings were in progress at the National Space Technology Laboratories (now Stennis Space Center). Solid rocket motor tests were underway in Utah and subsystems tests, such as checkout of the booster parachutes, were being completed elsewhere.

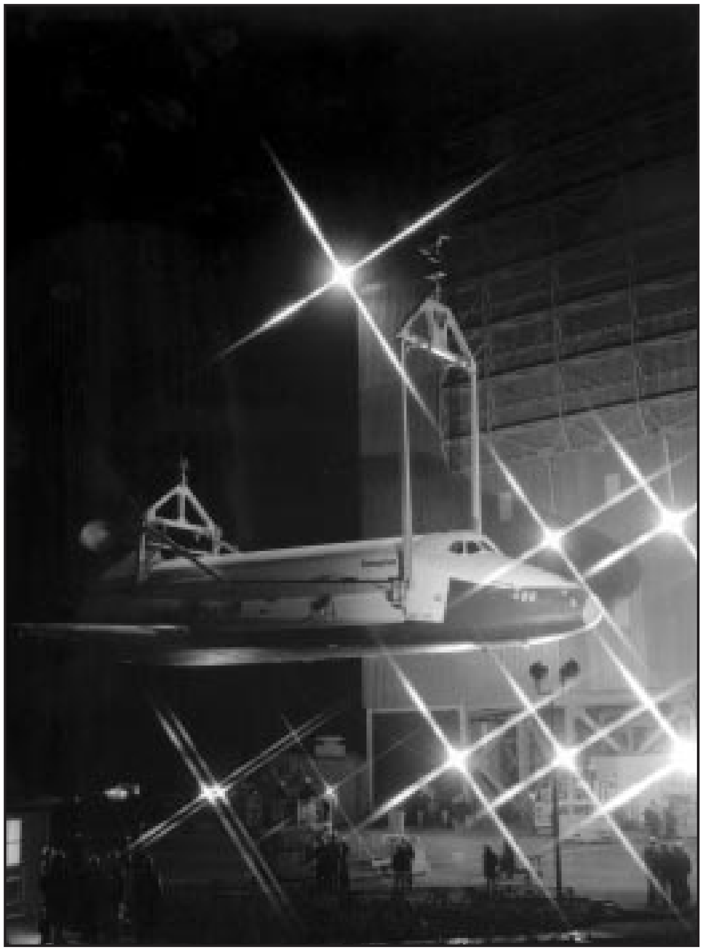
Marshall played a dominant role in the yearlong Mated Vertical Ground Vibration Test Program, the critical evaluation of the entire Shuttle complement—orbiter, tank, and boosters, which had been assembled for the first time. The phased test sequence began in March of 1978 when the orbiter

Enterprise arrived at Marshall and was greeted by thousands of employees and citizens. The orbiter was hoisted into the modified Dynamic Test Stand originally built for Saturn V testing, mated first to an external tank, and subjected to vibration frequencies comparable to those expected during launch and ascent. Several months later, the solid rocket boosters were added for tests of the entire Shuttle assembly. The test series confirmed the structural interfaces and mating of the entire Shuttle system and allowed mathematical models used to predict the Shuttle's response to vibrations in flight to be adjusted so that effects for future flight environments could be predicted adequately prior to launch. Marshall managed and conducted this important test program with support from the Shuttle contractors.

Concurrently, both the external tank and the solid rocket boosters underwent independent structural tests. In addition, captive firings of a 6.4-percent scale model Shuttle enabled engineers to determine the launch acoustic environment and its effects on both the vehicle and the launch pad at Kennedy Space Center.

Marshall's other principal test responsibility was for the main engine development. Engines were fired repeatedly during their development and later for flight qualification. The highlight of propulsion system testing was the main propulsion test series of cluster firings, in which three engines were mounted to an orbiter mockup and fired simultaneously while drawing propellants from an actual external tank. These tests, which began in 1977, certified not only the operational compatibility of the main propulsion system elements but also propellant loading procedures and propellant feed systems. In addition, Marshall established an in-house laboratory to test and verify the avionics and software system of the main engines through simulations of all operating conditions.

