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From Polymers to Propellants to Rockets – A History of Thiokol

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FROM POLYMERS TO PROPELLANTS TO ROCKETS: A HISTORY OF THIOKOL

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Abstract

In 1926, Dr. J. C. Patrick discovered a process for manufacturing the first synthetic rubber made in the United States. He named this polysulfide polymer Thiokol, and he and Bevis Longstreth formed the Thiokol Corporation in 1928 to commercialize it. In 1942, Thiokol developed the first curable liquid polysulfide polymer, and in 1945 Charles Bartley and others at the Jet Propulsion Laboratory used this polymer to formulate a new kind of composite solid propellant. In late 1947, Thiokol entered the field of solid propellant rockets and static tested its first solid rocket motor at Elkton, Maryland, in 1948. The following year, Thiokol moved its rocket operations to Redstone Arsenal in Huntsville, Alabama.

Over the next 33 years, Thiokol developed and produced rocket motors for a wide number of applications, including tactical missiles such as Falcon, Sergeant, Pershing, Spartan, Patriot, Hellfire, Maverick, Subroc, Standard Missile, and Sidewinder. It also developed propulsion stages for ICBMs including Minuteman, Poseidon, and Trident. Strap-on boosters for space launch vehicles included the Castor® series and the Space Shuttle SRMs. Retro rockets for bringing manned and unmanned capsules back to Earth were developed and applied successfully. A series of STAR™ rocket motors found many uses in space, including apogee and perigee kick motors, as well as the Viking and Pioneer space probes.

After expanding to five different locations for developing and manufacturing solid rocket motors, in 1982 Thiokol was absorbed into the Morton Salt Company to form Morton-Thiokol International, and its existence as an independent corporation came to an end.

Introduction

This brief history of Thiokol describes significant events and some of the people involved in them over the period 1926 to 1982. In 1982, the original Thiokol Corporation was absorbed by Morton, the Chicago-based salt manufacturer, ending its existence as an independent entity. Emphasis is placed on the early portion of this history, since the people who participated in it are disappearing from the current scene, and it is important to preserve as much as possible of those early days of polymers, propellants, and rocket technology.

The First Polysulfide Polymer

In 1926, Dr. Joseph Cecil Patrick was a 34-year-old chemist operating a small independent laboratory in Kansas City, Missouri. Although he received an M.D. from the Kansas City College of Medicine and Surgery in 1922, he found that he was more interested in chemistry than medicine, and he and a partner founded Industrial Testing Laboratory, Inc. This firm performed chemical analyses of many types, and also undertook development projects that ranged from studies of cholesterol in kosher food products for a local orthodox Jewish rabbi to attempts to find uses for the apple waste from a vinegar factory.

Another project he undertook in the early 1920s was to find uses for the by-product ethylene from petroleum cracking processes. Converting it to ethylene glycol was a desirable objective, since this compound had already found use as an antifreeze in automobiles and as a raw material for ethylene glycol dinitrate, a useful explosive. He began by looking for an improved method of hydrolyzing ethylene dichloride. One of the hydrolyzing agents he examined was a solution of sodium polysulfide.

The results of this work were described as follows:

"Along towards midnight on April 1, 1926, Dr. Joseph C. Patrick, a 34-year-old physician-turned-chemist, went into his Kansas City, Missouri, laboratory to inspect a chemical compound he had cooked up earlier in the day. Instead of the clear liquid he had expected, he found something that looked like blackstrap molasses and smelled like rotten eggs. Cleaning his laboratory the next morning, Dr. Patrick found the mixture had solidified. When he chopped it with a knife, a chunk flew out and bounced across the floor like a rubber ball. When he tried to dissolve it with solvents, he found that, unlike natural rubber, it was impervious to chemicals[1].

Like many inventors, "Doc" Patrick had begun by looking for one thing and finding another. He had been seeking a less expensive route to antifreeze and instead had discovered the first synthetic rubber to be commercially manufactured in the United States.

In 1958, Dr. Patrick was awarded the Goodyear Medal for this and other work in the field of polymers, and a paper commemorating this event[2] described the chemistry of the reaction as a simple condensation:

$$(CH_2)_2\,Cl_2 + Na_2S_X = C_2H_4S_X + 2NaCl$$ [2]

The first patent issued on this invention was granted in 1927 to Dr. Patrick and his coworker, Nathan Mnookin. According to one source, Mnookin's contribution was to provide a method of coagulating the mixture Dr. Patrick had produced, resulting in a solidified polysulfide rubber.[3]

In 1927, Dr. Patrick, hoping to capitalize on his idea, sold the rights to it to Standard Oil of Indiana. In 1928, he joined forces with a businessman from Kansas City named Bevis Longstreth and bought the rights back for $50,000. With another $25,000 of capital, they formed a corporation. They named it Thiokol – a new synthetic word for a new synthetic polymer – derived from the Greek words for "sulfur" (Theion) and "glue" (Kolla). The chemical terms "thio," for a sulfur-containing compound, and "colloid" come from the same Greek roots. At first, the company name was spelled "Thiocol." The building the company occupied in Missouri is shown in Fig. 1 and the two founders of the company are shown in Fig. 2. Dr. Patrick described the story of how they got together as follows:

Figure 1. Thiocol License Co. – 1928

Figure 2. The Founders: Dr. J. C. Patrick and Bevis Longstreth

"One day, shortly after the termination of the Standard Oil arrangement, Longstreth came to my office and told me that he had been offered a case of what purported to be genuine Scotch whiskey, at what appeared to be a reasonable price for that Prohibition Era, and would I make a chemical examination of a sample bottle which he had brought with him. I sent it into the laboratory for a routine examination, and while we waited for the report to come back, he asked me about the samples of synthetic rubber that were scattered over my desk. I told him the whole story, including the fact that I had come to the conclusion that if I was ever going to get this development off the ground, I would have to find a way to produce the polymer in a liquid form initially and that, since it was insoluble in any solvent, it would have to be formed as a dispersion, preferably as a water dispersion, capable of subsequent return by some means to the massive or gum form.

