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The Solid Rocket Legacy of Thiokol's Huntsville Division 1949-1996

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The former Huntsville Division of Thiokol was a key component of the United States' solid rocket industrial infrastructure from 1949 until its closing in 1996. The establishment of the Thiokol plant on the grounds of the U.S. Army's Redstone Arsenal in Huntsville, Alabama in 1949 helped form the industrial foundation for Redstone to meet its immediate post-World War II mission to develop and manufacture new rockets and missiles. Thiokol's Redstone Division, as it was then known, initially focused on the development and manufacture of polysulfide composite propellants on a large scale for military applications. This led to Thiokol's successful demonstration of case-bonded solid rocket motors (SRMs) up to 31 inches in diameter and its first motor production contract for the Falcon missile. Thiokol's Huntsville Division later developed and manufactured the more modern polybutadiene-based composite propellants, high energy interceptor propellants, and minimum smoke propellants for Army applications. As such, the Huntsville plant had a long and successful history of developing and producing solid rocket motors for interceptor missiles such as the MIM-14 Nike Hercules, CIM-10 BOMARC, LIM-49 Nike Zeus, LIM-49A Spartan, and MIM-104 Patriot, as well as motors for tactical missiles such as the MGM-29 Sergeant, MGM-31 Pershing, AIM-9L/M Sidewinder, AGM-114 Hellfire, AGM-65 Maverick, and RIM-67C Standard Missile. Thiokol Huntsville also made significant propulsion contributions to our nation's manned and unmanned space launch activities, from NASA's "Little Joe" Mercury capsule test vehicle in 1959 to the development and production of the Castor series of space launch boosters that are still produced today in Utah. In 1996, as a result of a declining tactical propulsion market and corporate decision to consolidate some operations, Thiokol closed the Huntsville Division. The history, achievements, facilities, products, and notable events and milestones from the 47-year history of Thiokol's Huntsville Division are described.

I. Introduction

WHILE the corporate history of the former Thiokol† has been written elsewhere, most notably in Sutton's self-published, anecdote-filled work[1] and associated paper,[2] there has been no publication dedicated solely to the telling the story of Thiokol's Huntsville Division from beginning to end. First known as the Redstone Division, Thiokol's Huntsville Division was a Government-owned, contractor-operated (GOCO) solid rocket plant that was located on the Army's Redstone Arsenal at Huntsville, Alabama and was an important part of the United States' solid rocket industrial base from 1949 until its closure in 1996. Although the early history of Thiokol Chemical Corporation is well known, it will be recounted here briefly to document the progression of events that led to the

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† Thiokol Chemical Corporation until 1982, Morton-Thiokol from 1982 to 1989, Thiokol Corporation from 1989 to 1998, then Thiokol Propulsion under Cordant Technologies Inc. until 2000, when Cordant was purchased outright by Alcoa Inc. Alliant Techsystems Inc. (ATK) purchased Thiokol Propulsion from Alcoa in 2001, creating ATK Thiokol Propulsion. In 2006, ATK reorganized its business operations and retired the Thiokol name.

establishment of the Thiokol plant on Redstone Arsenal, a presence that lasted 47 years and produced many technological "firsts," milestones, and early pioneers of the solid rocket industry.

II. Thiokol's Birth and Entry into the Solid Rocket Business

The story of Thiokol begins in April 1926 when Dr. Joseph C. Patrick, a physician and chemist, serendipitously produced the world's first synthetic rubber, polysulfide, in an experiment in his Kansas City laboratory. Patrick found that his liquid polysulfide compound solidified to rubber form and was impervious to solvents and chemicals. Patrick and his co-worker, Nathan Mnookin, were awarded the first patent for this invention in 1927. In 1928, Patrick and his new business partner, Bevis Longstreth, named the product "Thiocol," a composite word derived from the Greek words for sulfur (theion) and glue (kolla). Their eponymously named "Thiocol License Company" was incorporated in 1929.

Unfortunately, Thiocol's early work with polysulfide produced a conspicuous and undesirable byproduct: the odor of rotten eggs. The smell emanating from Thiocol's Kansas City lab proved unpopular with local residents and officials, and the company was encouraged to leave town. In 1930, the founders relocated the fledgling company to Yardville, New Jersey, near Trenton, an area that was much more tolerant of chemical industries. By this time, the company was renamed Thiokol Chemical Corporation.

Thiokol polysulfide rubber soon found application in sealants, lubricants, coatings, and in adhesives requiring resistance to solvents, weather, or electrical arcing. Although challenged during the Depression years, Thiokol remained in business and continued to manufacture its signature product throughout the 1930s and 1940s. During World War II, Thiokol experienced increased demands for its product, which was used to seal aircraft fuel tanks, fuselages, air ducts, gun turrets, and navigation domes. However, the company's future changed when the Jet Propulsion Laboratory (JPL), operated by the California Institute of Technology (Caltech), began to investigate the use of Thiokol LP-3 polymer as a binder for composite solid rocket propellants in the mid-1940s. JPL's initial success resulted in increased orders for LP-3, which caught the eye of new company president Joseph W. Crosby. Crosby soon learned that the Thiokol material was being used to develop solid propellants for rockets.

In 1946, JPL began work on an Army Ordnance project to develop and test the Thunderbird, a 6-inch diameter rocket containing T-10 polysulfide propellant. At about the same time, Crosby and other Thiokol executives were looking to expand their business. In 1947, with JPL's Thunderbird project nearing completion and Thiokol destined to lose a customer for its material, Crosby attempted to sell Thiokol polymer to industrial solid rocket manufacturers Aerojet and Hercules, but was not successful. He then turned directly to the Army and successfully lobbied for a contract to continue solid rocket development work based on polysulfide. In late 1947, Thiokol began its work on solid propellant rockets on the site of a former World War II ordnance plant in Elkton, Maryland, and static tested its first motor there in July 1948. However, Thiokol's initial presence in Elkton was short-lived.

III. The Early Years of the Redstone Division

With the end of World War II in September 1945, much of the United States' massive infrastructure of wartime ordnance and ammunition plants was no longer needed. The Army's huge Redstone Arsenal complex in Huntsville, Alabama, which was built during WW II to produce ammunition and chemical munitions, was deactivated and placed on standby status in early 1947. However, Army officials and local politicians were successful in reactivating the arsenal for a new post-war mission. In October 1948, the Army Chief of Ordnance designated Redstone Arsenal as the center of research and development activities in the field of rockets and related items.

As part of this transformation, the Army directed Thiokol to transfer its rocket development activities from Elkton to Redstone Arsenal in early 1949. With this directive, most of the original Elkton employees moved to Huntsville between April and July and were among the first 33 employees to establish what was first known as the Redstone Division of Thiokol. Among the equipment transferred to Huntsville was a new 50-gallon mixer that had never been used at Elkton. The group set up shop in modest facilities that included a research laboratory, small experimental plant, and an office building that were located in an area formerly designated as Lines 1, 2, and 5 during WW II. Despite these modest facilities, the Redstone Division static fired its first rocket motor, a 5-inch end-burner, on June 21, 1949 and made its first propellant mix on August 1. The first propellant mix was reportedly completed at night under the lights of a Studebaker car.[3] An early aerial photograph of the Redstone plant is shown in Figure 1. Along the main road from the parking lot, top to bottom, are the Chemical Engineering Office (Bldg. 7666), old engineering office, and Chemistry Laboratory (7667). The pilot plant is on the right and machine shop is on the left. In 1951, new administration (Figure 2) and engineering buildings were built and occupied. In Figure 3, Thiokol employees are shown working in the then new engineering building (7631).

Figure 1. Aerial view of Redstone Division in 1950, looking ENE toward "Line 2."

Figure 2. Administration Building (7650), looking west from Line Road.

The Thiokol crew at Redstone soon developed the "case-bonding" technique that allowed solid propellant slurry to be poured directly into a cylindrical rocket motor chamber with a mandrel-formed hollow cavity running the length of the propellant grain, known in modern terms as a "center-perforated grain" configuration. Under normal circumstances, this configuration restricts burning to the inner exposed surface of the grain, allowing the propellant to act as an insulator to protect the motor case from the heat of the combustion gases until burnout, and thus permitting the use of cases with much thinner wall thicknesses.[4] The radial-burning design also offered a greater degree of motor performance tailoring through the use of various geometric shapes.

Figure 3. Inside the Engineering Building (7631) in 1951.

The Redstone Division's first Army project consisted of building and static testing 5-inch diameter case-bonded motors containing about 10 pounds of polysulfide propellant, followed by scale up to 8.25-inch motors containing 100 pounds of propellant in a radial-burning star configuration. The flightweight design of the 8.25-inch motor, intended for use as a jet-assist take off (JATO) unit, was completed in October 1949 and the first near-flightweight motor was static tested in February 1950. The final flightweight design of the 8.25-inch motor was given the Army designation T-40. A total of 62 T-40 motors were static tested during development, which included 22 flightweight cases and three successful tests at -10°F. Even though the T-40 program was terminated due to lack of need, it soon became the foundation for Thiokol's first signature motor accomplishment, the Hermes.

In May 1950, Thiokol embarked on an ambitious development program that provided an historic demonstration of the potential for case-bonded solid propellant rocket motor design and scale-up.[5] At the time, the concept of using an internal-burning, case-bonded composite propellant was still in its infancy. The project, known by the test vehicle designation RV-A-10, was part of the Army's larger Hermes A-2 low-cost missile development program. General Electric was the prime contractor. By current standards, the Hermes motor was small—just 31 inches in diameter by 108 inches long—but it represented a significant step in scale-up at the time. The final motor design contained 4,690 pounds of polysulfide propellant which produced an average thrust of 35,400 lbf over a 24 second burn time.

Figure 4. Hermes Test Day at Redstone Division in 1951 (Dr. Harold W. Ritchey, first Technical Director of the Redstone Division, stands on the floor of the test bay).

The initial requirement for Hermes was to carry a 500-pound warhead a distance of 75 nautical miles. The payload requirement was later increased to 1,500 pounds. A full-scale, heavy-wall motor was successfully static tested on December 2, 1951, just 18 months after program start. This test has often been referred to as "the static test that launched an industry," and the event is recorded in a historically significant photograph (Figure 4). Between January 1952 and March 1953, there were 20 more rocket motor static tests at Redstone Arsenal and four RV-A-10 flight tests from Patrick AFB, Florida. The first flight test in February 1953 marked the first operational use of a 31-inch solid rocket motor. Of the four flight tests, two of the RV-A-10 vehicles reportedly achieved an altitude of 50 miles and a range of 36 miles or better. One spare rocket motor from the program was later returned to Thiokol and successfully static fired seven years later.

The Hermes program produced a number of firsts and significant accomplishments which enabled the rapid progression of solid rocket technology and helped launch a vibrant, competitive, multi-corporate industry by the late 1950s. The Redstone Division itself grew in size to over 500 employees by 1953. Among the trailblazing milestones demonstrated during the Hermes program were the first successful static and flight tests of a large, long-duration, internal-burning, case-bonded solid rocket motor; routine use of multiple propellant mixes for loading a single large motor, allowing the manufacture and casting of more than 5,000 pounds of solid propellant in a single day; routine use of subscale rocket motors for development; reuse of lightweight motor cases for testing; use of the "jelly roll" igniter to avoid the need for a heavy closure as an ignition aid; progressive pressure cure of the propellant grain to control physical properties; and the first use of jet vane thrust vector control in a large rocket motor.[6] In addition, Thiokol engineers encountered and solved unexpected problems with nozzle erosion and combustion instability. Hermes was the largest solid rocket motor of its time and was the forerunner of an impressive list of derivative motors which included the TX-12 Sergeant, the XM20, and the XM33/Castor series.

Due to the rapid growth of solid rocket development work at the Redstone Division and the anticipated need for production scale facilities, the Army awarded Thiokol a contract in 1952 to manage the Longhorn Army Ammunition Plant near Marshall, Texas, and design a new facility there known as Plant III to produce composite solid propellant rocket motors for second generation Army missiles.[7] In addition, Thiokol reactivated the Elkton, Maryland plant in 1951 to serve as a company-owned site for doing business directly with the Air Force and Navy.

Thiokol's success with case-bonded solid rocket motors began to attract the attention of the Air Force, and the Redstone Division soon received its first contract to develop the propulsion system for the Falcon tactical air-to-air missile. Hughes Aircraft Company was the prime contractor. Thiokol completed the development of the first generation Falcon rocket motor in 1952 and the first missile was launched from an aircraft in 1953. It became Thiokol's very first production rocket motor.

The M58 Falcon motor, depicted in the model shown in Figure 5, was 5.8 inches in diameter by 36.8 inches long and contained 31 pounds of polysulfide propellant. The Falcon motor went through a number of design upgrades and, by 1959, had achieved an operational temperature range of -65°F to +165°F, greater than any tactical weapon system of its day. Many details of the case bonding process were refined under this program. Production of the Falcon motor was shared by Huntsville, Longhorn, and Elkton, eventually totaling more than 55,000 motors in one of Thiokol's longest running motor programs. Field storage units demonstrated satisfactory performance more than 22 years after manufacture.

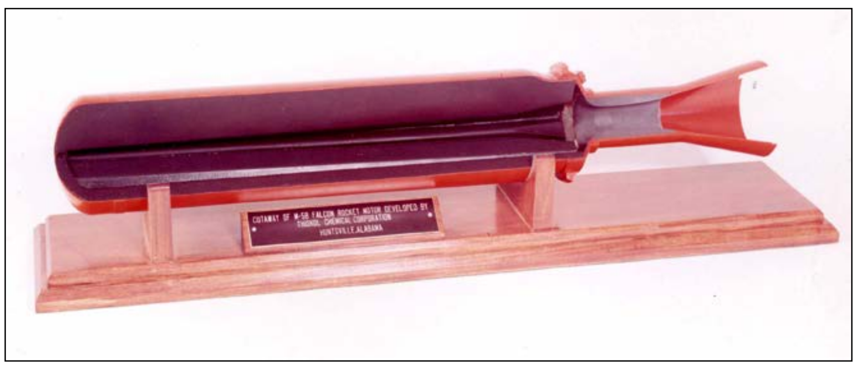

Figure 5. Cutaway model of the M58 Falcon rocket motor.

Following the successful RV-A-10 Hermes program at the Redstone Division, Thiokol sought to apply the newly developed 31-inch motor technology to other opportunities. The first candidate was Sergeant, an Army program to develop a surface-to-surface guided missile system to replace the liquid-fueled Corporal rocket. In 1954, the Redstone Division began the development of the TX-12 Sergeant for the Jet Propulsion Laboratory who designed the motor. Like Hermes, the Sergeant motor was 31 inches in diameter, but was 28 inches longer and contained 5,925 pounds of polysulfide propellant in a star-shaped center burning configuration. Development of the TX-12 motor was completed in 1958 and production of an eventual 400 motors was accomplished at Longhorn AAP. The solid-fueled Sergeant missile was lighter, more mobile, had greater range, and could be launched more quickly than its liquid-fueled predecessor.