As the launch of STS–1 drew closer in 1981, the Huntsville Operations Support Center (HOSC) in Building 4663 was a hub of activity during propellant loading, countdown, launch, and powered flight toward orbit. This facility had evolved considerably from the simpler Saturn era operations room. From the HOSC, Marshall personnel monitored the status of the propulsion systems; via a sophisticated communications network, they received data from sensors aboard the Shuttle and from Marshall management teams at the launch site.



Readying the Orbiter Enterprise for dynamic tests at Marshall.

Astronauts John Young and Robert Crippen at the Marshall Center following their flight.

STS–1 Legacies

In 1981, Marshall and the Nation once again watched expectantly as a new launch vehicle, the Space Shuttle, rose from the pad. This successful first flight of the orbiter Columbia introduced a new era and a continuing series of Shuttle missions. The Shuttle development effort evolved naturally out of the Saturn experience in large launch vehicles and propulsion systems. Marshall continued its close working relationship with contractors and maintained its strong technical competence in the relevant engineering disciplines. However, certain changes in NASA's philosophy and resources challenged Marshall in new ways. During the Shuttle period, the Marshall Center became a leaner, stronger institution as it adapted to these changes. For example, limitations on funding also meant limitations on test hardware.

The principal philosophical change evolved from the necessity of reuse. In a time of declining budgets and increased awareness of limited resources, reusability was a high priority. Marshall met the technical challenge of developing durable space hardware that could be recycled for many missions. Despite delays along the way, the Shuttle development program proceeded successfully. The achievement was especially noteworthy because the Center was also tasked with the administrative challenge of reassigning facilities and personnel. As Saturn work tapered off and Marshall became involved in other projects, the Center had to reallocate many of its resources. From 1965, the peak year of Saturn activity, to the first year of Shuttle activity in 1970, Marshall lost almost 20 percent of its civil service workforce as Federal budget cuts slashed the Center's funding in half. This trend continued well into the 1970s until the budget and staffing levels stabilized with staff at approximately 60 percent of the peak Saturn year.

The Center managed to cope with the reductions and still tackle very ambitious projects. As a result, development of a vehicle capable of routine access to space opened many possibilities for using space as a laboratory and workplace.

Jim Kingsbury, former Director of Marshall's Science and Engineering Directorate recalled, "The story of the Shuttle is a remarkable tribute to the dedication of an awful lot of men and women in the most trying of political times—not only technically challenging, but politically challenging. It was in the '70s, in the post-Apollo era, that the Nation in general turned sour on space. In the last half of the '70s the Nation began to respond again, but the administration was very negative on the NASA program. And so, it was a real struggle to develop a machine as complicated as that one with the reliability that it has, with the limited dollars they had. And I think its performance is attributed to a lot of people who worked awfully hard."

Robert Lindstrom, who was Shuttle Projects Manager at Marshall in 1981, described the launch of STS–1 as "flawless," a sentiment shared by Alex McCool, who currently manages the Shuttle Projects Office at Marshall. As McCool points out, Marshall's Shuttle responsibilities did not end with development of operational main engines, external tanks, and solid rocket boosters. On January 28, 1986, at 73 seconds into the flight of the 25th mission, orbiter Challenger broke up under severe aerodynamic loads. The flames from a leaking right-hand solid rocket motor caused a severe rupture of the external tank, destroying it. The crew and the vehicle were lost.

The months that followed brought unparalleled changes in NASA's institutional management and in its technical operations. On March 24, 1986, NASA directed the Marshall Center to form a solid rocket motor redesign team to requalify the motor of the Space Shuttle's solid rocket booster. In addition to Marshall personnel, the team included personnel from other NASA Centers, industry, and academia. President Ronald Reagan directed NASA to implement the recommendations of the Presidential Commission on the Space Shuttle Challenger Accident. As part of satisfying those recommendations, NASA developed and implemented a plan to provide a redesigned solid rocket motor. After a nearly error-free countdown, Discovery and the STS–26 crew lifted off from Pad 39B on September 29, 1988.