He became quite interested in the account, and the appearance and feel of the specimens that he had seen, and the next day called me by phone and suggested that I go to his office for a talk. He then told me he had a relative who was a member of a firm of investment bankers and that the firm was quite research minded. He suggested that he and I go to New York and talk it over with them. We did, and after a thorough investigation, the firm of Case, Pomeroy and Company suggested the formation of a corporation to manufacture or license others under the patents."[4]

In 1930, they moved from Missouri to Yardville, New Jersey, on the outskirts of Trenton. By this time, the name was now spelled "Thiokol." The

1930s were a difficult period for Thiokol, like many American corporations. At the depth of the Depression in 1932, the unemployment rate was as high as 25%, and many corporations went into bankruptcy and disappeared, along with the jobs they had created. But Thiokol survived, manufacturing solid polysulfide polymers that found applications in gaskets, sealants, lubricants, coatings, and adhesives that required the unique resistance of polysulfide polymers to solvents, weather, or electrical arcing.[5]

In 1938, the company moved again, this time to its long-time location on North Clinton Avenue in Trenton (Fig. 3).

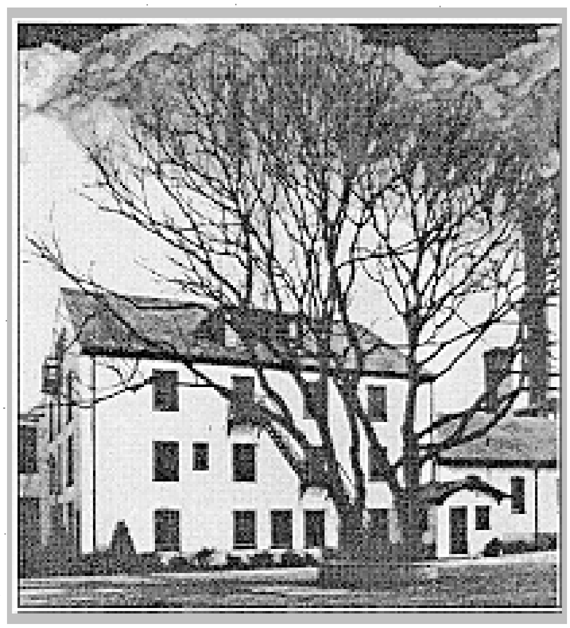

Figure 3. North Clinton Ave. – 1938

The First Liquid Polysulfide Polymer

After developing and commercializing the first synthetic rubber to be manufactured in the U. S., the fledgling corporation provided another first for the polymer industry. In 1942, Dr. Patrick and H. L. Ferguson discovered a route to the first liquid polymer that contained no volatile solvent and could still be converted to a rubber-like solid. This development was to have far-reaching and enormously positive financial consequences for the company. A summary of these polymers is shown in Fig. 4. A significant amount of work in scaling up this process to commercial levels was done by J. S. Jorczak and many others at the Clinton Avenue plant.

In World War II, the family of polysulfide polymers found a sizable application for their unique solvent resistance in providing the sealants and linings for wartime aircraft fuel tanks, and Thiokol began to experience increased demands for its product. In fact, the demand grew so rapidly that the Dow Chemical Corporation was asked by the U. S. Government to assist the tiny Thiokol Corporation in scaling up the production of polysulfide polymers for the war effort. "In addition to sealing wing tanks . . . [they] were used for sealing fuselages, air ducts, gun turrets, navigation domes and jettison fuel tanks."[6] Experiments in making substitute tires and chewing gum were not as successful, however.

Just as Thiokol's future was beginning to improve, Bevis Longstreth died prematurely in 1944. At first, this left the fledgling company in turmoil. Sales Manager Joseph Crosby, "Doc" Patrick, Harry Ferguson, and Dr. Sam Martin had a meeting and recommended to the Board of Directors that the company carry on with them as a committee to run it. The Board approved this hastily improvised arrangement, but after six months the Board elevated Joe Crosby from sales manager to general manager, and after another six months to president, a post he kept for many more years. He finally retired in January 1971 as Chairman of the Board at the age of 74. At the time of Longstreth's death, Crosby was 49 years old and he had joined Thiokol eight years before in 1936, becoming sales manager in 1941 (Fig. 5).

For the year 1944, the total sales of the corporation were a modest $1.2 million, with an even more modest profit of $11,995.[7] The Annual Report for that year states that "liquid polymers are still largely in the development and appraisal stage, but nevertheless their sales volume has been steadily increasing . . ."

Harry Ferguson, then executive vice president, put it more succinctly: "No one has liquid polymers. Liquid polymers will sell." At that time Thiokol had a salesman on the west coast named Walt Boswell. In fact, he was the only Thiokol salesman west of the Mississippi.[8] Thiokol chemists, hoping to find as-yet unknown applications for the new type of polymer, began circulating technical information on the new material.