Another early project for the Redstone Division was the manufacture of the original solid rocket motor for Loki, an unguided, barrage-type anti-aircraft weapon developed by JPL for the Army Ordnance Department in the early 1950s. Following initial investigations with liquid fueled rockets, the Army asked JPL to develop a solid propellant for Loki in 1951. By 1952, Thiokol was engaged in early work to develop techniques for the mass production of

Loki motors. The 3-inch Loki motor was built in two parts, becoming the first industry demonstration and practical application of a segmented grain system. It was manufactured by attaching a separately-cast cylindrical section to a head end section to form the finished rocket motor.[8]

By March 1953, Thiokol loaded and fired 550 Loki rocket motors containing JPL-formulated ammonium perchlorate/polysulfide propellant with Thiokol ZL-157 polymer as the binder. However, in early 1956, JPL pulled out of the program and the Loki artillery rocket project was cancelled due to lackluster flight test results. Surplus JPL Lokis were later modified and re-purposed as meteorological sounding rockets in the mid- to late 1950s before being replaced by later versions of the rocket motor manufactured by small propulsion companies of the time.[9]

In 1955, the Redstone Division began the development of the XM10 rocket motor for the Army's Lacrosse surface-to-surface tactical missile. Following its development at Redstone, the production of Lacrosse motors took place at Longhorn beginning in 1958. Lacrosse was one of the first motors to incorporate a blast tube nozzle. Production problems at the missile system level later plagued the program, delaying their delivery and eventually forcing the Army to terminate the large scale procurement of Lacrosse. A limited number of missiles were deployed for just three years, from 1960 to 1963, and the Army removed Lacrosse from its active inventory in 1964.[10]

However, Thiokol's Lacrosse motor was also notable for being the first solid rocket motor to incorporate a small "rocket-type" igniter instead of the customary powder-based or pyrotechnic igniters of the period. The concept of using a small rocket motor to ignite a larger rocket motor was simple and straightforward, with the smaller rocket motor providing a controlled, pre-determined pressure rise inside the larger rocket motor during the ignition phase while producing hot ignition gases and solid particles over a longer period of time—a very desirable characteristic for high length to diameter ratio (high L/D) motors that take longer to achieve equilibrium operation and ensuring more reliable motor ignition at temperatures as low as -75°F.

The rocket-type igniter concept was conceived at the Redstone Division in 1954 and first fired in a Lacrosse motor on December 19, 1955. This enabling technology was first reported to the industry in October 1956 at the Joint Army-Navy-Air Force (JANAF) Second Symposium on Solid Propellant Ignition, held in Kansas City, Missouri. Soon thereafter, Thiokol named this invention the "pyrogen," which literally means "producing of heat,"[11] although a more precise definition in terms of a rocket motor system is "an ignition system in which a solid propellant grain is ignited and its combustion products (hot gas and flame) are vented directly into the free volume of the rocket motor." Two early Thiokol pyrogen igniter designs are shown in Figure 6. A pyrogen igniter was also used in the Sergeant motor and was quickly adopted by other solid rocket motor manufacturers, becoming the standard for igniting large rocket motors to this day.

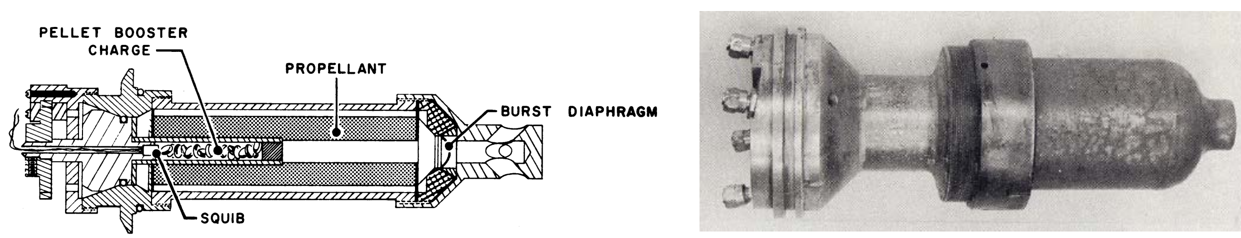

Figure 6. Early Thiokol Pyrogen igniters.

By 1955, the Air Force had been assigned the responsibility to develop the United States' first solid fueled land-based Intercontinental Ballistic Missile (ICBM) system, the LGM-30 Minuteman. To meet the Air Force's need for missile nose cone re-entry data, it contracted with Lockheed and Thiokol to develop the multi-stage X-17 flight test vehicle using an XM20 motor developed by the Redstone Division for the first stage and three smaller Thiokol 9-inch diameter Recruit rockets from the Elkton Division as the second stage. The XM20 was another 31-inch rocket motor derived from the Hermes. After reaching an altitude that placed the nose cone test samples above the earth's atmosphere, a third stage consisting of a single Recruit rocket accelerated the test vehicle to a speed simulating ICBM reentry conditions.

With a total of 8,000 pounds of solid propellant in its three stages, the X-17 further proved the utility and reliability of early solid rocket motors. The X-17 program experienced only one failure out of 36 test flights, which was attributed to a lack of sufficient stiffness in the structural design of the missile assembly. The X-17 later provided NASA with valuable data for the design of the Mercury space capsule, as well as data for the Air Force's Thor and Atlas ICBMs. In addition, four of the X-17 units were provided to the Navy and Lockheed in 1956 to use in obtaining data for Polaris, the Navy's first-generation Submarine-Launched Ballistic Missile (SLBM). The Polaris Test Vehicle (PTV) based on X-17 was used to test the system's first thrust termination system and a jet-vane guidance steering system. In yet another application, three ship-launched modified X-17A vehicles carried nuclear warheads into the upper atmosphere over the South Atlantic Ocean in 1958 as part of the Operation Argus high altitude nuclear testing program, which was not fully declassified until 1982.[12]

From the late 1950s through the 1960s, a robust R&D budget environment and dynamic solid rocket industrial base resulted in rapid improvements in composite solid propellants. The emergence of synthetic liquid polybutadiene for use in solid propellants would be an enabling technology for decades to come. In 1954, the Redstone Division began investigating the first generation polybutadiene-acrylic acid (PBAA) binder for use in solid rocket propellants and, by 1956, began to add small amounts of aluminum particles to PBAA propellants to suppress acoustic resonance and increase impulse. Soon, Thiokol's promising PBAA propellants, which it designated as the "HA" series (for Hydrocarbon "A"), became the baseline for several rocket motors, most notably the "Big B" demonstration motor. In 1957, Redstone successfully tested a 54-inch diameter Big B motor containing 12,000 pounds of PBAA propellant, followed in 1958 by the successful firing of a 72-inch Big B containing more than 20,000 pounds of PBAA propellant, the first and largest SRM of its size to be tested up to that date.[13] These initial Big B tests demonstrated the feasibility of large SRMs for ballistic missile propulsion applications and provided a technological foundation for Thiokol's future pursuit of the Minuteman ICBM solid rocket stages.

To improve the tear strength of PBAA propellants, a small amount of acrylonitrile was later added and Thiokol's "HB" series of polybutadiene-acrylic acid-acrylonitrile (PBAN) composite propellants was born. Although PBAN propellants eventually gained wide use in ballistic missile stages and launch vehicle boosters, most notably in Minuteman, Titan, and the Space Shuttle boosters, their mechanical property limitations at very hot and cold temperatures and modest solids loading capability were not particularly attractive for the high performance tactical and interceptor applications that were being pursued by the Redstone Division. Thiokol chemists would soon begin looking at yet another polybutadiene polymer, carboxyl-terminated polybutadiene, or CTPB.

While the Redstone Division served as the center of mass for Thiokol's solid rocket business throughout the 1950s, it did not possess sufficient acreage or remoteness desired for the development and manufacture of extremely large solid rocket motors for ballistic missiles. In 1956, Thiokol purchased 11,000 acres of land in northern Utah near Promontory Point to build a large solid rocket plant to compete with Hercules and Aerojet for a share of the solid-fueled ICBM business. The first buildings of the new Utah Division were occupied in 1957 and, like the reactivation of the Elkton and Longhorn facilities earlier in the decade, Huntsville contributed valuable experience and personnel resources to seed the new Utah site. Following the Big B static test at Redstone in 1958, the program and its assets were transferred to Utah to support Thiokol's large motor programs.

The Redstone Division did have another small, but very important role in the Minuteman program: it designed and developed the safe-and-arm device for the 66-inch diameter M55/TU-122 first stage motor that was built by Thiokol in Utah. Redstone's safe-and-arm design incorporated previously unheard of features such as sealing the device with nitrogen to protect electrical contacts, a stainless steel housing with an integral built-in electric motor, and other elements that made it a model for future safe-and-arm devices. In fact, the Air Force directed that the Thiokol safe-and-arm design be used in the Minuteman second and third stages built by Aerojet and Hercules, respectively. The Minuteman safe-and-arm units remained functional more than 50 years after their original manufacture.

IV. Expansion into Space Programs and Interceptor Missiles.

In 1958, Thiokol received a major contract (DA-01-021-506-ORD-698) from the Army Rocket and Guided Missile Agency (ARGMA) and NASA for the development, manufacturing, and delivery of improved, high performance 31-inch XM33-type rocket motors. The scope of this two-year contract included XM33 motor design modifications, PBAA propellant development, igniter system development, and motor loading and static testing, as well as a task to modify Thiokol's 15-inch diameter TX-77 rocket motor for use as a sounding rocket. The TX-77 was originally developed as a booster for the X7 and Q5 target drones. The NASA modification required removing the baseline canted nozzle and replacing it with a straight, in-line nozzle for use in research rockets.

The ARGMA/NASA contract was the genesis for Thiokol's Castor motor series and the first flights of a rocket motor containing the new PBAA propellant. Table 1 lists the 31-inch motor variations that were developed and tested during the program. All of the XM33 motors were loaded with TP-H8038 PBAA propellant except for the Pollux, which used legacy TP-E8081 polysulfide propellant as an interim measure until the newer polybutadiene formulation became available for the Castor motor variations. Due to Thiokol's unusually early success in the program, NASA reduced the total number of development static tests from 11 to five and the number of Pre-Flight

Rating Test (PFRT) static firings from eight to six. This landmark contract produced an impressive series of XM33 motor designs and capability for the Army, NASA, and other customers.

The Huntsville Division's material contributions to NASA's manned space program began with the first successful flight of the Little Joe test vehicle at Wallops Island, Virginia on October 4, 1959, which was propelled by a cluster of four XM33E4 Pollux motors and four Elkton Recruit motors.[14] As shown in Table 2, other configurations of the Little Joe used either two Pollux or four XM33E2 Castor (later known as Castor I) motors. Completion of the first Little Joe test program provided essential data for the design of the Project Mercury space capsule that would be used in America's first manned suborbital flight in 1961.

Table 1. Castor Motors Developed Under the ARGMA/NASA Contract.

Common Name	Army Model No.	Thiokol Designations	Application	No. Made	No. Static Tested	No. Deli-vered	No. Flown thru 4/61
Castor	XM33E2	TX33-28, -36	Little Joe Test Vehicle	24	6	17	12
Castor	XM33E3	TX33-20, -33, -34, and -37	Mach 20 Test Vehicle	12	3	3	
Pollux	XM33E4	TX33-24 , -29, and -38	Early Testing of Little Joe	12	2	10	10
Castor	XM33E5	TX33-31, -32, and -35	Scout 2nd Stage	8	2	6	4
	XM33E6		Project Shotput			4*	
			TOTAL	**56**	**13**	**40**	**26**

*replaced canted nozzle with straight nozzle on XM33 motors built under a previous contract.

Table 2. Little Joe Flight Test Record.

Designation	Launch Date	Boost Propulsion
LJ-6	August 21, 1959	4× Pollux
LJ-1A	October 4, 1959	2× Pollux
LJ-2	December 4, 1959	4× Castor
LJ-1B	January 21, 1960	2× Pollux
LJ-5	November 8, 1960	2× Pollux
LJ-5A	March 18, 1961	4× Castor
LJ-5b	April 28, 1961	4× Castor

As Castor I gained in popularity, its use expanded to other applications. At about the same time as the Little Joe test project, NASA also began the development of a new, in-line four stage solid launch vehicle called the Scout, which initially used a Castor I for its second stage. The NASA Scout was first launched from Wallops Island, Virginia on July 1, 1960, marking the beginning of a highly successful three-decade run of cost-effectively launching small payloads into low Earth orbit. The Air Force also had a version of the vehicle called the Blue Scout. In 1963, an XM33E5 Castor was successfully static tested in a vacuum chamber, simulating more than 100,000 feet in altitude and setting a new record for static testing a large solid rocket motor under vacuum conditions. In the 1970s, Castor I was also used as propulsion for Sandia National Laboratory's Strypi series of scientific rockets. In 1964-65, under contract to NASA, Redstone developed an upgraded Castor II containing CTPB propellant to replace the Castor I as the Scout's second stage.[15] However, both motors remained in production into the 1990s, setting a number of records along the way. In 1976, an 82-month old Castor II was successfully flown on Scout, and a 132-month old Castor I was successfully used in a Strypi rocket. On June 2, 1979, NASA successfully launched its 100th Scout vehicle from Wallops Island.[16] In 1990, Thiokol reported that a Castor I was successfully fired after 21 years of storage.[17] The long-running and reliable Scout concluded its 34-year record of service with its final launch on May 8, 1994, using a Castor II second stage made by the Huntsville Division.

The Trailblazer I was a suborbital, three-stage vehicle that was used by NASA and the Air Force for scientific missions requiring high altitude probes and high velocity re-entry. The first stage was a Castor I with two Recruit strap-on motors, and the second stage was a TX-77 motor also known as "Lance." Various upper stages were used with the Trailblazer I, which was launched 15 times from Wallops Island between 1959 and 1963. The TX-77 was also the second Stage for the more powerful Trailblazer II, which was launched 11 times between 1962 and 1973.

In yet another application, the Castor I motor became the first strap-on solid rocket motor to be used for low altitude thrust augmentation on a liquid engine-powered orbital space launch vehicle. In 1958, the U.S. Air Force and NASA began mating upper stage engines to the main engine of the Thor Intermediate Range Ballistic Missile (IRBM) to launch satellites into space. By 1963, increasing payload requirements necessitated the use of auxiliary boost propulsion to attain desired liftoff thrust levels. The solution, considered novel for such a scale at that time, was the attachment of three Castor I motors to the main Thor booster structure at 120° intervals. The addition of the Castors nearly doubled Thor's liftoff thrust rating.

On February 28, 1963, the first launch of a Thrust Augmented Thor (TAT)-Agena D with three Castor I strap-ons took place from Vandenberg AFB, California (Figure 7). Unfortunately, the vehicle suffered a guidance failure later in the flight, veered off course, and was destroyed by the range safety officer. After another failure on March 18, 1963 (due to a second stage malfunction), the TAT-AD went on to record success in 59 of 63 launch attempts. The Thrust Augmented Thor eventually evolved into the Delta family of launch vehicles and the Castor I motor was the progenitor of a generation of monolithic strap-on solid motors that have been used in some variant of almost every major U.S. space launch vehicle to date, including Titan, Atlas, and the Space Shuttle.[18]

Figure 7. First TAT-AD Launch with three Castor I strap-ons in 1963.

The year 1964 was a workhouse year for the Huntsville Division's XM-33/Castor motor series, culminating in 92 successful flight tests and two static tests. The 1964 launch record included eight successful Scout launches using a Thiokol XM33 second stage and the first overland launches of the original Athena vehicle. A total of 14 motors were flight tested in November 1964 alone. Huntsville also implemented the first vacuum casting of XM33 motors, virtually ensuring void-free propellant and greatly decreasing the motor rejection rate.[19]

As Thiokol's solid rocket business surged in the 1950s, employment at Huntsville surpassed 1,600 people by the end of 1958. Following the qualification of the TX-30 second stage (sustainer) motor for the Nike Hercules anti-aircraft missile, which was developed at Redstone between 1956 and 1958 and later transitioned to Longhorn for production, contracts for the development of the Bomarc B booster, the three-stage Nike Zeus interceptor, and the two-stage Pershing tactical missile all came in close succession, driving Redstone Division employment to its historical peak of 2,100 people in 1959.