Throughout the late 1980s and the 1990s, the Marshall Center continued ongoing technology advancements to improve the Shuttle propulsion system. In particular, Marshall played a key role in upgrading the Space Shuttle main engines. The engines were successfully test fired in 1988 using a modified Space Shuttle main engine in Marshall's Technology Test Bed, actually a reconfigured Saturn V first-stage test stand. Improvements also included the development of silicon nitride (ceramic) bearings for the Space Shuttle main engine. The Center also developed a new liquid oxygen pump using the latest technology of investment casting (versus welded components). Space Shuttle mission STS–89 in January 1998 marked the first flight of redesigned Space Shuttle main engines designed to increase the reliability and safety of Shuttle flights.

In 1994, the Center embarked on development of a new super lightweight Space Shuttle external tank. The tank made its premier as part of the STS–91 mission in 1998. The new tank featured aluminum lithium—a lighter stronger material than the alloy used to manufacture previous external tanks. The new tank was essential for launching Space Station components that were designed to be assembled in a more demanding orbit than previously planned. The new design resulted in payload weight savings in excess of 7,000 pounds, which could be translated into 7,000 pounds of vital payload. Structural and modal testing for the tank was completed at Marshall. The Center also developed weld schedules and materials characteristics for the new tank. All the work on the new tank was achieved successfully after a tight schedule of about 3½ years under cost.

Today, the Marshall Center continues to manage safe, continuous, robust, and cost-effective operations for the Space Shuttle propulsion elements. The Center also has responsibility for continuing to streamline operations and aggressively develop and implement significant upgrades to enhance safety, meet the Shuttle launch manifest, improve mission supportability, and improve the system to sustain the Space Shuttle for its lifetime.

STS–1 Astronauts John Young and Robert Crippen.

Chronology

Late 1960s:
President Nixon establishes the Space Task Group to make recommendations regarding America's next decade in space. The group's recommendation focuses on the need for a reusable shuttlecraft.
Source: *NASA Astronautics and Aeronautics, 1971, p. 62.*

Early 1970s:
NASA initiates Space Shuttle development activities. Marshall will be responsible for the Shuttle's major propulsion elements: the Space Shuttle main engines, solid rocket boosters, and external tank.
Source: *NASA Press Kit, "First Space Shuttle Mission STS–1," April 1981.*

April 30, 1970:
NASA lets three $6 million contracts for Phase B studies on the Space Shuttle main engine—Aerojet-General Corporation, Rocketdyne Division of Rockwell Division of North American Rockwell, and Pratt & Whitney Aircraft. Marshall will manage the contracts.
Source: *NASA Astronautics and Aeronautics, 1970, p. 157.*

December 22, 1970:
NASA selects McDonnell Douglas Astronautics Corporation and North American Rockwell for parallel 11-month definition and preliminary design studies for a reusable Space Shuttle. A Space Shuttle Task Team at Marshall will manage the McDonnell Douglas work.
Source: *MSFC Release, December 22, 1970.*

March1, 1971:
The Mississippi Test Facility (known today as the Stennis Space Center) is selected as the site for sea-level testing of the Space Shuttle main engine.
Source: *NASA Astronautics and Aeronautics, 1971, p. 60.*

January 5, 1972:
President Nixon formally endorses plans for the Space Shuttle. Following the announcement, then NASA Administrator James Fletcher says, the Space Shuttle "will change the nature of what man could be in space. By the end of decade the Nation will have the means of getting men and equipment to and from space routinely."
Source: *NASA Astronautics and Aeronautics, 1972, pp. 4–5.*