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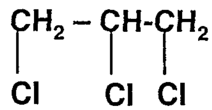
Polymer Formation and Structure

$ClCH_2CH_2OCH_2OCH_2CH_2Cl + Na_2S_x$

Dichloroethyl formal — Sodium polysulfide



1, 2, 3 trichloropropane (TCP)

→ $H(SCH_2CH_2OCH_2OCH_2CH_2S)_n$

Ethyl formal polysulfide polymer

Polymer Properties

Designation	Density, g/cc	Molecular Weight	TCP, mol %	Viscosity, poise	First Year of Use
LP-2	1.27	4000	2.0	400	1943
LP-32	1.27	4000	0.5	400	1949
LP-3	1.27	1000	2.0	10	1943
LP-33	1.27	1000	0.5	15	1950

Figure 4. Thiokol Liquid Polysulfide Polymers

Figure 5. J. W. Crosby

The First Polysulfide Propellants

In those days, one of the most active laboratories in the United States in the field of rocket propulsion was the Guggenheim Aeronautical Laboratory, attached to the California Institute of Technology. This lengthy designation was frequently shortened to GALCIT; later, it became known as the Jet Propulsion Laboratory, or JPL. It was located in Boswell's territory, in Pasadena. This laboratory contained some of the most active scientists and engineers in the American Rocket Society. Theodore von Karman was the director of GALCIT in those days, and Frank Malina and Martin Summerfield were two of the active workers in the field of rocket propulsion. For the most part they concentrated on liquid rockets, but they did develop a small solid propellant rocket designated the GALCIT 27, to provide a jet-assisted takeoff (JATO) for airplanes. This solid rocket had a 2-lb charge of black powder, pressed in 22 increments at 18 tons of pressure into a solid end-burning cylindrical charge that was 10 inches long and 1.75 inches in diameter. It burned for 12 sec, and the liner consisted of blotting paper. On August 12, 1941, an airplane (with Lt. Homer Boushey as the pilot) took off in almost half the normal runway length, using these crude rocket JATOs. Despite this early success, JPL's emphasis continued to be placed on liquid rockets.[9]

The next advance in solids came from a joint effort between GALCIT and a newly formed commercial organization named Aerojet. This was the Private rocket motor, using a composite mixture of asphalt as the binder and potassium perchlorate as the oxidizer.

This entirely new type of propellant was first made by John W. Parsons in 1942.[9] It is reported that he watched a roof being tarred and conceived the idea for mixing this fuel-like material with a solid source of oxygen. One of the key steps in processing this material required heating the asphalt to 350°F and adding potassium perchlorate as the oxygen source. The mixture was then put into a combustion chamber, bounced a few times to provide settling action, and cooled. A hard material with very little elongation and tensile strength resulted, but it was a considerable improvement over the pressed black powder charges. It had an operating temperature range from -9° to + 120°F, and it produced a specific impulse of 186 seconds in the GALCIT 61-C formulation. Designs using it required a complex system for inhibiting the exterior of the propellant, insulating the interior of the rocket motor case, and suspending the charge inside the latter. This general type of design was known as the trapped-grain approach, since it was necessary to hold (or trap) the grain, so it would not be ejected from the nozzle before it burned completely.

In late 1943, a young JPL engineer named Charles "Chuck" Bartley was searching for a better binder material than the brittle asphalt. He began by using synthetic rubber, in gum form, mixed with potassium perchlorate. This approach required cutting out thin sheets into star grain cross sections and then pressing and binding several of these perforated discs together with an adhesive. At first he evaluated the newly available Buna S (polybutadiene-styrene) synthetic rubber and then later, the DuPont-produced neoprene (polychloroprene). These were improvements, but the process was time-consuming and expensive.

"Bartley told me he was attending a meeting of the American Chemical Society when he discussed his desire for this type of material (a liquid that would polymerize to a solid elastomer) with the various attendees. There was a representative from the Shell (Development) Laboratories in the San Francisco area (Emeryville, California), who had just heard of a new development by Thiokol Corporation, a liquid polymer which could be cured to form a rubber."[10]

Chuck Bartley made contact with Walt Boswell and began ordering small quantities of liquid polysulfide polymer in the form of LP-3. It proved to be so well adapted to formulating solid propellants that Bartley began ordering larger and larger quantities for the work at JPL.

By late 1945, Bartley had demonstrated "that a rubber-like polysulfide developed by Thiokol Chemical Corporation possessed most of asphalt's desirable features with few of its drawbacks."[11] All of this work was conducted under Government security regulations, and the people in Trenton at first did not know what use JPL was making of their product, but they could see the orders increasing, and this excited their interest.

According to Mr. Crosby, "At that time we were looking for any source of business we could find, and I reviewed every purchase order for possible future business. When I saw the JPL orders increasing from samples to 5 gallons, and then to a drum of polymer, I called Walt Boswell and asked him what JPL was using it for. He said that they wouldn't tell him because it was classified. We applied for a security clearance, got it, and found they were using it for solid-fuel rockets.

Later, because they were having trouble curing it, we sent a chemist named Bob Alexander out to JPL to work with them for five weeks, and help them with their problems."[12]

About 1946, Army ordnance personnel became interested in the new development, and they funded a project with JPL to develop the Thunderbird, a 6-in.-dia solid propellant rocket. Bartley and two other young JPL engineers (J. I. "Jack" Shafer and H. L. "Larry" Thackwell, Jr.) began work on this program, using the polysulfide propellant. This type of propellant is shown in Table I, listed as T-10. To make the Thunderbird, they used a completely different manufacturing technique from the one required by the asphalt-based composite propellant. They first coated the inside of the combustion chamber with a thin layer of polysulfide polymer without the oxidizer, and then formed a grain in the cavity by "pouring" in the propellant, using a metal core to produce a grain cavity with a specific shape whose initial burning surface area was nearly equal to the final burning surface area just before burnout. It was a 10-point internal-burning star design.

The Thunderbird rocket motor was successfully tested in early 1948. Based on the results, JPL engineers proposed that by scaling up this manufacturing technique, using the Thiokol polysulfide propellant, a much larger rocket motor could be made – one as large as the German V-2 liquid rocket motor used in World War II that would have a range of up to 300 miles.[13]

Eventually the JPL Thunderbird contract with the Army was completed. Crosby, not wishing to see this source of LP sales end, asked the Army about other rocket manufacturers.