Figure 8. First Bomarc B Launch in 1960.

With the advent of high thrust solid rocket motors in the early 1950s, the Air Force sought to replace the liquid-fueled booster of the Cold War-era Bomarc "A" long-range surface-to-air nuclear interceptor missile with a solid rocket booster to more rapidly accelerate the missile to the takeover speed required for ramjet engine operation. Following the award of the Bomarc B JATO (or booster) contract in 1958, the Redstone Division quickly developed the 35-inch motor in time for the first launch of the Bomarc B test missile from Cape Canaveral in May 1959 (Figure 8). Thiokol's development of the Bomarc B Booster further advanced the state-of-the-art in aluminized propellants, jetevators, and blast tube technology. The first 36 Bomarc B missiles were flight tested without a single failure of the Thiokol booster motor.[20] Production of the booster motor was accomplished at the Thiokol's Utah Division, and Bomarc B missiles were deployed in the U.S. from 1961 to 1972 and in Canada from 1962 to 1972.

In 1957, the Redstone Division began to develop Thiokol's third generation "HC" series of hydrocarbon propellants based on carboxyl-terminated polybutadiene polymer. CTPB offered the promise of higher solids loadings for greater performance and better propellant mechanical properties over a greater temperature range than PBAA or PBAN. Thiokol's Chemical Division began supplying research quantities of CTPB polymer (initially designated ZL-434, then HC-434) to the company's rocket divisions in the fall of 1959, followed by pilot plant quantities in January 1960. The improved low-temperature performance of an HC type propellant was successfully demonstrated in large motor tests at Redstone in December 1961.

The Nike Zeus program was significant for both the United States and Thiokol. It was the nation's first anti-ballistic missile interceptor, and the Redstone Division became the exclusive developer of all three solid rocket stages, including the unique TX-239 spherical third stage. The third stage's canard steering and its "jethead" exhaust system, which discharged through four individually rotating blast tube nozzles,[21] are among the most innovative accomplishments in solid rocketry.

Demanding interceptor performance requirements drove the Nike Zeus program to conduct an intense propellant evaluation phase that resulted in 1,000 subscale and full scale motor firings in 1961 alone. After considering novel propellant solutions from other manufacturers at the time, the initial development of the Nike Zeus first and second stages began with polysulfide propellant, but transitioned to CTPB in the first stage and PBAA in the second stage for the final tactical motor design. The third stage was also loaded with PBAA propellant. To achieve the high propellant burning rate necessary to meet the performance requirements, Thiokol incorporated ferrocene, an iron-based organometallic burning rate catalyst, into the Nike Zeus propellants. Nike Zeus was the largest rocket developed during that decade and had larger payload capacity and range than its predecessor, the Nike Hercules. Nike Zeus was later replaced by the three-stage Spartan interceptor which would become another Huntsville Division propulsion product.

In 1958, Thiokol Redstone began work on a large two-stage, ground-mobile surface-to-surface Army tactical missile system known as Pershing. The Martin Company of Orlando, Florida was the prime contractor. Early Pershing development motors used an aluminized polysulfide propellant, which was later replaced with an aluminized PBAA propellant for a 7% gain in propellant specific impulse. A model of the 40-inch diameter Pershing first stage is shown Figure 9. Pershing featured a number of technological advancements for solid rocket motors, including jet vane thrust vector control and head-end ports for second stage thrust reversal. Hermes motors loaded with PBAA propellant were used as the test bed for the jet vane material evaluation. Pershing also marked the first use of an exploding bridgewire (EBW) initiator for ignition of the rocket motor. Thiokol's pioneering work on EBWs and through-bulkhead initiators (TBIs) in the 1960s greatly increased rocket motor ignition safety and reliability. On January 26, 1961, the Army conducted a successful test flight of the Pershing missile from Cape Canaveral, the same week as back-to-back test firings of the tactical Bomarc B missile at the Eglin AFB, Florida test range.[22] That same year, production of the Pershing stages began at Longhorn.

Figure 9. Model of Pershing First Stage.

With the exponential growth of its solid rocket business in the late 1950s, it became necessary for Thiokol to expand and improve its physical capabilities for research and development, manufacturing, and testing. In 1958, a $3.6 million expansion of Thiokol facilities on Redstone Arsenal was approved by the Army. Over the course of the next year, nine new buildings with 100,000 square feet of floor space were constructed on an additional 450 acres of arsenal land which was assigned to Thiokol by the Army. The new GOCO facilities included three administrative and technical buildings totaling 72,000 square feet, two propellant mixing facilities (200-gallon horizontal mixer and 300-gallon vertical mixer, respectively), a casting facility, a rocket motor preparation and assembly building, a case preparation building, and a radiographic inspection laboratory. Three more buildings were later added to the expansion campaign, bringing the total investment to $5.0 million. On May 7, 1960, Thiokol and Army officials hosted a ribbon-cutting ceremony, open house, and tours of selected new facilities of the Redstone Division. In 1961, the Research Laboratory was expanded by 1,200 square feet.[23]

The LIM-49A Spartan was the fourth generation ground-launched anti-ballistic missile system developed by the United States during the Cold War, following the Nike Ajax, Nike Hercules, and Nike Zeus. The Huntsville Division began the development of Spartan propulsion in 1965. The three-stage Spartan missile was designed as a direct upgrade of the Nike Zeus, increasing the diameter of the second stage from 36 to 43 inches and using a new, higher energy CTPB propellant in the first and second stages to increase the range over the Nike Zeus model by 200 miles. The new Spartan propellant was designated TP-H7034. Although the first two stages of Spartan were new, the Thiokol TX-239 spherical third stage developed for Nike Zeus was retained as the Spartan third stage.

The Spartan propellant contained a new burning rate catalyst developed by Huntsville called "Plastiscat-IV" or "P4" for short. Up until this time, the use of ferrocene in solid propellant proved somewhat problematic—its high vapor pressure limited the amount of the crystalline red powder that could be used in the formulation, and the propellant burning rate characteristics tended to change during long periods of motor storage due to ferrocene evaporation. Thiokol chemists solved this problem by developing a liquid ferrocene derivative that functioned both as a plasticizer and a catalyst, hence the name "Plastiscat," which was patented and trademarked by the company. The numeric suffix simply indicated that Plastiscat-IV was the fourth one made in the series (and the first one that worked).[24]

Spartan development and production took place at the Huntsville Division between 1965 and 1975. Spartan motor static firings are pictured in Figure 10, Figure 11, and Figure 12. Spartan became part of the short-lived Safeguard defense system that was deployed for less than a year before being deactivated in early 1976. The short-range, high-speed component of Safeguard was the two-stage Sprint interceptor missile. The ambitious Sprint program further extended the state-of-the-art in high energy solid propellants, achieving incredibly high burning rates that have since been unmatched in a fielded U.S system. Although Thiokol received one of the early Sprint propulsion study contracts in 1963,[25] it lost the eventual production contract to Hercules.

Figure 10. Spartan First Stage firing.

Figure 11. Spartan Second Stage firing.

Figure 12. Spartan Third Stage firing.

Following the deactivation of the Safeguard anti-ballistic missile system in 1976, the Army eventually disposed of decommissioned second stage Spartan motors by static firing at Redstone Arsenal. However, 46 Spartan first stage motors were placed into bunker storage at Anniston Army Depot, Alabama and Red River Army Depot, Texas, remaining there for the next three decades until becoming a safety concern due to deterioration of the propellant grain.

On June 8, 2007, following four years of intense planning and preparation led by a team of personnel from the Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) at Redstone Arsenal, the safe disposal of the first of 22 motors at Anniston was accomplished.[26] The development of a risk mitigation plan to facilitate a process for disposing of the Spartan rocket motors required an initial safety and condition assessment of the propellant grain. The AMRDEC team visually inspected the propellant in a random sample of motors from both storage sites and found the grains to be in a "slumped" condition (i.e., collapsed on itself) due to long term storage in the same horizontal position and likely deterioration of the propellant-to-case bond over time.[27] As shown in Figure 13, the grain slumping condition created significant areas of surface-to-surface contact, prompting safety concerns over possible electrostatic or friction-induced initiation from overland transport vibration.

The Spartan motors were declared unsafe to move off-site, so the Army team devised a desensitization technique whereby water was pumped into the propellant cavity and sealed by means of an aft closure assembly to secure the motor for local transport to a burning pit on the Government installation, where linear shaped charges affixed to the case exterior were initiated to sever the case and ignite the propellant for a safe, open air burn of the propellant in each motor (Figure 14). The safe disposal of the Spartan motors stored at Anniston was completed in 2007 and at Red River in 2009.

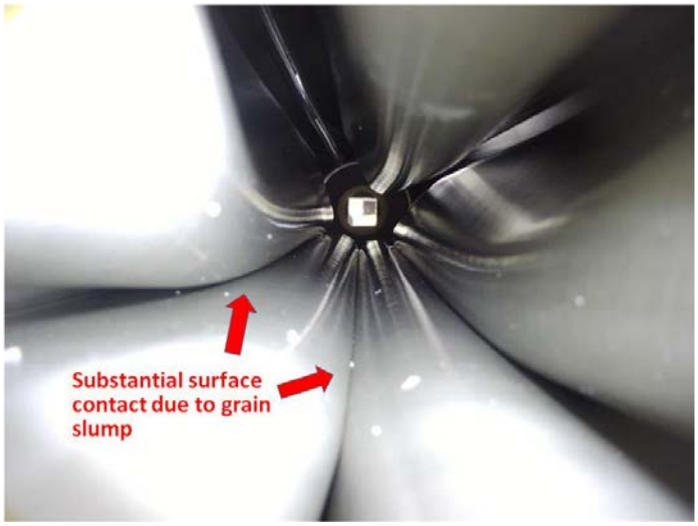

Figure 13. Grain slumping condition in Spartan motors.

Figure 14. Spartan motor after burn.

Among the Huntsville Division's last work related to interceptor missiles was the Solid Propellant Booster Development (SPBD) program, which was awarded to Thiokol in 1989 by the U.S. Army Strategic Defense Command (ASDC). The Army selected Thiokol based largely on its 30-year history of participation in interceptor programs including Nike Zeus, Spartan, Sprint, and Sentry, which produced a succession of technological advances in booster motor technology, especially with high-energy, high burning rate propellants. The Sentry program's Interim Propulsion Test Vehicle (IPTV) motor, developed and tested at the Huntsville Division in the early 1980s, was the most advanced motor of its type built to date and provided the SPBD program with a point of departure for comparing overall motor and component performance.

The primary objectives of the SPBD program were to further develop and demonstrate high-performance, non-detonable Class 1.3 propellants in production scale mixes; an advanced, tapered graphite epoxy composite case; low-cost, lightweight polyacrylonitrile (PAN)-based graphite fiber/phenolic nozzle; compatible case liner and insulation materials; and a laser ignition system. The test bed for the integration and demonstration of these technologies was the Huntsville Division's TX-868 motor. The TX-868 contained TP-H8316 propellant, which was an 88% solids formulation containing 68% ammonium perchlorate, 20% aluminum, 7% hydroxyl-terminated polybutadiene (HTPB) binder, and 5% Catocene burning rate catalyst.[28]

In 1992, the first SPBD motor exploded during static testing due to an undetected propellant/case unbond, causing extensive damage to the test facility (Bldg. 7620). A second Thiokol TX-868 was later fired successfully at the Army's Redstone Technical Test Center (RTTC). For the second test, the nozzle throat diameter was increased to provide a longer motor burn at lower pressure. Unfortunately, due to appropriation delays, the SPBD program was cancelled in 1993 and several other TX-868 motors built by Thiokol were eventually destroyed.

As the U.S. raced toward human spaceflight with the October 1958 establishment of NASA as the successor to the National Advisory Committee on Aeronautics (NACA), the agency evaluated both liquid and solid propulsion solutions for its future lunar exploration space launch vehicle, and Thiokol secured its share of early big booster studies. In 1960, NASA awarded the Redstone Division a six-month contract to conduct preliminary design studies "for a super-size solid fuel booster for a vehicle weighing seven million pounds, with booster thrust levels two to three times the vehicle weight."[29] Thiokol's notional solution for the first stage was a cluster of seven 168-inch diameter by 63-foot long rocket motors, each producing 2.4 million pounds of thrust with a burn time of 82 seconds.[30] Thiokol's solid rocket cluster design was part of NASA's Nova space launch vehicle concept, which eventually yielded to the liquid-fueled Saturn launch vehicle series for the race to the Moon.

In April 1963, Thiokol got into the large solid rocket space booster business in a big way by winning one of two competing Air Force contracts to build and test a prototype 156-inch diameter motor and an objective 260-inch diameter solid rocket motor.[31] Government oversight of the 260-inch motor program was later transferred to NASA. Building and testing such mammoth motors required new facilities and a coastal location that would permit the transport of delivery units by ocean barge to Cape Canaveral. To meet this need, Thiokol purchased land near Brunswick, Georgia to build its Space Booster Plant, while Aerojet built its facility near Homestead, Florida. Once again, the Redstone Division supplied key personnel and experience for this new Thiokol plant. In fact, Thiokol administratively combined the Redstone and Brunswick plants under a single management structure called the Alpha Division. For the next two years, the former Redstone Division was known as the Huntsville Plant of the Alpha Division.

In February 1965, the Brunswick plant achieved a big booster milestone with a spectacular nozzle up firing of a 156-inch motor from an in-ground vertical silo that served both as the cast/cure pit and the test cell. The 156-inch motor produced more than 3 million pounds of thrust, the most powerful motor tested up until that time, and was ignited with a unique aft end pyrogen system that was designed and built at the Huntsville plant. The 26-inch diameter TX-359 pyrogen igniter, based on Huntsville's Matador booster, was mounted in a rail carriage assembly, retained by an explosive bolt assembly until after ignition, and then expelled by the exhaust of the 156-inch motor.

Thiokol's Alpha Division structure lasted for only two years, when it was separated into the Space Booster Division and the Huntsville Division. The latter name would last for the next 32 years, while the former was short lived. Even though the Space Booster Division successfully demonstrated the 156-inch motor, NASA cancelled Thiokol's big booster contract following the April 1965 low pressure hydrotest failure of the 260-inch maraging steel rocket motor case at the manufacturer's location.[32] Following the cancellation of the booster contract, Thiokol converted the Georgia plant to other uses. One 420-gallon Baker-Perkins vertical blade propellant mixer was moved from Georgia to Huntsville and was placed back into service in 1981 as the "G" mixer in Building 7382.

The Huntsville Division also had a hand in the manned Apollo programs of the 1960s and 1970s. Although overshadowed by the large, liquid-fueled main engines, each Saturn V launch vehicle was equipped with 15 smaller, Thiokol-built rocket motors for performing auxiliary propulsion functions. While Thiokol's Elkton Division provided the eight TE-M-424-6 first stage retro-rockets, one TE-M-80 tower jettison motor, and four TE-M-29-4 Saturn Recruit second stage retro-rockets, the Huntsville Division provided the two TX-280 third stage ullage motors, which were fired just prior to ignition of the S-IV third state engine to force the liquid fuel into position at the base of the fuel tanks in order to counteract the effects of zero gravity and prevent cavitation of the fuel pump system. Other versions of the Saturn launch vehicle used either three or four TX-280 motors.