March 15, 1972:
Dr. Fletcher announces that the Space Shuttle will be powered by recoverable, reusable, solid rocket motors in a parallel burn configuration rather than by pressure-fed, liquid-fueled rockets. The "choice was made in favor of the solid parallel burn because of lower development costs and lower technical risks," Fletcher said.
Source: *NASA Astronautics and Aeronautics, 1972, p.102.*

March 19, 1972:
Marshall's Space Shuttle Task Team is abolished with the formation of a permanent Shuttle Program Office at Marshall. Roy E. Godfrey will manage the office.
Source: *Marshall Star, May 17, 1972.*

May 16, 1972:
The Marshall Center reaches an agreement with the U.S. Army Corps of Engineers, Huntsville Division, to provide facility design and construction in support of the Space Shuttle.
Source: *NASA Astronautics and Aeronautics, 1972, p. 184.*

August 23, 1972:
A definitive contract for the Space Shuttle main engine is signed with Rocketdyne.
Source: *Marshall Star, August 23, 1972.*

September 6, 1972:
Marshall announces plans for a series of 20 water-entry simulation tests with a 120-inch-diameter solid rocket casing assembly. The tests were designed to provide data for assessment of Space Shuttle booster water recovery methods and to aid in preliminary solid rocket motor design.
Source: *NASA Astronautics and Aeronautics, 1972, p. 309.*

During 1972:
Studies by NASA and the aerospace industry concentrate on the technical and economic aspects of the different kinds of boosters.
Source: *NASA Astronautics and Aeronautics, 1972, pp. 4–5.*

August 16, 1973:
NASA signs a contract with Martin Marietta Corporation for the design, development, and test of the external tank.
Source: *NASA Astronautics and Aeronautics, 1973, p. 246.*

November 20, 1973:
NASA signs a contract with Thiokol Corporation for negotiation of a contract for design, development, and test of the solid rocket motors.
Source: *NASA Astronautics and Aeronautics, 1973, p. 327.*

November 21, 1973:
The Marshall Center was conducting drop tests using a solid rocket booster scale model and a three-parachute recovery system to determine the feasibility of keeping parachutes attached to the booster rather than releasing them on impact with the water. The 11½-foot diameter scale model, attached to the parachutes, was dropped from a 200-foot height into the Tennessee River.
Source: *Marshall Star, November 21, 1973.*

April 24, 1974:
A Space Shuttle main engine component is hot-fired for the first time at Santa Susana, California in a successful run of a preburner assembly.
Source: *Marshall Star, April 21, 1974.*

September 4, 1974:
The Marshall Center's first static firings related to the Space Shuttle program were underway. A small-scale (6.4 percent) model of the vehicle was used to gather acoustical data vital to design and development activities.
Source: *Marshall Star, September 4, 1974.*

October 9, 1974:
The Marshall Center was completing a simulation facility, designed to enable engineers to test and verify the Space Shuttle main Engine avionics systems using flight type hardware. No engines would be fired in the Hardware Simulation Laboratory. The main engine "firings" would be mathematical.
Source: *Marshall Star, October 9, 1974.*

November 13, 1974:
The Marshall Center announces that a contract had been awarded by the Huntsville Division, U.S. Army Corps of Engineers, to Alegernon-Blair Industrial Contractors for modifications of the Saturn S–IC Test Stand for structural testing of the external tank.
Source: *Marshall Star, November 13, 1974.*

March 26, 1975:
Rocketdyne completes the first Space Shuttle main engine and the integrated subsystem test bed a month ahead of schedule. The engine was not built for flight but for static testing.
Source: *Marshall Star, March 26, 1975.*

April 16, 1975:
The first Space Shuttle flight-like test hardware, a ground test hydraulic actuator for the Space Shuttle main engine, arrived at the Center. Each of the orbiter's three main engines will use two of the actuators to gimbal the engine for steering control.
Source: *Marshall Star, April 16, 1975.*