"There are only two – Aerojet and Hercules." Crosby made contact with both. Both replied, saying they had no interest in the Thiokol polymer, despite the promising JPL results, because its high sulfur content (32%) made it a poor fuel. Crosby went back to the Army, asking, "Are you going to let this work die on the vine?" In the spring of 1947,[14] an Army Ordnance representative, Dr. Colin Hudson, visited Trenton and asked if Thiokol was interested in going into the business of making rockets on their own, since Aerojet and Hercules were not interested.

Crosby, Ferguson, and Martin took about two days to think it over and decided they had little to lose and perhaps a lot to gain. They asked the Army for funding – to get started.

The Army replied, "We don't have very much money."

"How much?"

"Oh, about $150,000." In those days, that was more than 10% of Thiokol's annual sales. In order to get the contract, Thiokol found that it was necessary to prepare something the Army called a proposal. Not having ever done this before, Thiokol hired their first employee for rocket work, a man named Glen Nelson, who came to them from the Explosives group in DuPont. The proposal was duly written in late 1947, forwarded to and accepted by the Army, and Thiokol was now committed to entering the solid rocket industry.

At about the same time, Thiokol bought a prospective site for its rocket activities outside of New Brunswick, New Jersey, and they began searching for someone – anyone – who knew something about rockets.

Dr. Martin remembered a friend of his, a Dr. William Mebane, from their days together as graduate students in chemistry at the University of North Carolina. Dr. Mebane was then teaching at the Naval Post Graduate School, located in those days in Annapolis, Maryland. Dr. Mebane, who had had some experience with rockets was brought in as a consultant to Thiokol. Dr. Mebane reviewed the New Brunswick site and did not feel it was suitable.

Thiokol then found an idle World War II ordnance plant in Elkton, Maryland, so they sold the New Brunswick property and rented the Elkton site. In early 1948 Lou Welanetz (a Ph.D. chemist) was hired as the first general manager for the Elkton site. Some of the other early employees hired at that time were Jack Buchanan, a young engineer from Stanford, Anthony Guzzo from Cornell, and George Martin. Jack Buchanan remembers those early days:

"I graduated from Stanford in 1942, and was inducted into the Army, ending up as an Army officer at JPL, assigned to the rocket program. While there, I met Mr. Crosby and Mr. Ferguson, who were visiting "Chuck" Bartley, and Mr. Crosby eventually had Dr. Welanetz hire me at Elkton in March of 1948, to work on the Army contract he had received a little earlier.[15]

The town of Elkton welcomed the new facility, because of the jobs it would provide for the ex-ordnance plant employees. Elkton had at that time a thriving fireworks industry, started by immigrants from Italy who had passed their pyrotechnic formulas and processes down from one generation to another for many years. All of this, plus the many reinforced-concrete barricades on the property left from World War II made Elkton much more attractive than New Brunswick.

On top of this, an Army Colonel (probably Col. Carroll Hudson) came to town and told Elkton that this move by Thiokol was a big development in the town's economy, and that all support needed should be given.

About six weeks later, according to Mr. Crosby's recollection, the Colonel gave Thiokol orders to pick up and march – to Huntsville, Alabama. A photograph of Colonel Hudson and Thiokol management at Redstone Arsenal in 1949 is shown in Fig. 6.

Figure 6. Redstone Arsenal 1949 Lt. Col. Gillespie, Dr. Lou Welanetz, J. W. Crosby, Col. Carroll Hudson, Harry Ferguson, H. G. "Griff" Jones, and Maj. Frank Austin

What happened within the Army to cause such a reversal of plans? These details have been supplied by "Griff" Jones:

"Col. Toftoy became convinced the Army needed a rocket site of its own. A Col. J. P. Harris, then Commandant of Picatinny Arsenal, at first opposed this decision, but in later discussions recommended that Redstone Arsenal in Huntsville, Alabama (which had been declared surplus), be looked at as a possible site. Col. Toftoy flew to Huntsville and inspected it sometime in 1947 or 1948 and came back enthused over its possibilities. However, the new Secretary of Defense (James Forrestal) and the Chief of the Army (General Johnson) were implementing a post-World War II austerity program. I therefore worked up a proposal for Col. Toftoy to give to General Hughes. Col. Toftoy made the presentation.

At first there was no reaction. General Hughes left the room and went to his office, without a sign of encouragement. Finally he came back and said, "I'll support it." The final outcome was shown in an Army Ordnance document dated 3 March 1949. In the first paragraph, it states:

"It has been determined that the best interests of the Government will be served by the transfer of the activities of the Thiokol Corporation, Elkton, Maryland to the Rocket Research and Development Center at Redstone Arsenal, Huntsville, Alabama." This document was signed by Colonel Toftoy, by order of Major General Hughes.

For 1948, Thiokol reported sales of $1,139,662 and profits of $52,371. By 1958, Thiokol sales had grown to nearly 80 times this value, for a total of $88,993,121, with resulting profits of $3,007,699.[16] Very few companies in the history of American industry have experienced a similar rate of expansion, and no one, including Joe Crosby, who signed the 1948 Annual Report, had any intimation of what was in store for them. Then in 1959, sales doubled again in one year, reaching a total of $190,198,753.

The first decade of Thiokol's work in rockets had ended, but even more growth was in store for it.

The First Polysulfide Rocket Motors

In early 1948, actual operations began at the Elkton site. Beginning with six engineers, the organization rapidly expanded to about 30 people. Thiokol began making polysulfide propellants, like T-10, using mixers of the commercial kitchen equipment-type (KitchenAid and Hobart) and moving up to larger Baker-Perkins horizontal twin rotary blade mixers. The first rocket motor made by this group was tested in July 1948, and Fig. 7 shows one of the young engineers, Donald W. Kershner, holding it. Close inspection of the photo shows that it was an end-burning grain, reportedly insulated with an asbestos fiber tape. The test bay where this first motor was fired is still in use today, as part of the test area of the present Elkton DLV Operations of Thiokol Propulsion. Kershner was later to become general manager of the Elkton Division when it was reactivated in 1951.