The development of the TX-280 ullage motor was accomplished with a 13 motor qualification program that included exposure to temperature cycling, vibration, shock, thermal aging, and temperature gradient. At least two TX-280 motors were static fired in an altitude chamber at the Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee. Qualification was completed in 1965, and the Thiokol rocket motors performed with 100% success in all 13 launches of the Saturn V vehicle.[33]

In the 1960s, the Huntsville Division was also an industry trailblazer in the demonstration of novel manufacturing techniques for solid rocket motors. One example is case-on-propellant (COP) manufacturing technology, in which a high strength fiber/resin matrix is wound over a live propellant grain and cured to produce a loaded composite rocket motor case. Thiokol investigated filament wound COP manufacturing technology at Redstone as early as 1960. In 1964, Thiokol announced the development of a filament winding facility for the manufacture of high-strength, lightweight "plastic" rocket motor cases at the Huntsville Division, including the establishment of COP manufacturing capability.[34] The company contracted for the design and fabrication of a filament winding machine capable of manufacturing COP motors up to 60 inches in diameter and 216 inches in length.[35] This led to a contract from the U.S. Army Missile Command (MICOM) for the High Performance Air Defense Propulsion System (HiPADS) program which culminated in the successful static test of a 12-inch diameter TX-417 subscale COP motor (Figure 15) and a full-scale 20-inch diameter TX-377 motor with a propellant mass fraction in excess of 91% in 1965.

These results made COP technology a candidate for insertion into the first-generation Patriot surface-to-air missile (first designated AADS-70 and initially known as SAM-D). To address concerns about the ability of composite-cased rocket motors to withstand the Army field environment, MICOM awarded Thiokol a contract to build additional TX-417 motors for environmental testing. Eight motors were successfully static tested after being

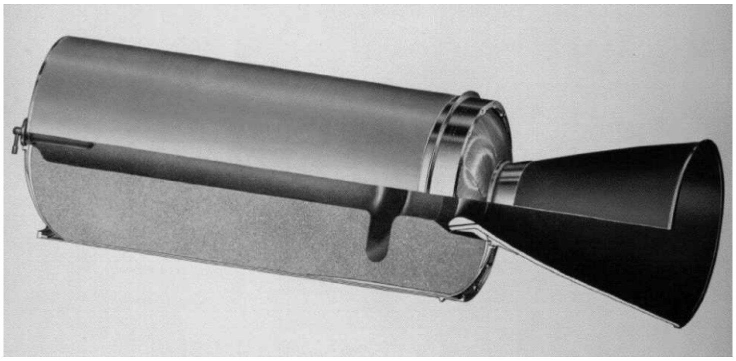

Figure 15. TX-417 HiPADs Subscale Demonstration Motor.

subjected to rigorous environmental conditioning, three were hydroburst (exceeding design ultimate) after similar exposure, and three others were provided for additional evaluation. Thiokol's second COP motor program successfully demonstrated the reproducibility and cost effectiveness of this novel motor manufacturing technique, as well as its ability to withstand the extremes of the Army environment. Despite the success of the COP motor tests, Patriot remained on the path to a conventional metal motor case. Lack of near-term interest in COP for tactical motors and the need for floor space at the Huntsville Division led Thiokol to move the winding machine out of Building 7382 and transfer it to Utah. Thiokol's Elkton Division eventually revived the COP technique in the early 1990s for the manufacture of advanced, high-performance upper stages, including the development and production of the Mk 136 Third Stage Rocket Motor (TSRM) for Standard Missile-2 Block IV and Standard Missile-3.

As the U.S. launch vehicle market continued to develop and expand in the 1960s, Thiokol leveraged its successful Castor I and II motor designs for the next generation Castor IV (Figure 16). In 1969, the Huntsville Division began the development of the Castor IV motor with in-line nozzle as first stage propulsion for the Athena H launch vehicle of the U.S. Department of Defense's Abres program. The Castor IV was 40 inches in diameter and used the same PBAA propellant as the Castor I. The propellant grain was a conventional center perforated design with six longitudinal slots. The Castor IV first flew on Athena in 1971, and was later adapted and used as a strap-on application for the Delta 3900 series vehicle. Castor IV strap-ons successfully boosted 36 of 37 Delta 3900 series vehicles between 1976 and 1989. In 1972, Thiokol static tested an extended length version of the Castor II motor, the Castor II-X, as a potential strap-on for Delta, but it was bypassed in favor of the higher performance Castor IV.

In 1983, the Huntsville Division developed the upgraded Castor IVA using essentially the same hardware as Castor IV, but loading it with the higher performance TP-H8299 propellant for a 12% gain in motor performance. The Castor IVA was qualified for flight in 1987, and Thiokol manufactured several different versions for various core and strap-on applications, including in-line nozzle, canted nozzle, and ground- and air-ignited versions with different nozzle expansion ratios. The Castor IVA debuted as a strap-on in the first launch of the Atlas IIAS vehicle on December 15, 1993. Four Castor IVA's (2 ground start + 2 air start) were used with the Atlas IIAS. For additional utility, the Huntsville Division developed the Castor IVB with movable nozzle in 1990, swapping the Castor IVA's fixed nozzle for a flexible-seal (flexseal) movable nozzle with hydraulic blowdown thrust vector control (TVC) capable of 6° of vectoring capability.

From 1990 to 1992, Huntsville developed its last Castor motor design, the Castor IVA-XL, as a potential performance upgrade for the Delta launch vehicle. The Castor IVA-XL was nearly 8 feet longer and provided 30% more performance than the Castor IVA/B.[36] It also had ground-ignited and altitude-ignited versions. Thiokol completed the qualification of the Castor IVA-XL in 1993 with the last of three successful static firings at Redstone Arsenal. Unfortunately, the Castor IVA-XL market did not materialize for Delta due in large part to McDonnell Douglas' selection of the competing 40-inch Graphite Epoxy Motor (GEM) developed by Hercules, therefore Thiokol began to pursue the

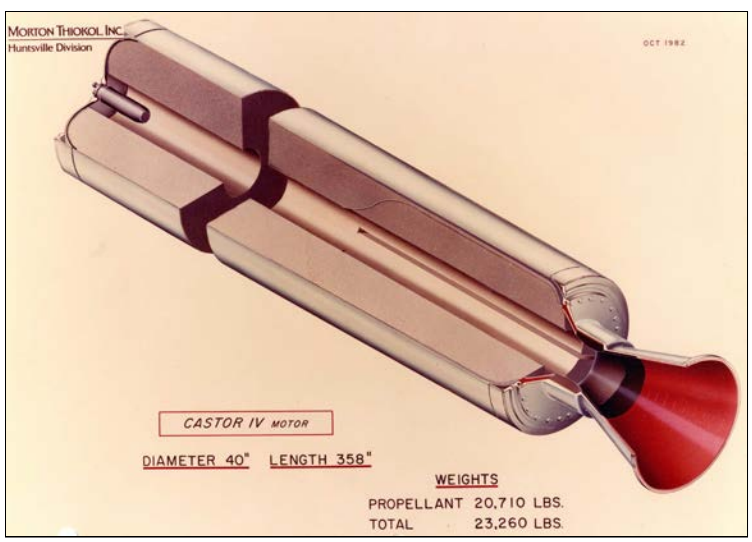

Figure 16. TX-526 Castor IV motor.

international market for the extended length motor. Production of the Castor IVA-XL, along with the Castor IVA and IVB, was transitioned to Thiokol's Wasatch Division in Utah in 1995.

The growth and evolution of the Huntsville-legacy Castor motors are illustrated in Figure 17, and their manufacturing, test, and flight history is presented in Table 3.

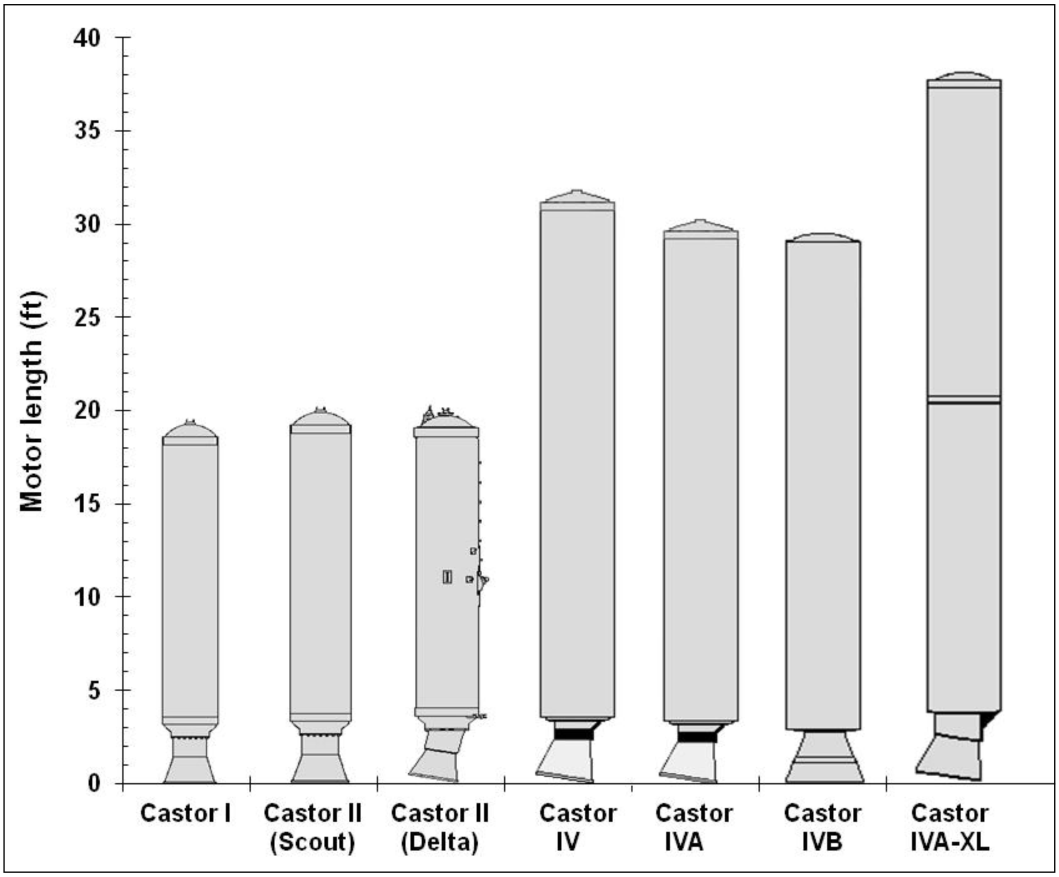

Figure 17. Castor Motor Evolution.

Table 3. Huntsville-Manufactured Castor Motor History.[37]

Model	First Loading	IOC	No. Loaded	No. Static Tested	No. Flown (as of 1996)
Castor I	Mar 14, 1957	Oct 1959	663	34	576
Castor II/IIA	Feb 13, 1964	Jun 1965	950	24	926
Castor IIX	May 18, 1972	--	1	1	0
Castor IV	Mar 8, 1969	Aug 1970	400	8	360
Castor IVA	Jan 26, 1983	1987	278	6	272
Castor IVB	1989	1990	16	6	10
Castor IVA-XL	1992	1993	3	3	0

V. Contemporary Tactical Motor Development and Production

The decade of the 1970s brought about the next significant advance in composite propellants: the maturation and introduction of formulations based on HTPB binder. HTPB propellants offered the promise of increased performance via higher solids loading than CTPB and attractive mechanical properties over the wide temperature ranges required for tactical rocket motor storage and operations. Huntsville developed an 88% solids HTPB propellant in 1971. By the 1980s, HTPB supplanted CTPB and other binders as the formulation of choice for many tactical missile systems.[38]

In 1970, Thiokol established a production plant at the Huntsville Division, providing the company with the capacity to manufacture tactical class rocket motors in larger quantities and positioning it for growth in the market. The production plant was organized as a separate cost center from the research and development plant, enabling Thiokol to more competitively price its mass-produced rocket motors. The production plant was mostly located in what was known as "Area 2" or "Line 2," and its administrative headquarters was located in Building 7728, the former location of the Rocket Engineering Department in the 1950s. The production plant first manufactured TX-481 "smoky" Maverick motors and performed all-up-round (AUR) assembly of 7,000 TOW missiles in the 1970s. MT-4A, an aziridine bonding agent developed by the Army and used in Patriot propellant, was scaled to production by Thiokol and manufactured in the 50-gallon reactor in Building 7722.

The production plant was closed down for a short time between the completion of smoky Maverick production in 1978 and the start of reduced smoke Maverick (TX-633) production in 1980. Also in 1980, Building 7625 was modernized and customized for the start of Patriot (TX-486) production, exclusively housing that operation through 1996. The production plant was merged back into the main plant at the end of 1981, just as reduced smoke Hellfire (TX-657) motor production was starting. A circa 1985 diagram of the "North Plant," identifying the buildings which housed the Huntsville Division's composite propellant manufacturing, rocket motor assembly, research laboratories, shops, and administrative and engineering offices, is shown in Figure 18.

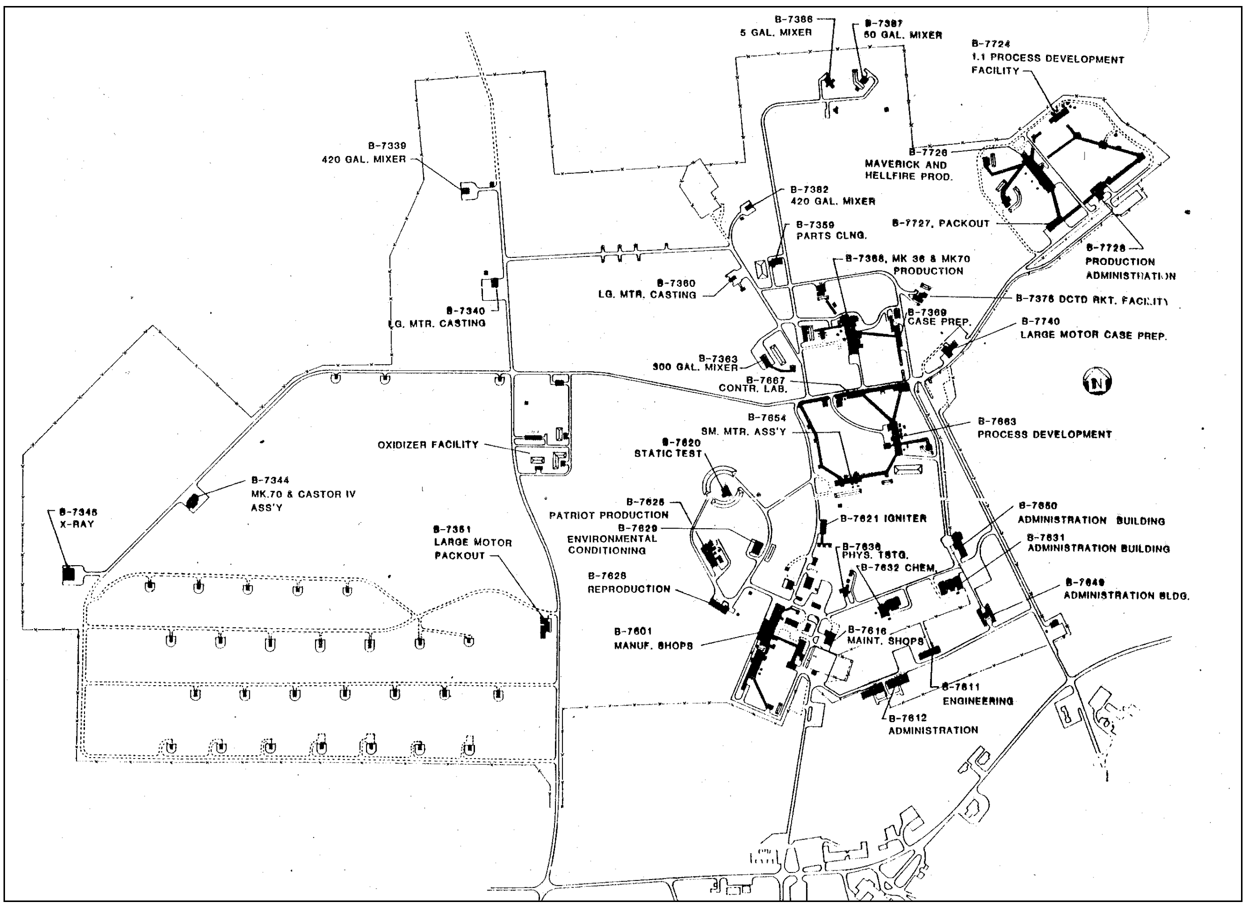

Figure 18. Thiokol North (Main) Plant layout circa 1985.