June 7, 1975:
The integrated subsystem test bed engine is successfully fired for the first time. The test lasted 0.8 seconds.
Source*: NASA Astronautics and Aeronautics, 1975, p. 105.*

June 11, 1975:
The prime contractor for the external tank, Martin Marietta Aerospace, awards a subcontract to Avco for the manufacture of the intertank to provide support between the liquid-oxygen tank and the larger liquid-hydrogen tank.
Source: *NASA Astronautics and Aeronautics, 1975, p. 108.*

June 24, 1975:
The integrated subsytem test-bed engine main chamber firing is conducted.
Source: *NASA Astronautics and Aeronautics, 1975, p. 120.*

November 20, 1975:
The external tank critical design review is completed at the Michoud Assembly Facility, clearing the way for production.
Source: *Marshall Star, November 26, 1975.*

During 1975:
The solid rocket motor design, development, test, and engineering project is definitized. The resulting development program will include seven full-scale motor static tests and delivery of 12 flight motors for the first six development flights.
Source: *Space Shuttle Status Report to Congress, 1978, p. 187.*

September 10, 1975:
Marshall engineers were completing tests aimed at refining the means of towing recovered solid rocket boosters to shore for refurbishment and reuse.
Source: *NASA Astronautics and Aeronautics, 1975, p. 186.*

October 22, 1975:
Fixtures were nearing completion at the Michoud Assembly Facility for manufacturing the external tank, which stood 154-feet tall with a 27-foot diameter and designed to hold more than a million gallons of propellant and weigh more than 1.5 million pounds. Several of the fixtures at the assembly site were more than half the length of a football field and several stories high. Two fixtures at Michoud, each supported by massive steel tripods anchored in concrete on each side, were so huge and so imposing that they were nicknamed "Trojan Horses."
Source: *Marshall Star, October 22, 1975.*

During 1975:
A 405-foot-tall Saturn V Dynamic Test Stand at Marshall was being modified under a contract between the Army Corps of Engineers and Universal Construction to provide a mated ground vibration test facility. The structure would be used to test the vehicle in launch and boost configuration to determine the bending modes and dynamic response during launch and ascent conditions. The orbiter Enterprise was used later in the tests at the facility.
Source: *Marshall Star, November 5, 1975.*

July 28, 1976:
Assembly of the first external tank was underway at the Michoud Assembly Facility.
Source: *Marshall Star, July 28, 1976.*

During September 1976:
The Space Shuttle main engine critical design review was conducted clearing the design for further testing.
Source: *Space Shuttle Status Report to Congress, 1978, pp. 157–158.*

December 17, 1976:
United Space Boosters, Inc., of Sunnyvale, California, is selected as the solid rocket booster assembly contractor, immediately following completion of the solid rocket booster critical design review that was eight months ahead of schedule.
Source: *Marshall Star, January 5, 1977.*

March 14, 1977:
An external tank intertank test article is delivered to the Marshall Center for structural tests. It passed all tests by November 1977.
Source: *Marshall Star, March 16, 1977.*

March 16, 1977:
The Space Shuttle main engine had been successfully tested at rated thrust conditions for 60 seconds during the previous weekend with a total test duration of slightly over 80 seconds.
Source: *Marshall Star, March 16, 1977.*

July 18, 1977:
The first firing of a solid rocket motor takes place in Utah. The motor runs for about two minutes in what observers describe as a "near perfect" test. The motor is referred to as Development Motor–1.
Source: *Marshall Star, July 20, 1977.*

September 9, 1977:
The first external tank, the Space Shuttle's largest component, rolls off its New Orleans assembly line.
Source: *Marshall Star, September 14, 1977.*

During September 1977:
Pressure tests are conducted to demonstrate the capability of the solid rocket motor cases to be used up to 20 times.
Source: *Marshall Star, September 14, 1977.*

November 30, 1977:
The external tank liquid oxygen structural test article had recently been delivered to the Marshall Center.
Source: *Marshall Star, November 30, 1977.*