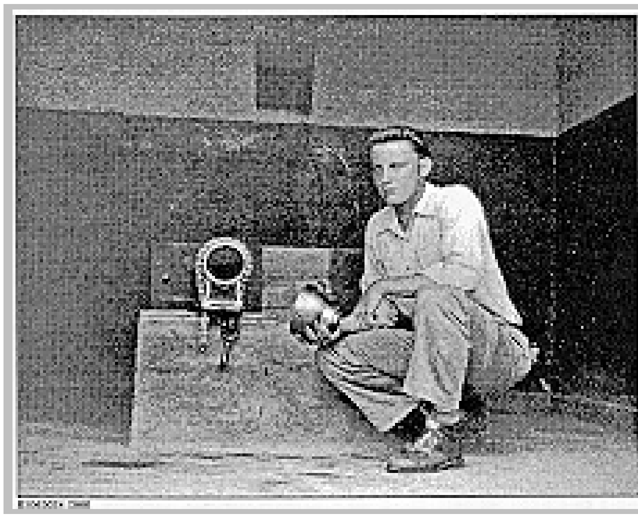


Figure 7. The First Thiokol Rocket Motor (July 1948)

Thiokol began in Huntsville in 1949 with a small Army-funded contract and added to it with funds from its own meager profits. This first Huntsville contract was for $36,774 and it was signed by Joe Crosby and Col. Carroll Hudson of Army Ordnance. The Army had only about $250,000 a year to support Thiokol, but to a company whose annual sales were heading downward from a war-time peak of slightly over $1,000,000 a year, this was a big opportunity. Dr. Mebane left the Navy in 1949 and became the first general manager of the Redstone Division.

In 1949, the most influential person in Thiokol's rocket history arrived on the scene in the person of Dr. Harold W. Ritchey (Fig. 8). Dr. Ritchey had unquestionably one of the best possible backgrounds for assuming technical direction of Thiokol's infant rocket activities.

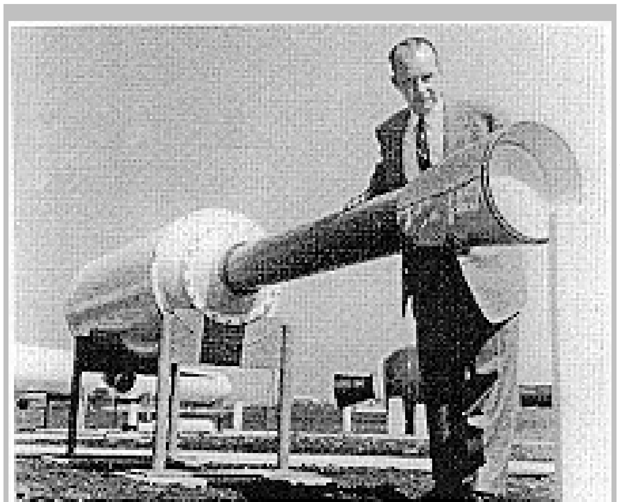


Figure 8. Dr. H. W. Ritchey

He had received a B.S. in chemical engineering in 1934 from Purdue University, followed in 1936 by a M.S. in physical chemistry, and a doctorate in physical chemistry in 1938. World War II found him stationed as a Navy Lieutenant at San Pedro, California, in charge of the Navy Harbor Defense School, an antisubmarine school. Because of his background, the Navy ordered him to take courses aimed at making him an expert in the ordnance engineering of explosives and gun propellants. Part of this involved a period at Cornell University, where he was assigned by the Navy to pursue an M.S. in chemical engineering. By agreement with his professor and course director, "Dusty" Rhodes, who was also head of the Chemical Engineering department he elected to prepare a thesis on rocket propulsion entitled "The Mechanics and Thermodynamics of Propulsion by Jets."

In January 1945, the German Army, in a last desperate move in World War II, began launching V-2 rockets from various locations in Europe toward London, and rockets instantly became a matter of very high priority to the U.S. military. Dr. Ritchey was ordered to return quickly to the Naval Post Graduate School and to begin the task of teaching the first course in rockets to the aspiring young naval officers of that institution. As a part of this, he wrote his own text for the course. At that time, he became acquainted with Bill Mebane, a fellow instructor, and only four years later, on Easter Sunday of 1949, Mebane sent him a telegram offering him the job of technical director of the newly formed Thiokol Rocket Operations. Very shortly thereafter he flew to Huntsville and Elkton, and accepted the position, starting work on June 1, 1949.

Beginning in April 1949 and continuing through July, about 30 people began moving from Elkton to Huntsville, and the Elkton operation closed down, but only for two years. A short two months after arriving in Huntsville, they fired their first motor on June 21, 1949, an end-burner,[17] but very soon thereafter they began testing internal-burning, case-bonded motor designs, and Thiokol made rapid progress in developing the engineering and manufacturing details of this type of design, under the technical direction of Dr. Ritchey.

Also, in 1949, Thiokol had scaled up their 5-in. motor case-bonded design with approximately 10 lb of propellant to an 8-in.-dia case-bonded motor containing 100 lb of propellant and successfully tested it. Jack Buchanan remembers:

"The Army contract called for this motor to be tested on a certain date, and we fired it on the required date, but it was 11:30 at night when we fired it." This motor, known as the T-40, was probably the first successful demonstration that internal-burning case-bonded motor designs using polysulfide propellants could be successfully scaled up to larger diameters.[18] T-131 and T-41 (the first Falcon design) motors were also being tested at this time). This scaleup factor of 10 to 1 was shortly to be exceeded by a much more ambitious project, known at first as the Hermes A-2, and later as the RV-A-10.