A circa 1981 aerial view of the Huntsville plant is presented in Figure 19. In the foreground (left to right) are Buildings 7613, 7612, and 7611, which were built by the Army as part of the 1960 facility expansion. Buildings 7613 and 7612 initially housed Thiokol's program management, project engineering, and other plant administrative functions before being turned back over to the Army in 1969 and 1983, respectively. Some of these functions moved to the new Thiokol-built Building 7649 in 1982. Thiokol's Engineering Department remained in Building

7611 until the plant closed in 1996. The original 1950s-era buildings appear just to the right of center in the photograph.

Figure 19. Aerial view of Huntsville Division Main Plant looking north, circa 1981.

The AGM-65 Maverick was the first general purpose fire-and-forget tactical air-to-ground missile for defeating hardened targets such as bunkers, bridges, radar or missile sites, and ships. Designed to replace the long-standing Falcon missile, the Maverick was developed in the late 1960s, first flown in 1969, qualified in 1971, and placed into service by the U.S. Air Force in 1972. Propulsion for the AGM-65A and B versions of the Maverick missile, used solely by the Air Force, was provided by a Thiokol Huntsville-manufactured TX-481/ SR109 smoky rocket motor. Over 27,000 smoky Maverick motors were produced by Thiokol from 1971 through 1980.

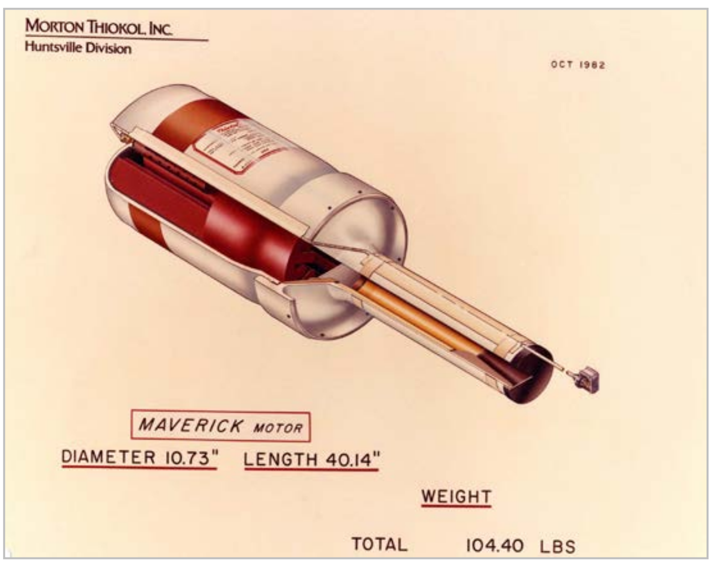

Figure 20. TX-633 Reduced Smoke Maverick motor.

In 1977, the Huntsville Division qualified the SR114 reduced-smoke HTPB motor for the Air Force AGM-65D with imaging infrared (IIR) seeker. It achieved initial operational capability (IOC) in 1986. The SR114 reduced-smoke motor was also used in the USMC's AGM-65E laser-guided Maverick and the Navy's AGM-65F IIR version. The AGM-65F uses the IIR seeker of the AGM-65D in combination with the warhead and propulsion sections of the AGM-65E. It also features a safe/arm device (SAD) for shipboard use.

The TX-633/SR114 Maverick rocket motor, illustrated in Figure 20, featured an aluminum case, blast tube nozzle, and forward-mounted pyrotechnic igniter. It was qualified for storage and operation between -75°F and +175°F, the greatest range for any fielded motor to date. Thiokol produced SR114 Maverick rocket motors at the Huntsville Division until 1995.

In 1976, Thiokol received a contract to develop and qualify a rocket motor for AGM-114 Hellfire missile, which was designed as the primary armament for the Army's AH-64 Apache helicopter. In addition to requirements for greater range and lethality than existing weapons, Hellfire exploited lower cost materials and manufacturing processes. The Thiokol TX-657 reduced smoke Hellfire motor featured an aluminum case with built in wing rails, a one-piece cellulose phenolic nozzle, forward-mounted pyrotechnic igniter, and a net cast propellant grain that required no trimming.[39] Production began in 1982, and Thiokol Huntsville built nearly 9,000 TX-657 motors until it was later replaced with a minimum smoke propellant version.

Thiokol further capitalized on its strong position in reduced smoke HTPB propellants with yet another important development program win in 1978. That year, the Huntsville Division won a competitive Air Force contract to develop a reduced-smoke motor for the AIM-9L Sidewinder. Development was completed in May 1980 with the successful static test of 23 TX-683 rocket motors that had been subjected to various simulated AIM-9L environments including vibration, aeroheat, thermal, and shock. Following the completion of qualification in April 1981, Thiokol began the production of the Mk 36 Mod 9 reduced-smoke Sidewinder motor (Figure 21) under a Navy contract later that year. Thiokol shared production of Sidewinder rocket motors with second-source Hercules/ McGregor through 1995. Huntsville also qualified and produced the nearly identical Mk 112 motor for the Rolling Airframe Missile (RAM), a ship-launched version of Sidewinder.

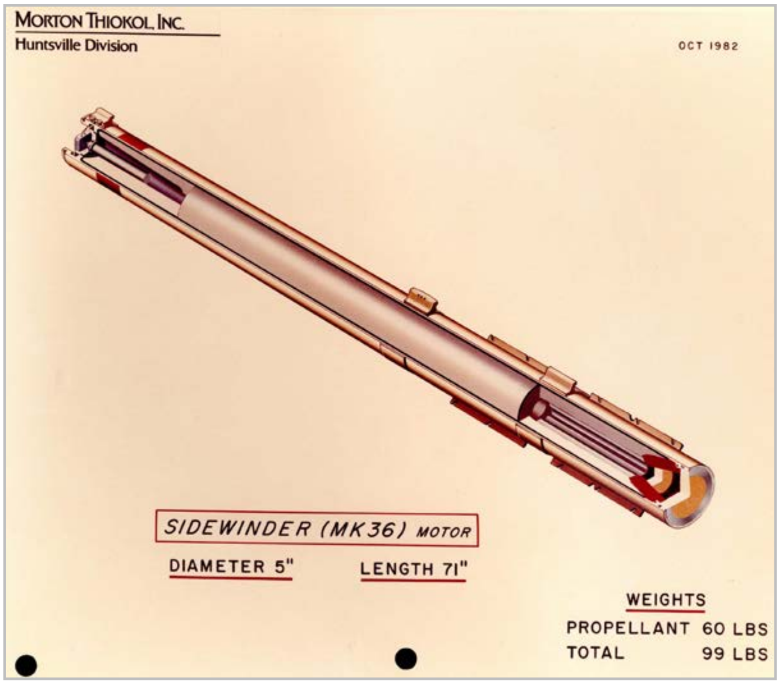

Figure 21. TX-683 Sidewinder motor.

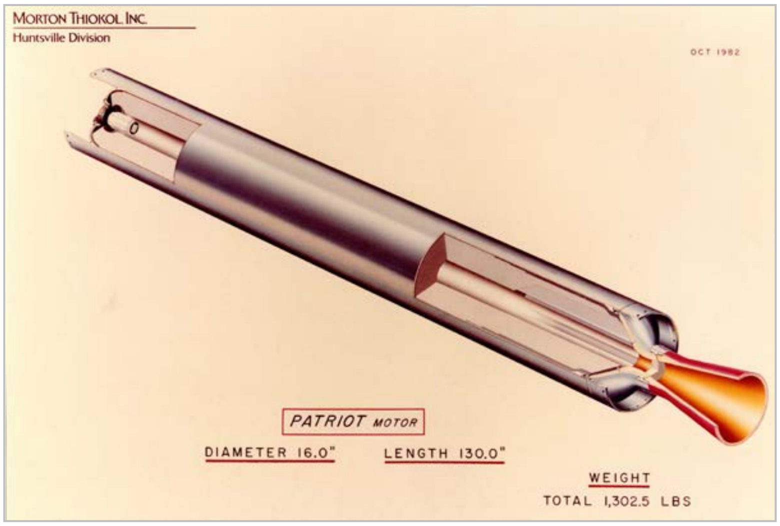

Figure 22. Cutaway Diagram of TX-486 Patriot motor.

The MIM-104 Patriot is an Army surface-to-air tactical weapon system providing primary air defense for troops in the field. It became well known for its use during the Operation Desert Storm in early 1991. Patriot was conceived in 1959 and was originally known as the SAM-D (for Surface-to-Air Missile Development) until 1976. In 1967, the Huntsville Division was selected as the propulsion contractor for the advanced development program, with Raytheon serving as prime contractor and then-Martin Marietta as the missile contractor. In 1972, the same team was selected to carry Patriot through its engineering development and manufacturing phases, at which time Thiokol upgraded the original CTPB propellant to a new, moderately-aluminized HTPB propellant and lower cost nozzle[40] and igniter. As a result, Patriot became the United States' first tactical propulsion system containing HTPB propellant to enter engineering development and production. Thiokol's Patriot motor is illustrated in Figure 22. The first Patriot canister-launch flight test took place in 1974, and rocket motor production commenced at the Huntsville Division in 1981 in a new, dedicated 20,000 square foot facility (Figure 23). Eventually, over 6,500 motors were produced by Thiokol. In 1985, the U.S. Government approved the transfer of Patriot rocket motor technology to Germany and Japan. Thiokol provided the knowledge, information, and technical support necessary for both countries to establish domestic capability for manufacturing Patriot rocket motors.

Huntsville's Patriot motor design and technology served as the basis for several derivative applications. A Patriot modification designated TX-690 was developed as a booster for the Navy's planned ramjet-powered BQM-111A Firebrand target drone built by Teledyne Ryan Aeronautical. Unfortunately, weight and funding challenges forced the cancellation of Firebrand in early 1982, dashing Thiokol's hopes for modest production of 30 to 50 motors per year.[41] Still another version of the Patriot motor served as propulsion for the DARPA/Army Assault Breaker demonstration test series. In the early 1980s, Huntsville designed and demonstrated an air-launched version of the Patriot motor for a Martin Marietta IR&D program. Thiokol Utah used the Patriot as the basis for its commercial TU-758 Malemute motor, which was manufactured in the late 1970s and early 1980s for use as a spin-stabilized stage for sounding rockets sponsored by the Air Force, Sandia National Laboratories, and NASA. Surplus TX-486 Patriot motors have also been used for NASA's Sounding Rocket Program.

Figure 23. Aerial view of Bldg. 7625 Patriot production facility, looking east toward Redstone Arsenal Gate 3 at top.

With the cancellation of the Firebrand program, the Navy eventually established a new requirement for a dedicated anti-ship missile target that became known as the AQM-127 Supersonic Low Altitude Target (SLAT). Under contract to Martin Marietta, the Huntsville Division was once again called upon to design and develop a solid rocket booster for a ramjet-powered target vehicle. The Huntsville Division developed the TX-812 booster between 1983 and 1986, and several dozen units were manufactured to support the vehicle flight test program. Unfortunately, two AQM-127 flight test campaigns in 1987-89 and 1990-91 were largely unsuccessful and the program was terminated. Surplus SLAT boosters were placed into storage at the Naval Air Warfare Center Weapons Division in China Lake, California.

The Huntsville Division developed and qualified the Mk 70 rocket motor for the RIM-67C Standard Missile-2 Block II ER between 1978 and 1980. The Mk 70 motor, illustrated in Figure 24, contained 1,500 pounds of aluminized HTPB propellant. The development/qualification program consisted of 96 motors, which included 22 development and pre-flight rating test (PFRT) units and 28 qualification test motors. Much of the environmental testing was conducted by the U.S. Army Missile Command's Test and Evaluation Laboratory at Redstone Arsenal. In 1980, the first four SM-2 Block II ER flight tests were conducted at White Sands Missile Range and the first at-sea flights of four missiles were launched from the USS Luce.[42]

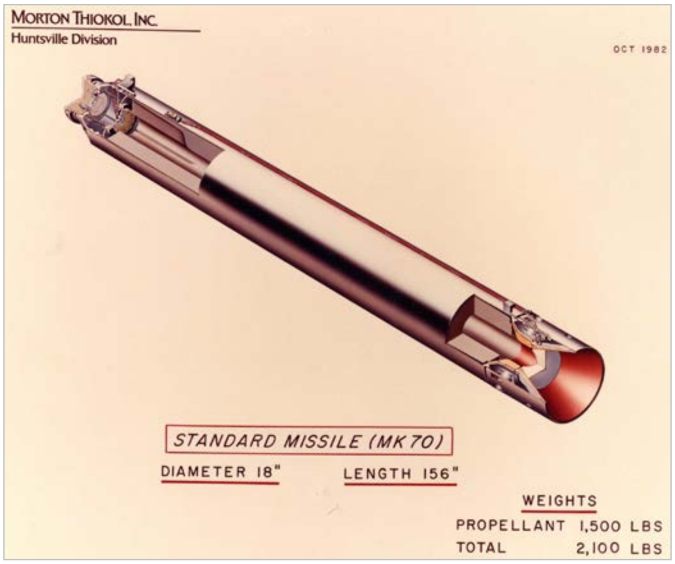

Figure 24. TX-664 Mk 70 rocket motor.

A total of 2,046 TX-664 Mk 70 rocket motors were produced by the Huntsville Division from December 1980 to April 1992 at the Sidewinder/Mk 70 production facility which was upgraded and automated in 1982 (Figure 25). Hercules/ABL built 400 functionally equivalent Mk 70 motors as a second source between 1988 and 1991. Following its retirement from tactical service, surplus Mk 70 motors have been used for sled track propulsion, sounding rockets, and as boosters for target vehicles such as Raytheon's Terrier Missile Target (TMT) and Orbital ATK's GQM-163A "Coyote" Supersonic Sea-Skimming Target (SSST) for the U.S. Navy.

Figure 25. Sidewinder/Mk 70 facility looking south.

In 1982, the Huntsville Division tailored the Mk 70's aluminized HTPB propellant for use in the solid rocket booster for the MQM-107 Variable Speed Training Target (VSTT) drone aircraft. The MQM-107, originally developed by Beech Aircraft for the Army, was eventually adopted by the Air Force and is still in service at the time of this writing. Designed to boost the MOM-107 drone to a speed of 200 knots in less than two seconds, Thiokol's TX-632 booster, shown in Figure 26, was incredibly simple in design, consisting of a commercial high pressure aluminum bottle threaded at both ends for nozzle and forward closure attachment, and then filling it with propellant. Thiokol manufactured over 2,000 TX-632 booster motors in the 1980s.