During November 1977:
The intertank structural test program is completed for the first external tank.
Source: *MSFC Release 77–234*

During December 1977:
The tanking test on the external tank is conducted at National Space Technology Laboratories.
Source: *Marshall Center News Release 77–234.*

During 1977:
Solid rocket booster testing begins at Marshall and other facilities in the U.S. Because of renewed testing at Marshall, modifications are made on a Saturn test stand to accommodate structural testing of the solid rocket boosters.
Source: *Marshall Star, December 21, 1977.*

January 18 1978:
The solid rocket motor Development Motor–2 test is successfully conducted in the Utah desert.
Source: *Marshall Star, January 25, 1978.*

March 6, 1978:
The liquid hydrogen tank and interstage section of an external tank had been unloaded from the NASA barge Orion at the Marshall Center docks on the Tennessee River. Plans call for this section of the external tank to be used in a structural test program at Marshall. A complete external tank, which arrived at the same time on the barge Poseidon, will be used for mated vertical ground vibration testing.
Source: *Marshall Star, March 8, 1978.*

March 18–19, 1978:
About 85,000 people gather at the Marshall Center to get a close-up look at the Space Shuttle orbiter Enterprise and a complete external tank. The orbiter arrived piggyback in Huntsville on a 747 aircraft. Plans call for the orbiter and external tank to be mated in Marshall's Dynamic Test Stand. Later the solid rocket boosters will be added. The elements will be used for mated vertical ground vibration tests at Marshall.
Source: *Marshall Star, March 22, 1978.*

May 10, 1978:
In a static firing, a Space Shuttle main engine successfully completes a test at 100 percent of its rated power level for the full duration expected during actual flight.
Source: *Marshall Star, May 17, 1978.*

May 19, 1978:
Three Space Shuttle main engines roar to life in the first major test of the Shuttle's main propulsion system. Orange flame and a huge cloud of white smoke pour from beneath the stand during the 15-second run.
Source: *Marshall Star, Marshall May 24, 1978.*

October 19, 1978:
The solid rocket motor Development Motor–3 test is successfully conducted in the Utah desert.
Source: *Marshall Star, October 25, 1978.*

February 17, 1979:
The test of the solid rocket motor Development Motor–4 , the final development test, is conducted. This test series verifies the basic design requirements and paves the way for solid rocket motor qualification testing designated as Qualification Motor–1 and Qualification Motor–2.
Source: *Marshall Star, Marshall February 21, 1979.*

March 19, 1979:
The NASA barge Poseidon, with Space Shuttle components aboard, pulls out from the Marshall Center dock on the Tennessee River to begin an 11-day trip to Kennedy Space Center. On board are the external tank used at the Marshall Center for mated vertical ground vibration testing and two solid rocket booster nose cap forward skirt assemblies. The items will to be used at the Kennedy Center in "Pathfinder" operations—a checkout of movement and assembly "fit checks" at the Vehicle Assembly Building—and for training in "stacking" the Space Shuttle on the mobile launcher platform.
Source: *Marshall Star, March 21, 1979.*

June 13, 1979:
The first of a series of test firings of solid rocket motors is initiated to qualify the motors for manned flight. The test is referred to as Qualification Motor–1.
Source: *Marshall Star, June 20, 1979.*

June 27, 1979:
A major milestone in the Space Shuttle main engine test program is reached when a flight configuration engine successfully completes the first series of tests preliminary to flight certification. The test series, which began March14, 1979, totaled 16 firings and accumulated 5,245 seconds of firing time.
Source: *Marshall Star, July 4, 1979.*

July 6, 1979:
The first flight external tank (ET–1) is delivered to Kennedy Space Center from the Michoud Assembly Facility.
Source: *Marshall Star, August 8, 1979.*

September 27, 1979:
The second in a series of test firings of a solid rocket motor is conducted to qualify the motors for manned flight. This test is referred to as Qualification Motor–2.
Source: *Marshall Star, October 3, 1979.*