The first two rocket projects pursued by Thiokol for Army Ordnance were the T-40, intended for use as a JATO unit, and the T-131 gun-boosted, air-launched rocket. The latter consisted of a high-explosive (HE) round that was to be fired from a conventional gun in the normal manner, and then boosted to a higher velocity and longer range by a polysulfide propellant grain burning as a rocket motor. This program demonstrated in an unusual manner the superiority of the mechanical properties of polysulfide propellants over the more rigid binders in use at the time, and the superior ruggedness of case-bonded grain designs. It was unique in that the mandrel used to form the internal surface of the grain was a large screw thread; this was selected because of its expected resistance to the very high acceleration forces placed on it during the gun launch.

Dr. Ritchey remembers: "The first T-131 used T-10 with a star design, which was formed by melting out the Wood's metal mandrel after the polysulfide curing process was completed. The high rotation rate of the T-131 caused by the rifling in the gun barrel caused severe erosion on one side of the star points, because of the high gas velocity. When we changed to T-13 propellant this erosion became very bad and we also needed more burning surface area. Both problems were solved by the screw-thread design."[19]

The third project in 1949, in the form of the T-41 motor, was designed for the Falcon air-to-air missile with Hughes Aircraft Company acting as the missile developer for the Air Force. This design was very similar to the JPL Thunderbird motor mentioned earlier, with a reduced length. The Falcon missile is shown in Fig. 9.

Figure 9. Falcon – The First Polysulfide Production Motor

A report of that period states that "at the end of July, installation of the Huntsville facilities was proceeding at a satisfactory rate and all production equipment" (including the 20-gallon mixer, the largest used at Elkton) "remaining at Elkton was in transit to the Huntsville location. Pilot line operations will be resumed there early in August.[20] Thiokol was as good as its word; the first batch at Huntsville was mixed on August 1, 1949. According to Dr. Ritchey, "The first batch of propellant that was mixed and cast at the Redstone Division was done on August 1st of 1949. The facilities had not been completed at the time and we had no electricity in the casting bays . . . The operation became quite late and finally it got dark . . . The first batch was cast by the lights of my old Studebaker . . . I pulled it up in front of the casting bay and shined the lights in so the operators could see to finish the operation."[21] The mixing equipment at Huntsville was augmented by the addition of 50- and 100-gallon mixers; the latter gave Thiokol a capability of mixing approximately 1000 pounds of propellant per batch.

Falcon – the First Polysulfide Production Rocket Motor

By the end of 1949, 18 mixes had been made in the 50-gallon mixer, and several new projects had been added and had reached the loading stage. In addition to the T-40 JATO, the T-41 Falcon, and the T-131 gun-boosted round, other rocket motors under development were the T-44, T-45, T-36, T-84, and the improved Falcon, the T-42. Processing of these polysulfide propellants was difficult because of the problems resulting from the cure exotherms and shrinkage resulting from the conversion of the liquid polymer to the solid elastomeric state. These were solved by the introduction of a temperature-programmed cure cycle. Also, a slit-plate vacuum-casting system was introduced to remove mixing bubbles. Later on, pressurized curing was introduced to allow propellant to flow back into the motor from the head-cap area, and this further improved the processing of these propellants."[22]

According to Dr. Ritchey, "In the summer of 1950, controlling the manufacturing of T-10 propellant (with a pressure exponent of 0.82) was driving me wild and I was ready to do anything to substitute T-14 (pressure exponent of 0.34) for it. One hot June [day in] 1950, in an unairconditioned office in Huntsville, before the administration building was built, with a ten-cent compass and ruler, I designed . . . a double-web design – [with a] burning surface twice or more the case perimeter, as the (T-42) design required. What a simple thing to make a major breakthrough!"

With the rapidly accumulating successful experience from these many and varied programs in its grasp, Thiokol and its engineers were now ready to take on a much more ambitious project.

Sergeant – The First Big Polysulfide Motor

In the meantime, during 1949, JPL had been struggling unsuccessfully to scale up the technique they had originated to a 15-in.-dia motor named the Sergeant. Dr. Von Karman is reported to have defined the succession of JPL rocket motors by explaining to one Army Ordnance general that they would start naming them with the rank of Private, advancing through Corporal to Sergeant, and continuing until they reached the rank of Colonel. They would then stop, because "everyone knows that nothing above the rank of Colonel works." Fortunately for Von Karman, this amused the general controlling his funding rather than antagonizing him.

Unfortunately for Dr. Von Karman, the first 12 tests of the JPL design for the Sergeant test vehicle did not work. The General's reaction to this string of failures is not known.

By the summer of 1950, Louis "Louie" Dunn, director of the laboratory, had de-emphasized solid propellant research to the point where one of the original triumverate (Bartley, Shafer, and Thackwell) defected. Larry Thackwell moved to Huntsville and joined Thiokol.

In the 1940s, Vannevar Bush, an electrical engineer from the Massachusetts Institute of Technology (MIT), was the acknowledged leader of American science during World War II and the postwar period. He headed the Office of Scientific Research and Development (OSRD), along with James Conant, the Harvard chemist, and together they established the forerunner of what was to become a pivotal practice for the U.S. – Government funding of contractor-executed military research and development programs.

In December 1945, Bush assessed the state of the art, and pronounced, "I say technically I don't think anybody in the world knows how to [build an accurate ICBM] and I feel confident it will not be done for a long time to come." [23] Four years later, in 1949, he modified his position and admitted that such a weapon was now possible, but the cost would be extremely high.