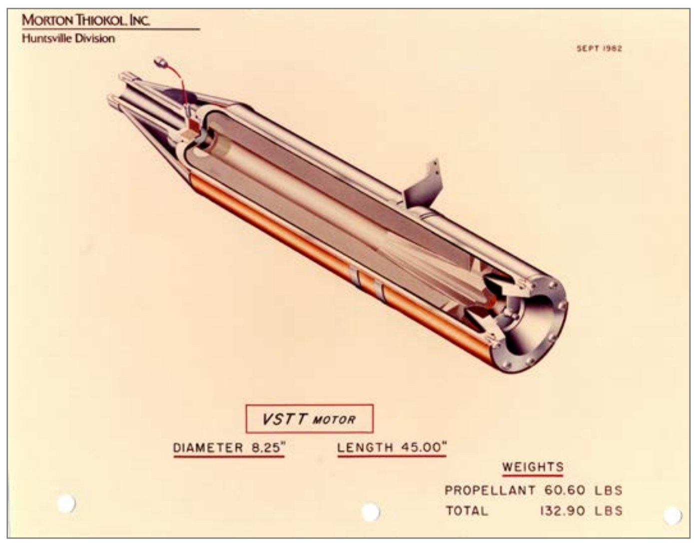

Figure 26. TX-632 VSTT motor for MQM-107.

In the late 1970s, the Huntsville Division became involved in the development of Class 1.1 "minimum smoke" propellants, using the liquid energetic plasticizers trimethylolethane trinitrate (TMETN) and butanetriol trinitrate (BTTN) instead of the nitroglycerin component typically used by Hercules in their minimum smoke propellants. In 1984, then Morton Thiokol completed the construction of a new $7.5 million facility for the production of minimum smoke propellants on a 150-acre tract of Redstone Arsenal known as the "old Rohm and Haas area." This area was the original location of the former Redstone Ordnance Plant Lines 3 and 4 where chemical munitions were manufactured during World War II. Rohm and Haas later conducted propellant research there from 1949 to 1970. A layout of the new area, designated as Thiokol's "South Plant," is shown in Figure 27. Here, Thiokol built a new minimum smoke propellant mix building and established production-scale nitramine grinding capability. Building 7649 and the South Plant represented a significant and rare capital investment by Thiokol in Huntsville Division facilities.

With the capability for production-scale manufacture of minimum smoke propellants in hand, the Huntsville Division moved out to secure business for the new facility. After successfully qualifying a minimum smoke version of the Hellfire motor (TX-773) in 1982, Thiokol secured contracts for the eventual production of over 31,000 units through 1996. Huntsville manufactured two variants of the minimum smoke Hellfire motor, one each for the Army and Navy. To meet service safety requirements, the Navy version of Hellfire incorporated a safe-and-arm device that was unique for its very small size and its location inside of the motor. In 1984, Huntsville completed the qualification of the minimum smoke TX-771 TOW-2 flight motor as a second source to then-Hercules. However, second source production of TOW-2 was rather modest, reaching just over 24,000 motors by the end of 1995. Many of the Thiokol TOW-2 motors were designated as foreign military sales (FMS) to the Swiss Army.

Between 1982 and 1996, the Government also made very significant capital investments in the Huntsville plant, constructing approximately 50 new buildings that included a replacement for Building 7631, a complex of laboratory and testing facilities (Bldgs. 7310, 7654, and 7663) to replace 7632 and 7636, and a massive building, 7347, for processing Class 1.1 rocket motors like Hellfire and TOW-2. Building 7347 was located in the Line 1 area of the North Plant and was commonly known as the “T-Building” because of its shape. With the completion of the T-Building complex, all Class 1.1 motor loading operations were moved from the South Plant to the new facility, and the Mk 36 Sidewinder manufacturing operation was moved into the South Plant space. With the new construction, Thiokol’s presence on Redstone Arsenal reached at least 234 buildings and 1,172 acres of land.[43] By 1992, the Huntsville Division occupied 1,258 acres and more than 1 million square feet of research, engineering, and production space.

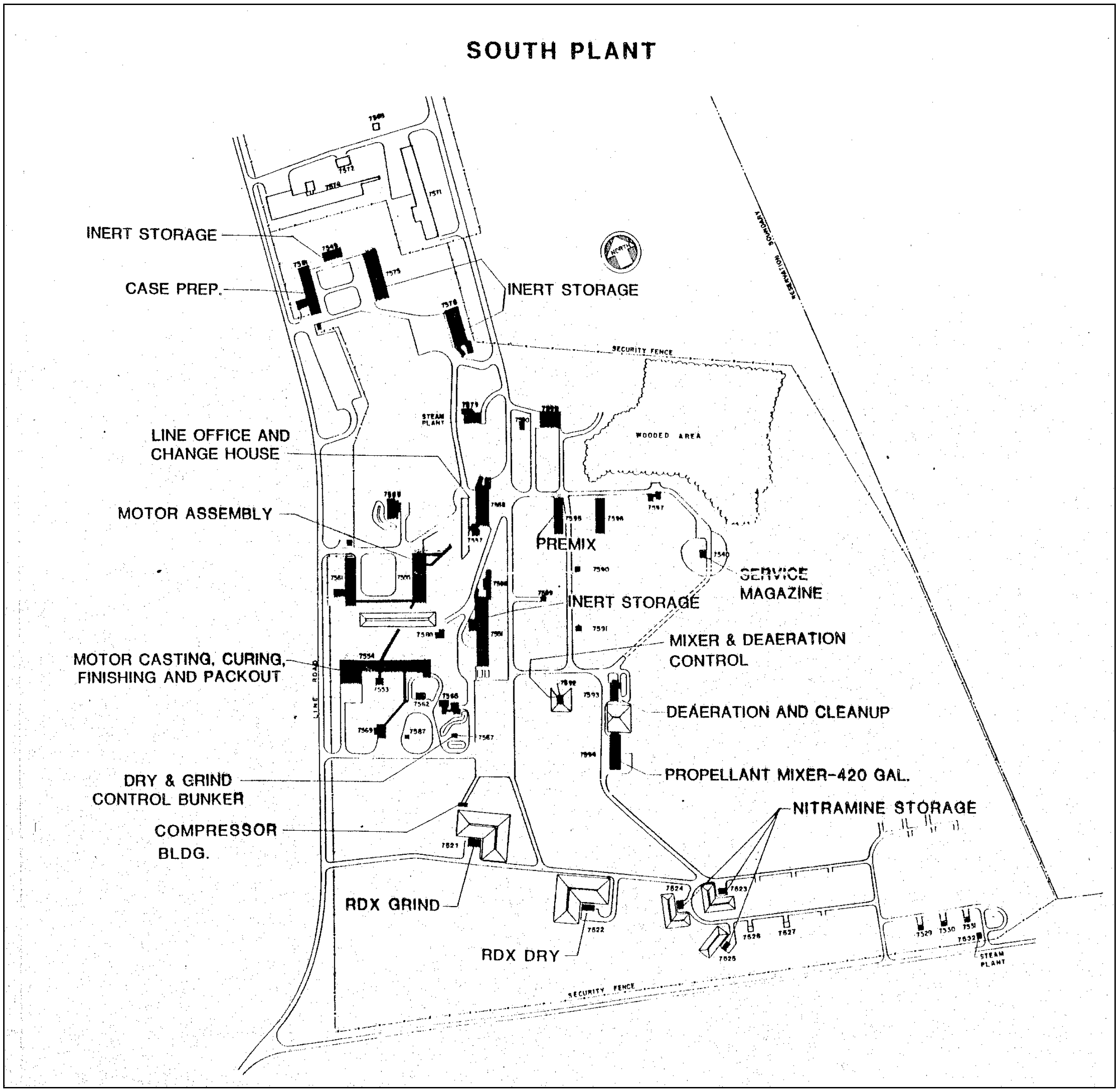

Figure 27. Thiokol Minimum Smoke (South) Plant layout circa 1985.

From the early 1960s to the 1990s, the Huntsville Division participated in a number of Government-approved cooperative programs with other nations. These international activities ranged from the manufacturing and delivery of propellant grains and complete rocket motors to the transfer of propulsion technology through licensing agreements. Huntsville's first international endeavor involved licensing and technical assistance to Sweden's Bofors Corporation for the manufacture of M58 and M60 Falcon rocket motors. Thiokol later provided gun-boosted rockets and base-bleed propellant grains for artillery projectiles.

Huntsville also manufactured propellant grains for Germany and licensed Nissan Motor Company of Japan to establish the capability to manufacture M30 sustainer motors for their Nike-J missile system. By the mid-1970s, Thiokol's relationship with Nissan expanded to include supplying Castor II strap-on motors for Japan's N-1 launch vehicle while later licensing the technology for Nissan and its subcontractors to indigenously manufacture their own motors. Japan began using its own Castor II motors for N-vehicle launches beginning in 1979.[44]

In 1986, the Huntsville Division began the development of the TX-833 reduced smoke, lightweight rocket motor for the VT-1 surface-to-air missile, which was developed by LTV (later Loral Vought Systems and then Lockheed Martin Vought Systems) for the French company Thomson-CSF (later Thales Group). Thiokol's 6.5-inch diameter TX-833 motor featured a high strength T-40 graphite composite manufactured by Brunswick Defense (later Lincoln Composites and then General Dynamics' Lincoln Operations) and was loaded with 69 pounds of TP-H8313 reduced smoke HTPB propellant. The VT-1 motor achieved a propellant mass fraction of 0.84.[45]

The VT-1 was slated to be used by France and Germany to replace their respective inventories of Crotale and Roland missiles. The VT-1 could reportedly achieve a flight speed of Mach 3.5 and was capable of 35 g maneuvers over a range of five miles.[46] Unfortunately for Thiokol, the long-term sustained production of VT-1 motors never materialized. Following the completion of LTV's manufacture of the first 1,000 VT-1 missiles for France in December 1992, production was assumed by Euromissile GIE, a joint venture of France's Aerospatiale and Germany's MBB. Thales Air Defense Ltd., formerly Shorts Brothers, reportedly took over European production of VT-1 beginning in 2001.[47]

VI. Solid-fueled Airbreathing Propulsion

In 1953, the Redstone Division entered the solid-fueled airbreathing propulsion arena by winning the first of a series of Army contracts that produced 621 direct connect static tests, 30 hot wind tunnel tests, and 10 flight tests in two- to six-inch diameter ducted rockets over the next five years. Thiokol static tested its first ducted rocket in 1954. Four Thiokol ducted rockets with an annular inlet configuration were flight tested at Redstone Arsenal in 1955 and three more with a nose inlet configuration were tested at Wallops Island, Virginia in 1958.

In 1963, Huntsville began work on the Air Force-sponsored Solid Propellant Augmented Rocket Motor (SPARM) program. The air-launched SPARM vehicle is illustrated in Figure 28. A modified AQM-37A drone served as the airframe. Thiokol developed the SPARM propulsion system, which was freejet tested at the U.S Air Force's Arnold Engineering Development Center (AEDC) at Tullahoma, Tennessee. In 1966, SPARM was flight tested off of an F-4J aircraft at the Navy Missile Center at Point Mugu, California, successfully demonstrating integral booster and two-phase sustain thrust operation. Thus, SPARM became the United States' first air-launched solid-fueled ducted rocket vehicle and the first ducted rocket with integral booster.

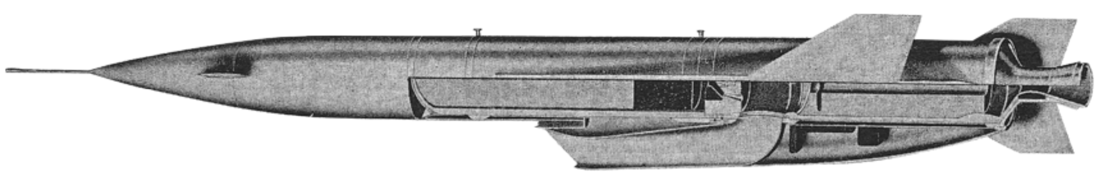

Figure 28. Cutaway view of the Thiokol SPARM vehicle.

Table 4 presents a summary of Solid Fueled Airbreathing Propulsion technology and development programs conducted by Thiokol between 1953 and 1980.

Table 4. Thiokol Huntsville Airbreathing Programs 1953-1980.

Year	Contract/Project No.	Program	Sponsor
1953	DA-01-021-ORD-4460	Research, design, development; 621 static tests, 18 hot wind tunnel tests, four flight tests.	Army
1955	DA-01-021-ORD-4488		Army
1955	DA-01-021-ORD-5409	Development and delivery of 6 ducted rockets; 8 wind tunnel tests and 3 flight tests.	Army

Year	Contract/Project No.	Program	Sponsor
1963	AF08(635)-3680	Solid Propellant Augmented Rocket (SPARM); develop and deliver 3 test missiles.	Eglin AFB
1964	AF04(611)-10217	Air Launch Propulsion System Study (ALPS); evaluate air augmented, solid and packaged liquid propulsion systems for defense suppression missions.	Edwards AFB
1965	AF04(611)-10719	ALPS Continuation	Edwards AFB
1965	G-65-107	Advance technology in supersonic combustion	Thiokol IR&D
1965	AF04(611)-10924	Ducted Rocket Technology Demonstration program; demonstrate ducted rocket propulsion system in wind tunnel.	Edwards AFB
1965	AF33(657)-14408	Missile Application Propulsion Study (MAPS); Study program to furnish parametric data.	Wright-Patterson AFB
1966	G-66-101	Supersonic Combustion	Thiokol IR&D
1966	JHU/APL 230648	Manufacture and deliver 20 fuel-rich propellant motors.	JHU/APL
1966	F04611-67-M-0035	MINOX; develop fuel-rich propellants.	Edwards AFB
1967	DAAH01-67-C-1790	Development of Solid Fuels for Supersonic Combustion program.	Army
1967	G-67-101	Advance technology of propellants, off-design performance, and supersonic combustion.	Thiokol IR&D
1968	G-68-402	Air augmentation thrust modulation.	Thiokol IR&D
1968	F04611-69-C-0023	Fuel-rich Boron Propellant Environmental Characterization Program; extend environmental limits of basic propellant developed under the Ducted Rocket Technology Demonstration Program.	Edwards AFB
1968	F04611-69-C-0024	Air Augmented Rocket Combustion Program; SABRE (Solid Air-Breathing Rocket Engine); study high altitude subsonic combustion.	Edwards AFB
1969	113-69-D003	Conduct studies that lead to improve technology for solid and liquid fueled gas generators.	Thiokol IR&D
1969	F04611-69-C-0051	TSAR (Throttleable Solid Augmented Rocket); demonstrate throttleability.	Edwards AFB
1969	F44620-68-C-0049 Mod 3	Conduct basic mixing experiments to verify fundamental turbulent mixing model.	AFOSR
1970	F04611-70-C-0079	Sampling and Analysis of Combustion Products of an Air Augmented Rocket	AFRPL, Edwards AFB
1977	F04611-76-C-0025	Advanced Strategic Air Launched Missile (ASALM) Boosters Demonstration	AFRPL, Edwards AFB
1977	F33615-77-C-2107	Support Marquardt Ducted Rocket Engine (DRE) Development	AFAPL, Wright-Patterson AFB
1978	F04611-78-C-0015	Smokeless Ducted Rocket Program. Design, Fabricate, and Demonstrate a Minimum Smoke Ducted Rocket Propellant and Combustor.	AFRPL, Edwards AFB
1979	F33615-79-C-2049	Provide solid fuel gas generators for Marquardt Variable Flow Ducted Rocket (VFDR).	AFWAL, Wright-Patterson AFB

In 1966, to support its growing airbreathing propulsion business, Thiokol constructed a direct connect test facility (Bldgs. 7375 and 7376) capable of providing 15 lb/sec of air at 1000°F. The initial test of a four-inch afterburner in the new facility was followed by 100 more tests that same year. A layout of the Huntsville Division direct connect facility is shown in Figure 29. It featured a high capacity, high pressure compressor (280 standard cubic feet/minute at 3500 psi); a high-pressure, high capacity gas-fired pebble bed heater (12 million BTU/hr); and 33,500 lb of air storage at 70°F. The facility was later upgraded with the installation of a thrust stand and oxygen-hydrogen heaters which expanded air flow capacity to 120 lb/sec at 1850°F and 20 lb/sec at 3500°F (Figure 30 and Figure 31).