February 8, 1980:
A major milestone in the Space Shuttle main engine test program is reached when a flight configuration engine successfully completed the second series of tests preliminary to flight certification. This second series of tests began September 22, 1979.
Source: *Marshall Star, February 20, 1980.*

February 13, 1980:
The solid rocket motor passes its last major test with a 2-minute firing at Thiokol's Utah facility. This test is referred to as Qualification Motor–3.
Source: *Marshall Star, February 20, 1980.*

March 13, 1980:
The first full-power level test (109 percent of rated power level) of the Space Shuttle's main engine is completed.
Source: *Marshall Star, March 19, 1980.*

July 26-27, 1980:
The third Space Shuttle main engine is reinstalled on the orbiter Columbia over the weekend at Kennedy Space Center. The other two engines had been reinstalled the previous weekend. The three engines had been removed from Columbia and shipped to National Space Technology Laboratories for a series of successful test firings that recertified them for flight. The additional firings were conducted because several modifications and component replacements had been made since the original certification firings.
Source: *Marshall Star, August 6, 1980.*

November 7, 1980:
The mating of the solid rocket boosters and the external tank for STS–1 is completed in the Vehicle Assembly Building at Kennedy Space Center.
Source: *Marshall Star, November 12, 1980.*

December 2, 1980:
The fourth and final cycle of preliminary certification tests of the Shuttle's main engine first flight configuration is completed.
Source: *Marshall Star, December 4, 1980.*

December 3, 1980:
Engineers in the Marshall Center's Huntsville Operations Support Center gear up to work in teams around the clock to support the final major test of the Space Shuttle as an integrated flight system.
Source: *Marshall Star, December 17, 1980.*

December 29, 1980:
STS–1 arrives at Complex 39's Pad A at the Kennedy Space Center.
Source: *Marshall Star, December 3 and January 7, 1981.*

January 17, 1981:
NASA's test version of the Space Shuttle's main propulsion system successfully completes its last scheduled test firing. The firing that lasted 10 minutes, 29 seconds is the 12th and longest, test of the system to date.
Source: *Marshall Star, January 21, 1981.*

February 20, 1981:
The Space Shuttle three main engines roar to life for 20 seconds on the launch pad at Kennedy Space Center during the flight readiness firing of the orbiter Columbia's engines.
Source: *Marshall Star, February 25, 1981.*

February 27, 1981:
Testing of the method selected to repair areas of debonded insulation on the external tank is completed at National Space Technology Laboratories.
Source: *Marshall Star, March 4, 1981.*