In the last months of World War II, the success of the German V-2 had galvanized the U.S. Army into initiating a study of rocket technology, in general, and, in particular, the liquid-fueled V-2. This effort was begun in November 1944 as an Army contract with General Electric and was named the Hermes program. Starting in 1946, 67 V-2s captured from the Germans were fired over the next five years at White Sands Proving Grounds in New Mexico. In 1950, Dr. Werner von Braun and many of the other German engineers from Peenemunde were moved with their families to the small town of Huntsville, Alabama, next to Redstone Arsenal. Under Project Hermes, they began work on the A-1, a modified and smaller version of the V-2 with an initial range target of only 38 miles, as compared to the V-2 range of 125 miles.

At the same time, Army Ordnance personnel, impressed by the speed and ease with which Thiokol/Huntsville had scaled up case-bonded, internal-burning polysulfide propellant rocket motors, approved a second development program – a solid fuel version of the Hermes, to be known as the Hermes A-2. General Electric would continue as the prime contractor, and Thiokol would design and build this new 31-in.-dia rocket motor. JPL would also be involved in the program. In February 1949, JPL began static testing of a 15-in.-dia motor as the initial step to the design of a 31-in.-dia motor.

This diameter was selected because when a case manufacturer who could roll and weld steel cylinders in the size range was found (Excelco in upper New York state), Excelco had existing tooling for making 31-in.-dia rolled and welded steel tubes.[24] The payload requirement was increased from 500 to 1500 lb, and this increased the optimum diameter from 26 to 31 in.

The entire Thiokol funding for this pioneering project was slightly less than $2,000,000. The design called for a 5000-lb propellant charge and a length of 108 in. Thiokol made two key decisions that changed the unsuccessful JPL design to a successful Thiokol motor. The first was to change to a lower web fraction grain with larger radii on the star points to prevent grain cracks from developing during full-scale and subscale motor firings.[25] This change was based on the results of photoelastic grain studies that Thiokol requested be done at the Armour Institute (later to become Illinois Institute of Technology). The other (and less significant) change was to use a thicker case wall (0.200 in.) than that used by JPL (0.065 in.) in the 12 unsuccessful tests on the Sergeant test vehicle program earlier. The original General Electric/JPL design had a high loading density, a high web fraction, and six star points. Type B was the same grain design used by Thiokol in the T-40 motor, with seven points. Type C was also a Thiokol design, with six points, and a lower web fraction than the Type A design. Type D, the one finally used in the Hermes, was a later design with five star points and an even lower stress concentration. In particular, the star points were rounded off to reduce stress, and to distribute the stress evenly over the entire cross-sectional area of the motor.

Effort on the Hermes A-2 rocket motor and its transporter started in May of 1950, and the first full-scale static test was made 18 months later in December of 1951. And it was successful.

This first scaleup by a factor of 50 to 1 for less than 2 million dollars made it clear that Dr. Bush's statements about the practicality of ICBMs were rapidly being overtaken by the ever-increasing pace of events at Thiokol. This first motor weighed 6,555 lb, including 4,786 lb of T-14E1 propellant, in a 31-in.-dia by 118-in.-long case with a 0.25-in. wall thickness of 4130 steel. It burned for 41.2 sec, delivering an average thrust of 17,172 lbf, with a total impulse of 795,000 lb-sec. A photo taken after this first static test is shown in Fig. 10.

Figure 10. Hermes A2 Firing December 1951 – The First Big Motor

Over the next 15 to 20 months, 20 additional full-scale static tests of the Hermes were conducted, and a final flight design was selected. During the course of the development program, the designation for this motor was changed to RV-A-10.

By the time the four successful flight tests of RV-A-10 had been made at Patrick Air Force Base in Florida, starting with the first in February 1953 and ending with the fourth in March, it had been established beyond all doubt that Dr. Bush's doleful predictions about the ICBM were not correct with regard to the technical feasibility of the propulsion system and its cost.

The Hermes A-2/RV-A-10 program produced an impressive series of firsts:

- The first successful static and flight tests of large (31-in. dia x 108-in. length), long-duration (41.2 sec), internal-burning, case-bonded solid propellant rocket motors.
- A manufacturing process that was low in cost and high in reproducibility.
- A method of using multiple mixes to cast motors of any size, with a capability of 5000 lb demonstrated in one day of mixing and casting.
- Engineering data and methods that were able to design rocket motors with high reliability despite the use of scaleup factors as high as 50 to 1.

The success of the Army-supported Hermes program began to attract the attention of the Air Force. Since the Army exercised full control over all groups located on its Redstone Arsenal, it demanded in 1950, when the Falcon was being developed, that the Air Force transfer the necessary funds to the Army first, and then the Army would fund Thiokol for the necessary program, after diverting a portion of the funds to the upkeep of the arsenal and its personnel.

Because of this, the Air Force approached Crosby and asked him to consider investing in a second rocket plant so that the Air Force and Thiokol could deal with each other directly. As a result, in 1951, Thiokol reactivated the original Elkton site and hired a limited number of chemists, engineers, and technicians to staff it. They sought out the young chemical engineer named Don Kershner, who had worked as a summer student at Elkton during the 1948 period, and put him in charge. All of the experienced Huntsville personnel were too busy to transfer back to Elkton, and so a new group was formed. By mid-1953, the revived Elkton Division consisted of only 20 people, while Huntsville had grown to about 400.

Because of the rapid multiplication of rocket development programs at Huntsville, in 1952, after winning a proposal competition, Thiokol took over the operation of the Longhorn Ordnance Works near Marshall, Texas, and began to refurbish it for the production of rocket motors to be used in Army missiles. The growth at the Redstone Arsenal site had crowded the facility to the point where the need for production of already-developed rocket motors was making it difficult to initiate the development of new or improved versions of the existing propulsion units. And so, by 1952, Thiokol found itself with not one, but three different locations involved in solid rocket activities. Huntsville was the Army-supported R&D facility, Longhorn was the Army-owned production facility, and Elkton was the Thiokol-owned facility for doing business directly with the Air Force and the Navy.