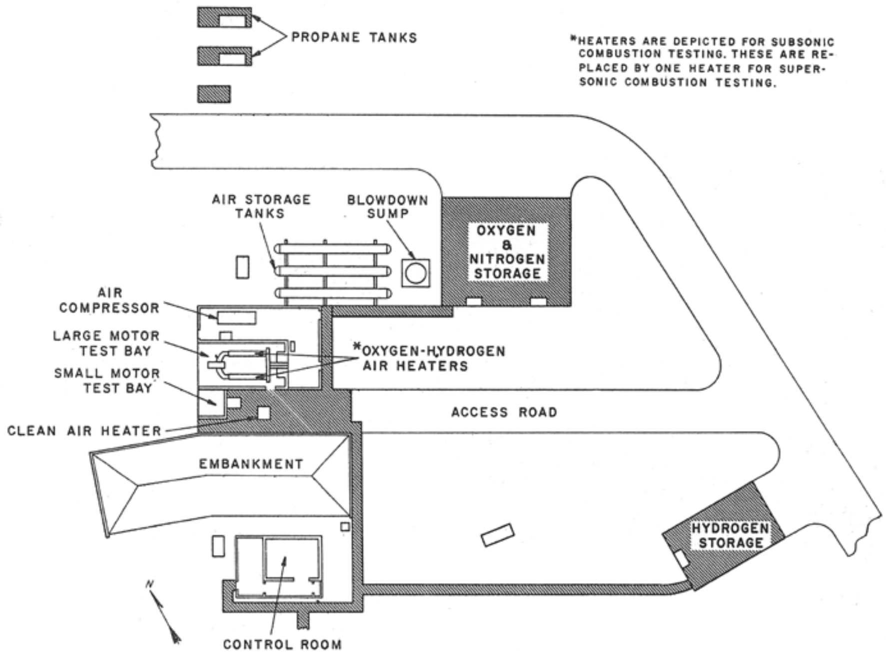

Figure 29. Layout of Thiokol Direct Connect Facility

Figure 30. Original Direct Connect Facility (1966).

Figure 31. Direct Connect Facility Upgrade.

In the late 1960s, Thiokol developed and investigated a burning rate control system for end burning propellant grains. Dubbed THERMATROL® for Thiokol Heat Exchange Rocket Motor Augmented Rate Control, the system employed small diameter tubes (Figure 32) longitudinally embedded within the propellant grain. The forward ends of the tubes were connected to a gas flow rate control system, controlling burning rate and producing the conical burning effect illustrated in Figure 33.

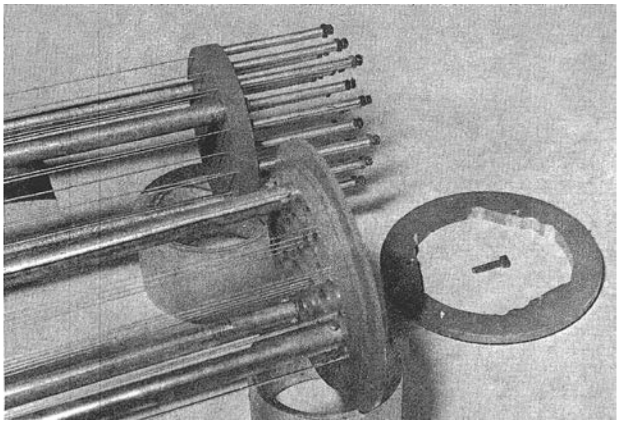

Figure 32. THERMATROL system.

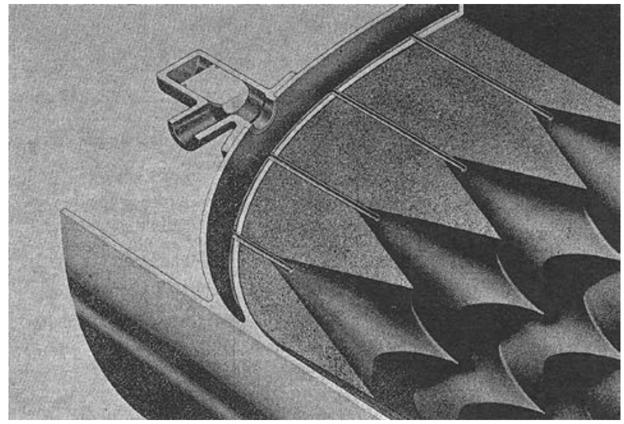

Figure 33. THERMATROL conical burn pattern.

In 1969, Thiokol investigated the use of a pintle nozzle for solid rocket throttle control under the Air Force-sponsored Throttleable Solid Augmented Rocket (TSAR) program. Four TX-338 TSAR controllable motors, illustrated in Figure 34, were successfully tested.

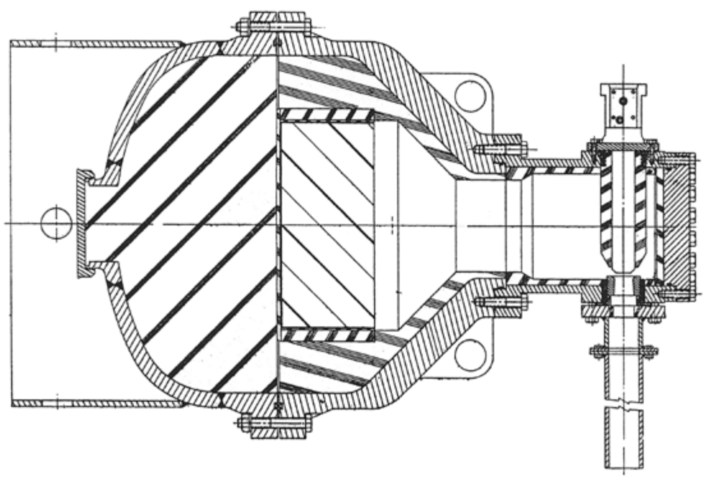

Figure 34. Cross-sectional view of TX-338 Throttleable Solid Rocket.

From 1976 to 1979, the Huntsville Division participated in the Air Force's Advanced Strategic Air Launched Missile (ASALM) Technology Development and Integration (TD&I) program, developing and ground-testing two separate integral HTPB booster/combustor designs for competing liquid fueled integral rocket ramjet (LFIRR) concepts. Despite being on two of the three teams competing for the follow-on ASALM Propulsion Technology Validation (PTV) program, a third Martin Marietta/Marquardt LFIRR concept with Hercules/McGregor booster was selected, ending Thiokol's involvement in ASALM.

VII. Plant Closure and Disposition of Programs.

The Division's rapid growth in its first decade of existence pushed employment at Huntsville to its historical peak of 2,100 people by 1959. Over the next five years, a fairly steady workforce of 1,500 was bolstered by the concurrent Nike Zeus, XM33 Castor, Bomarc B, and Pershing programs. As the development phase for these motors ended and the production of Bomarc B and Pershing was transferred to other Thiokol plants, employment at Huntsville experienced a natural regression in 1964 and then remained fairly steady at 500 to 800 employees for the next 25 years (Figure 35). In the late 1980s, Thiokol and other U.S. solid rocket companies benefitted from an escalation of defense spending under President Ronald Reagan, temporarily boosting employment at Huntsville to over 1,000 people. Unfortunately, the end of the Cold War and a declining tactical propulsion market forced

Thiokol to trim employment at Huntsville by more than 50% over the next four years. In 1991, it received yet another blow when Thiokol consolidated its solid propulsion research and engineering, including internal research and development (IR&D), into the company's Science and Engineering organization in Utah, thus eliminating nearly all of Huntsville's research and engineering analysis activities. Huntsville was left with just a project engineering group to support ongoing programs and an advanced design group to support proposal activities.

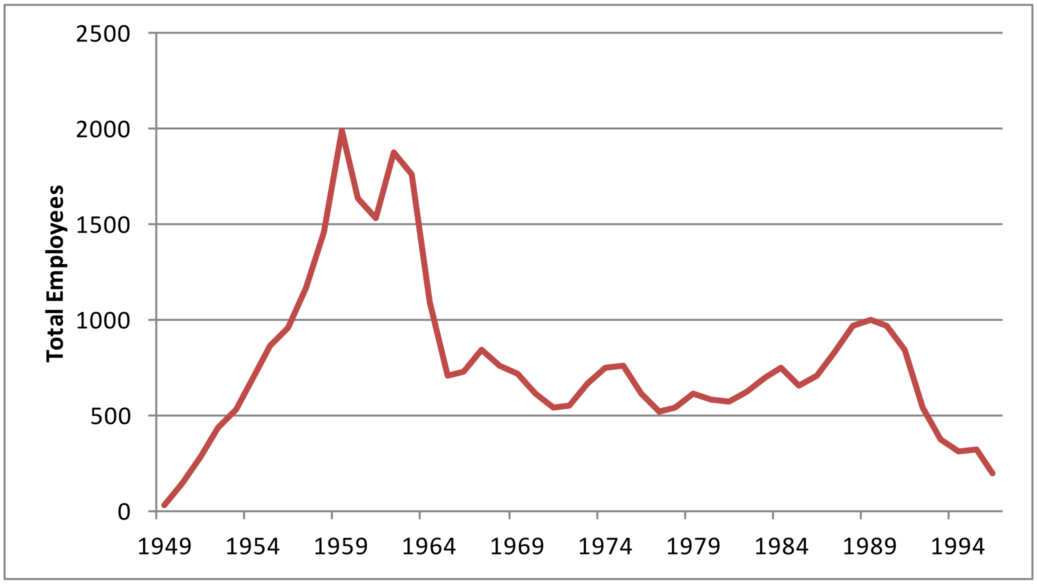

Figure 35. Huntsville Division historical employment.

Nevertheless, the Huntsville Division mounted a successful risk reduction effort for the early Ground Based Interceptor (GBI) program, resulting in the static firing of a 25-inch diameter second stage demonstration motor for the Martin Marietta/Lockheed/Thiokol team and the Army Space and Strategic Defense Command (SSDC) on June 24, 1993 at RTTC. The TX-883 demonstration motor featured a graphite/epoxy composite case and was loaded with high solids HTPB propellant. The high performance flexseal nozzle and Moog actuation system were supplied by the Elkton Division and the supporting motor engineering analyses for the development effort were provided by the Thiokol Science and Engineering organization in Utah. Despite the successful demonstration motor test, further procurement activities were suspended by the Government and GBI development did not resume for another five years.

In January 1995, Thiokol announced the establishment of its Defense and Launch Vehicles (DLV) Division, effectively consolidating the management of the company's Promontory, Huntsville, and Elkton plants under a single entity that was responsible for the company's line of space launch boosters, solid rocket upper stages, orbit transfer motors, strategic missile propulsion systems, air and ground-launched tactical missile propulsion systems, flares and decoys, and rocket motor demilitarization activities. Just two months later, on March 9, 1995, Thiokol President and CEO James R. Wilson announced a series of facility closures and consolidations intended to strengthen the company's competitive position in its defense and launch vehicle rocket motor business.[48] Among the casualties was the Huntsville Division, which was scheduled to be phased out over the ensuing 15 months and resulting in the loss of 320 jobs. The decision to close Huntsville was undoubtedly influenced by a declining tactical propulsion market, mirroring a similar decision by Hercules to close their McGregor, Texas solid rocket plant in 1995.

For the remainder of 1995, Thiokol completed its contractual obligations for the production and delivery of Mk 36 Sidewinder, Mk 112 RAM, Mk 70, and Castor IV rocket motors. The final delivery of TOW-2 motors was completed in December 1995 and the last Patriot motors were shipped from the Huntsville Division in May 1996. On July 9th, the final production lot of Hellfire rocket motors was shipped and the plant was formally shut down on July 15, 1996.[49] Over the next five months, facilities engineering work continued to secure and prepare the facility for transfer, and the last Huntsville Division employee turned the keys over to the Army in December.

Upon the closure of the Huntsville Division, the active Castor IV space booster product line was transferred to Thiokol's plant in northern Utah and selected intellectual property of tactical R&D and solid rocket programs such as Patriot, Castor I and Maverick was transferred to Elkton. Of these three motors previously produced at Huntsville, only the Castor I containing an HTPB propellant upgrade in refurbished cases was later produced at Elkton. Functionally-equivalent Patriot motors were later manufactured by Atlantic Research Corporation and Maverick motors were manufactured by Alliant Techsystems (now Orbital ATK). Huntsville's three 420-gallon production mixers were either transferred or sold; one was transferred and put into service at the Elkton plant, one was sold to a company in Spain, and the third was sold to Bristol Aerospace (Magellan Corporation) and is currently in use at their Rockledge plant in Winnipeg, Canada.

In 1997, Thiokol received a contract from Japan's Mitsubishi Heavy Industries (MHI) to adapt the Castor IVA-XL for use on the H-IIA vehicle. The tailored Castor IVA-XL's were designated "SSB." Production commenced in 1998 and four SSB's were flown on the February 4, 2002 and September 10, 2002 launches of the H-IIA. As part of the contract, Thiokol transferred the SSB manufacturing technology to MHI.

VIII. The Former Huntsville Division Site Today.

Since the closing of Thiokol's Huntsville Division in 1996, several buildings, including the original propellant research laboratory (Bldg. 7632), have been razed and others have been converted to new uses by the Army and support contractors. The Thiokol signage,[50] shown in Figure 36, was removed shortly after the plant closed. The former Thiokol Engineering Building (7611) temporarily housed the Army Foreign Military Sales organization and then the Army Materiel Command (AMC) when it began its relocation to Redstone Arsenal in 2006. A missile demilitarization facility was also operated on site for a period of time. Presently, AMRDEC manages and operates the research scale propellant mixers on site. In addition, AMRDEC took over the former propellant research laboratories (Bldgs. 7310, 7336, and 7349) that were newly built in 1992 but never used by Thiokol, and has established a world class propellant and energetics research and development facility there. Boeing once used Building 7649 for the Ground-based Midcourse Defense Segment program and initially took over the South Plant for the assembly of the GBI Boost Vehicle-Plus (GBI BV+) before relocating it elsewhere. The former Thiokol Line 2 area became the site for Raytheon's state-of-the-art Redstone Missile Integration Facility (MIF), which opened in November 2012.

Credit: The Huntsville Times / Jim Taylor

Figure 36. Former Entrance to the Huntsville Division plant, looking north from Redstone Road.