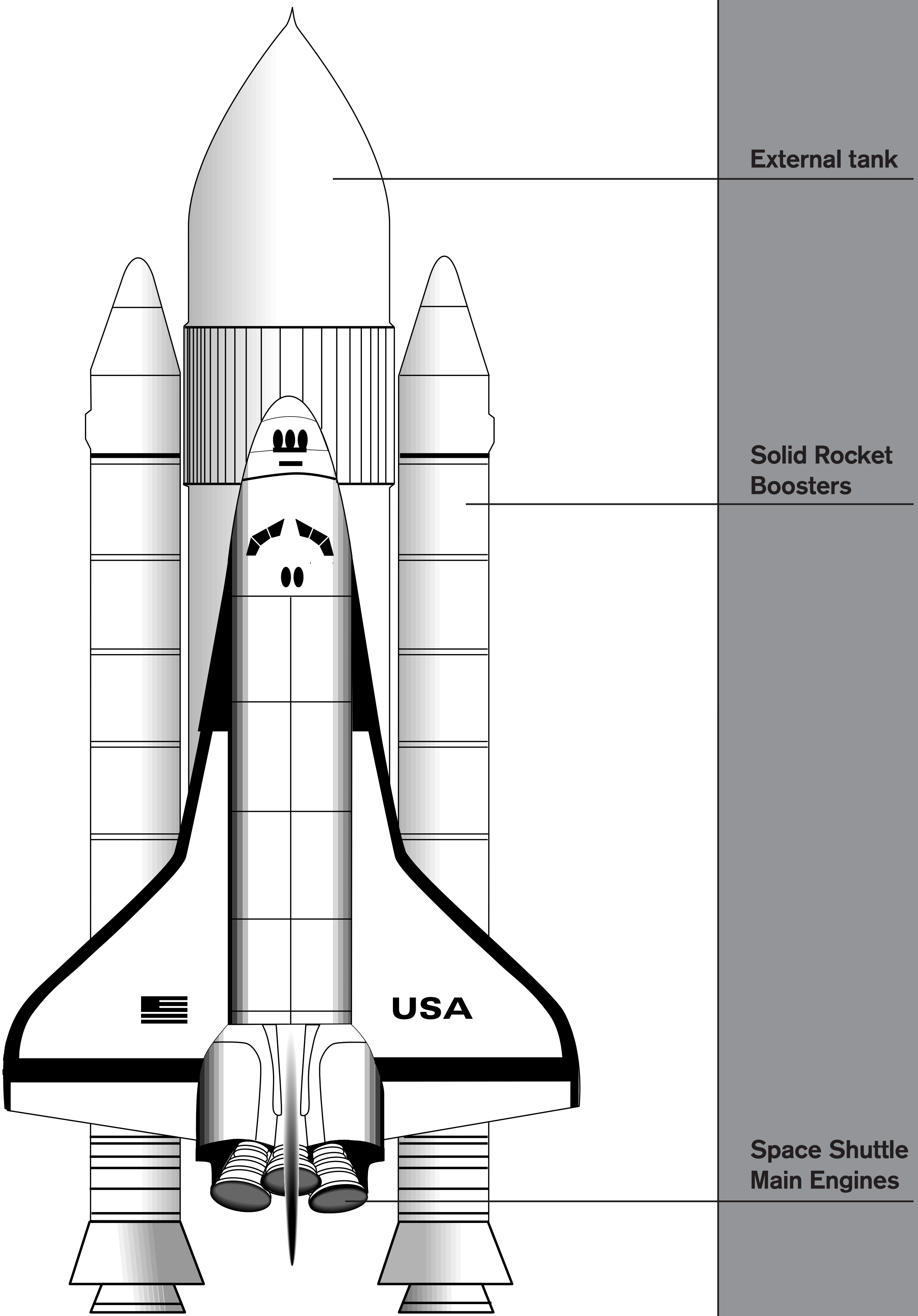
March 19, 1981:
The Dry Countdown Demonstration Test is conducted for STS–1.
Source: *Marshall Star, March 25, 1981.*

March 30, 1981:
The external tank is declared ready for flight following repairs to its thermal protection system and subsequent testing at the Kennedy Space Center.
Source: *Marshall Star, April 1, 1981.*

April 12, 1981:
Powered by Marshall Center propulsion elements, Columbia begins its voyage with a flawless 6:00 a.m. (CST) launch. Commander John Young and Pilot Robert Crippen guide the vehicle into orbit. The historic flight concludes two days later when Columbia lands at Edwards Air Force Base in California.
Source: *Marshall Star, April 15, 1981.*

Marshall Space Flight Center STS–1 Management Team in 1981

Dr. William R. Lucas	Director
Thomas J. Lee	Deputy Director
Robert E. Lindstrom	Manager, MSFC Shuttle Projects Office
James E. Kingsbury	Director, Science and Engineering Directorate
James B. Odom	Manager, External Tank Project
George B. Hardy	Manager, Solid Rocket Booster Project
James R. Thompson Jr.	Manager, Space Shuttle Main Engine Project
James M. Sisson	Manager, Engineering and Major Test Management Office


External tank
Solid Rocket Boosters
Space Shuttle Main Engines
USA

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