One of the unique legacy Thiokol facilities that has found other uses is the "Snake Pit," so named for its swampy location north of the former Thiokol plant in Test Area 10 (TA-10). It was actually located outside of the Thiokol security fence, but within the Redstone Arsenal perimeter and is only accessible by vehicle from the former plant site. The Snake Pit is a large circular concrete pit, 8 to 10 feet in diameter and 15-20 feet deep. It was originally built in the early 1950s as an underwater burnout facility for large solid rocket motors, but it was never used for that purpose. Over the years, the Snake Pit has been adopted for other research and test activities requiring remoteness and safe standoff from plant buildings and personnel. Subsequent uses of the Snake Pit include the water-jet washout of propellant from rocket motors, grinding experiments on cyclotrimethylenetrinitramine (RDX) using a Bantam Mikropulverizer, and conducting training and demonstration testing of energetic materials. The facility was upgraded in the early 1980s to serve as a test cell for hazard classification and insensitive munitions (IM) testing. Today, the Snake Pit is still used by AMRDEC and Redstone Arsenal tenant organizations to conduct various weapons and energetic materials test and evaluation activities.

IX. Summary and Legacy

In its 47-year history, Thiokol's Huntsville Division produced over 200,000 rocket motors and manufactured more than 44.6 million pounds of composite and minimum smoke propellants for military and space launch applications.[51] The Huntsville Division's major programs by decade are presented in Table 5, and a comprehensive historical tabulation of its products appears in Table 6 at the end of this paper.

Until its closure, Thiokol's Huntsville Division was a major component of the U.S. solid rocket industrial base and had an unquestionable impact on the development and growth of the industry after World War II. The Huntsville Division was the source of many industry firsts, key technological breakthroughs, and pioneers of the U.S. solid rocket industry. Some of its early 1960s developments like case-on-propellant manufacturing and the use of a pintle for solid rocket motor thrust management were years ahead of their time, and key IR&D investments in the 1970s helped to reduce the parts count and cost of tactical nozzles for systems like Hellfire, Maverick, Mk 70, and Sidewinder.[52]

Some Huntsville Division inventions did not initially gain acceptance, but nevertheless demonstrated the ingenuity and creativeness of its technical workforce. For example, in the 1960s, Thiokol engineers devised the "Thiovec" bearing for thrust vector control, an early version of the "trapped ball" nozzle designed to eliminate the need for external actuator hardware used in other movable nozzle designs. The Thiovec nozzle, shown in Figure 37,[53] provided internal vectoring capability by the application of pressure to "kidney seals" (metal-banded o-rings) around the ball-and-socket structure. During the 1970s and 1980s, Thiovec was successfully tested under a succession of small contracts that included a demonstration for the Standard Missile Mk 56 rocket motor (Figure 38), but it was never adopted for a system application. The trapped ball TVC concept has since been used in several solid rocket motors designed and built by other organizations, including the Elkton, Maryland plant.

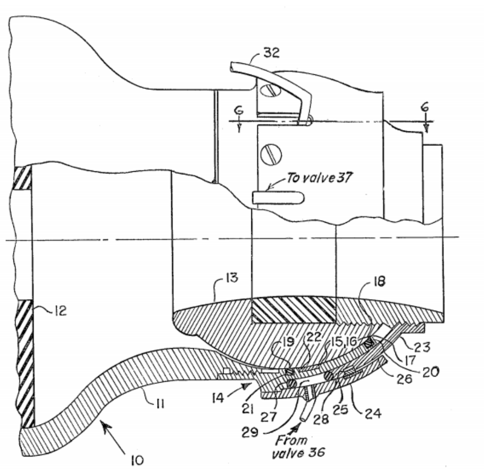

Figure 37. Schematic of Thiovec Nozzle.

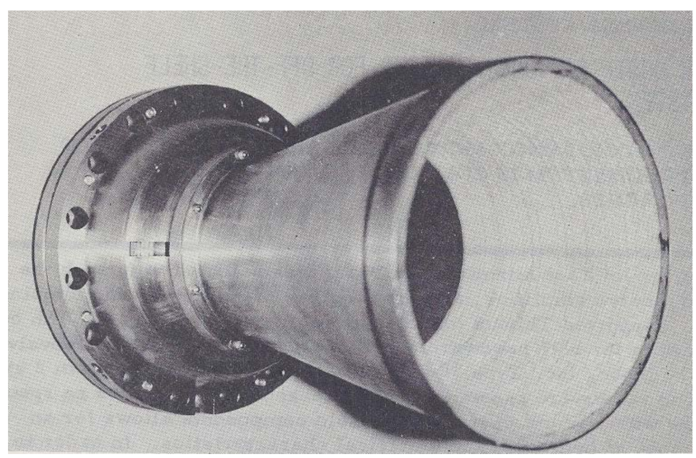

Figure 38. Mk 56 Thiovec Bearing Demonstration Nozzle.

A robust budget environment, the Cold War buildup, the Space Race, and the existence of five healthy major solid rocket companies made the 1960s the "golden age of rocketry." Clearly, solid rocket work in the 1960s was challenging, stimulating, packed with testing—good or bad—but nevertheless exciting, and the programs at the Huntsville Division were no exception. Thiokol and its employees had a tremendous sense of pride in their products which helped to defend our country, conduct scientific research, and launch satellites and humans into space. In the 1960s, the Huntsville Division patriotically displayed some of its products in a local parade (Figure 39). The company also maintained a "rocket garden" display of product models on the plant (Figure 40). This Thiokol tradition carried over to the Utah plant, whose rocket garden is still maintained by current operator Orbital ATK.

The Huntsville product portfolio touched ground, air, and space systems for the Department of Defense, NASA, Department of Energy, and international partners. Nearly 20 years after its closure, the Huntsville Division legacy lives on with some of its tactical motors still in service, as well as surplus motors being converted for use in sounding rockets, test vehicles, and other secondary applications. Upgraded or functionally equivalent designs of legacy Huntsville solid rocket motors have been produced by other organizations. Orbital ATK continues to offer the Castor IV series of motors as part of its Flight Systems product portfolio in Utah. Orbital ATK has also produced an upgraded version of the Castor I motor at Elkton, Maryland, and functionally equivalent SR128 reduced smoke Maverick rocket motors and Mk 36 Sidewinder rocket motors are manufactured at Rocket Center, West Virginia.

Many former Thiokol employees actively participate in the Huntsville Division Alumni Association (HDAA), which maintains a web site, email list service, and quarterly newsletter *The Next Stage*. Three distinct groups (ladies, management and engineering, and plant personnel) hold regular meetings and luncheons, and continue such traditional events as picnics, annual Christmas Party, and Engineering Department Christmas luncheon.

Table 5. Major Thiokol Huntsville Programs by Decade.

1950s	1960s	1970s	1980s	1990s
2-inch FFAR	15-mm RAP	30, 40, and 75 mm	Castor I	Castor IVA
Big B	Arbalist	ASALM Booster TD&I	Castor II	Castor IVB
Bomarc	Castor I (XM33)	Castor I	Castor IV	Castor IVA-XL
Falcon	Castor II	Castor II	Castor IVA	GBI Demo
Hermes	Castor IV	Castor IV	Hellfire (M.S.)	Hellfire (M.S.)
Lacrosse	Maverick (Smoky)	Firebrand	LARS	Maverick (R.S.)
Loki	Ducted Rockets	Hellfire (R.S.)	Maverick (R.S.)	Mk 70
Matador JATO	HiPADS	Maverick (R.S.)	Mk 70	Patriot (PAC-1 & PAC-2)
Nike Hercules	Jupiter Spin & Vernier	MLRS	Patriot	RAM Mk 112
Nike Zeus	Pershing	Patriot	RAM Mk 112	Sidewinder Mk 36
Pershing	SAM-D	Pershing	Sentry	SPBD
Sergeant	Selective Zone	Sidewinder Mk 36	Sidewinder Mk 36	TOW-2 Flight Motor
TX-77	Spartan	Spartan	SLAT Booster	
XM33 Motors	Space Booster	Mk 70	TOW-2 Flight Motor	
	TX-77	TOW Missile Assembly	VSTT	
	TX-280 Ullage		VT-1	

Figure 39. Thiokol parade float from the mid-1960s.

Figure 40. The former "Rocket Garden" Display Area at the Huntsville Division.

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Table 6. Major Solid Rocket Motors Developed by the Huntsville Division.

Motor Characteristics					Propellant Data			Manufacturing History				
Common Name	Model Designations	Dia (in)	Length (in)	Weight (lb)	Weight (lb)	Designation	Type	Dev Date	Qual Date	Prod Date	Qty Made	Note
ASALM Booster	TX-663 (Heavy)	16	86.9		668	TP-H8259	HTPB	1976-79	--	--	3	McDonnell Douglas/CSD Vehicle
ASALM Booster	TX-656	20	102		626	TP-H8257/60	HTPB	1976-79	--	--	4	Martin Marietta / Marquardt Vehicle
Big B	TX-25	54	169	15,856	10,014		PBAA	1956-57	--	--	1	ICBM Feasibility Test
Big B (Klunker)	TX-14	72	184	37,106	22,245		PBAA	1958	--	--	1	Tested in 1958
Bomarc B Booster	TX-131, XM51	35	214	7,843	6,569	TP-L8113	PS	1958-60	1961	1961-64	300+	Production at Utah Division
Castor I	TX-33-35/39	31	233	8,754	7,313	TP-H8038A	PBAA	1958-60	1960	1960-90	663	Little Joe, Scout, Athena, Strypii
Castor II	TX-354	31	235	9,511	8,220	TP-H7036	CTPB	1964-66	1965	1965-90	817	Used for Scout and Thor-Delta
Castor IV	TX-526	40	383	23,237	20,545	TP-H8038	PBAA	1968-69	1969	1969-90	390	Delta Strap-on
Castor IVA	TX-780	40	362	25,525	22,350	TP-H8299	HTPB	1982-83	1986-87	1987-95	221	Transferred to Utah in 1995
Castor IVA-XL	TX-874	40	462	32,727	28,914	TP-H8299	HTPB	1990-92	1992-93	--	3	Transferred to Utah in 1995
Castor IVB	TX-859	40	354	25,485	22,100	TP-H8299	HTPB	1989	1990	1991-95	23+	Transferred to Utah in 1995
Falcon (dual-thrust)	TX-18, M46	6.4	28.4	43	28	TP-L8006	PS	mid 50s	1959			Production at Huntsville
Falcon	TX-58-4, M58A2	5.8	36.8	45.7	31	TP-L8237	PS	1949-52			65	Production at Longhorn and Elkton
Falcon	TX-143, M60	8.25	31.5	84.2	60	TP-L8006	PS	late 50s		1961-79		Production at Huntsville
Firebrand	TX-690	16					HTPB	1978-80		1980s	42	Modification of Patriot; cancelled '82
Hellfire (M.S.)	TX-773	7	23.4	31.8	20.3	TP-Q7030	NEPE	1981-82	1982	1982-96	31,000+	
Hellfire (R.S.)	TX-657, M120	7	23.4	32.2	21.6	TP-H8225	HTPB	1976-79	1979	1980-82	8,750	
Hermes	TX-140, XM20	31	168	6,171	4,610	TP-E8080	PS	1950-53	--	--	26	22 static tests and 4 flight tests.
Jupiter Spin	TX-148, XM148		11.14	8.7	0.95	TP-E8032	PS	early 60s				
Jupiter Vernier	TX-83, XM83	14	19.5	112	45.5	TP-E8032	PS	early 60s				
Lacrosse	TX-10, M10	16	102.75	885	488	TP-E8104	PS	1955-57		1958-60		Production at Longhorn
Loki	TX-31, T2006	3	66			T-22	PS	1952-53		1954	500+	
Matador	TX-16, M16	26	129	2,938	1,365	TP-E8100	PS	1953-55	1955			Production at Wasatch
Maverick (R.S.)	TX-633, SR114	10.7	40.1	103.5	63.5	TP-H8254	HTPB	1975-76	1977	1981-92	7,970	
Maverick (Smoky)	TX-481	10.7	40	103.5	65	TP-L8006	PS	1965-71	1971	1971-78	27,000+	
Mk 36 Sidewinder (R.S.)	TX-683	5	70.9	100	60.4	TP-H8288	HTPB	1978-80	1980-81	1981-91	13,000+	check Benson
Mk 70 Terrier	TX-664-3	18	155	2,140	1,500	TP-H8238	HTPB	1977-80	1981	1981-92	2,046	Standard Missile 2 Block II ER
Mk 112 RAM	TX-758	5	70.9	95	60.4	TP-H8288	HTPB	1983-84	1984	-95	351+	For RAM Block 0 and 1 only
Nike Hercules Sustainer	TX-30, M30	28	174.4	2,840	2,172	TP-E8082	PS	1956-58	1958	1961-71	10,000+	Production at Longhorn
Nike Zeus FS Booster	TX-135	43	203	11,674	9,619	TP-H7015	CTPB	1958-63				153 flight tested
Nike Zeus SS Sustainer	TX-238	36	184	7,699	6,780	TP-H8126	PBAA	1960-64				124 flight tested
Nike Zeus TS Jethead	TX-239	29	43	811	670	TP-H8145	PBAA	1960-64				70 flights; also used as Spartan TS
Patriot	TX-486	16	130	1,311	1,098	TP-H8208	HTPB	1967-72	1969-78	1981-96	6,500+	
Pedro	TX-261-5	28	118	2,891	2,324	TP-H8126	PBAA	1961				Pershing Drop Boost Test Vehicle
Pershing First Stage	TX-174; M105	40	78.55	5,004	4,451	TP-H8159	PBAA	1958-61	1963	1961-	800+	Production at Longhorn
Pershing Second Stage	TX-175; M106	40	63.28	3,248	2,785	TP-H8156	PBAA	1958-61	1963	1961-	800+	Production at Longhorn
Pollux	XM33E4	31	240	8390	7,033	TP-H8038	PS	1958-60				Used for early Little Joe testing
Saturn S-IV Ullage	TX-280	8.3	36.3	88.4	58.7	TP-L8183	PS	1963-65	1965	1965 -	39	
Sentry Demo	TX-775	21.3	130.5			TP-H8295	HTPB	1980-81	--	--		
Sergeant	TX-12, M100	31	196	6,910	5,925	TP-E8057	PS	1954-58		1958 -	64 (Dev)	Production at Longhorn
SLAT Booster	TX-812	19.7	58.1	993	631	TP-H8283	HTPB	1983-86		--	--	Supersonic Low Altitude Target
Spartan First Stage	TX-500	43	204	12,199	9,928	TP-H7034	CTPB	1965-70	1970	1970-75	72	Safeguard Anti-ballistic Missile.
Spartan Second Stage	TX-454	43	203	14,230	12,570	TP-H7034	CTPB	1965-68	1970	1970-75	72	Safeguard Anti-ballistic Missile.
SPBD	TX-868	21.3	105	1,793	1,493	TP-H8316	HTPB	1989-92	--	--	~ 6	Tapered outer mold line (OML)
Starfire Booster	TX-664-4	18	155	2,096	1,500	TP-H8238	HTPB	1988				Mod of Mk 70; first launch 3/29/89
TOW-2 Flight Motor	TX-771	5.8	11.5	14	7.1	TP-Q7042	NEPE	1980-84	1984	1986-95	24,079+	Mostly FMS to Switzerland
TX-77	TX-77	15	187	1,644	1,200	TP-E8114	PS	1958-61		1961-	129+	Trailblazer Sounding Rocket stage
VSTT	TX-632	8	44.6	130	61	TP-H8301	HTPB	1982-83		1980s	2,108	Booster for MQM-107
VT-1	TX-833	6.5	59.8	83	69	TP-H8313	HTPB	1986-88		1990-92	1,000	T-40 graphite composite case.
X-17 First Stage	TX-20, M20	31	232	8,193	7,007	TP-E8081	PS	mid 50s			40+	Basis for XM33 series

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