The Air Force in those days had all of its propulsion R&D activities located at Wright Patterson Air Force Base in Dayton, Ohio, and they began funding Elkton, primarily to work on a JATO unit to be loaded with a polysulfide propellant using an ammonium nitrate oxidizer. Despite its known lower performance, the Air Force felt the lower cost of ammonium nitrate (about one-tenth that of ammonium perchlorate) would offer advantages in system cost over the long run. A recollection of those days has been supplied by P. R. Dykstra.

"In December 1950, I went to work in the Power Plant laboratory at Wright Patterson Air Force Base (this activity was moved to Edwards Air Force Base in 1958 and renamed the Rocket Propulsion Laboratory).

A Major Ed Hall had been assigned as the assistant chief of the Non-Rotating Engine Branch (in those days the Air Force felt that "non-rotating" was the most lucid way to describe rockets so as to distinguish them from serious engines). Since fifty-one JATO bottles were needed for each B-47 takeoff, he concluded that the Air Force needed a cheaper JATO bottle. He decided that the only hope for cheap rocket motors was ammonium nitrate propellant and he hired me to manage the Air Force ammonium nitrate work. . . ."[26]

In the period from 1951 to about 1955, the reactivated Elkton Division worked almost exclusively on ammonium nitrate propellants, but eventually the hygroscopic and phase changes of this oxidizer resulted in this work being dropped by the Air Force and Thiokol. Phil Dykstra left the Air Force and joined Thiokol, eventually becoming a vice president at the Wasatch Division.

After successful completion of the RV-A-10 program, Thiokol looked for an application for the technology developed under it. The first candidate was an Army program to develop a surface-to-surface guided missile system. Since the Corporal had been developed earlier as a liquid-fuel rocket, this new system was named the Sergeant.

Plans for the Sergeant began issuing in the spring of 1954[27] and by August, Col. Hudson had chaired an Ad Hoc Evaluation Committee that accepted the plans and started the Sergeant program in the fall of 1954. The Sergeant solid rocket motor was a direct descendant of the successful Hermes, with Thiokol continuing as the rocket motor developer and supplier. By February of 1958, the Sergeant system was ready for development, nearly two years ahead of its original schedule. It provided lighter weight, greater mobility, and greater range than the liquid-fueled Corporal.

The ICBM Initiative

By 1955, the Air Force had successfully won the responsibility for developing land-based ICBMs despite the Army's strenuous objections. Because of their need for nose cone reentry data, they contracted with Lockheed and Thiokol for the development of the X-17 test vehicle, using a modification of the Hermes as the first stage and three smaller Recruit rockets as the second stage. 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 drove the test vehicle into the atmosphere at a speed that simulated ICBM reentry conditions.

With a total of 8,000 lb of solid propellant in its three stages, the X-17 proved still further the reliability of solid motors; the program had only two failures out of 36 test flights and this was caused by a lack of sufficient stiffness in the structural design of the missile assembly, not by the rocket motors. After Lockheed stiffened the structure, based on a suggestion by Dr. Ritchey, there were no further failures. The X-17, still using Thiokol rocket motors later provided NASA with data for the upcoming Mercury capsule design as well as data for the Air Force on the Thor and Atlas ICBMs.

Also, four of the X-17 units were provided to Lockheed and the Navy in 1956 for obtaining data on the Navy's Submarine-Launched Ballistic Missile (SLBM) program, the Polaris. This Polaris Test Vehicle was used to test the first thrust termination system and a jet-vane guidance steering system.

Thiokol's rapid progress toward a simple, rugged, and powerful all-solid three-stage propulsion system continued to stimulate the Air Force's interest, offering an attractive solution to the flight readiness problems of the liquid Thor engine they were developing.

According to Dr. Ritchey, "The Air Force had long been interested in solid rocket ICBMs but the only suitable propellant was the polysulfide type, with an I_{sp} of less than 200 sec because of the low fuel value of its sulfur content . . . "

In 1952, research on polyhydrocarbon polymers with higher fuel values than those produced by polysulfide polymers was begun at the Huntsville propellant research laboratories, under the laboratory director, Dr. W. F. "Bill" Arendale. The work was done by Dr. Dean Lowry, ably assisted by a new young chemist, W. E. "Billy" Hunter.

The first attempts used polyisobutylene alone, then copolymers of isobutylene with isoprene, and then a copolymer of isoprene and butadiene. It was difficult to add functional groups to these polymers that could be cured easily. Eventually the Huntsville chemists developed a copolymer in 1954 of butadiene and acrylic acid, named PBAA, that possessed attractive properties. In those days the laboratory-size samples of this new material were synthesized in large 32-oz Coca-Cola bottles, since these were the right capacity and size (and cost) to fit the homemade polymerization cabinet used to produce sufficient quantities for characterization in experimental propellants.[28] The carboxyl groups provided by the acrylic acid were reacted with a liquid epoxide resin to provide a cured polymer binder.

PBAA was a definite improvement, and the first motor tests of a PBAA propellant produced a measured I_{sp} of 240 sec. Dr. Ritchey flew all night to take the news to the Air Force Ballistic Missile Division in Inglewood, California. However, PBAA propellants did not possess good tear strength, and so in late 1954, a third monomer was introduced – acrylonitrile. Now the acronym changed to PBAN, and the physical properties changed – for the better. This same polymer, originally developed by Thiokol, was produced in large quantities at the American Synthetic Rubber Corporation in Louisville, Kentucky, during the late 1950s. This is the polymer that has accumulated the largest production tonnages in the industry because it was used in the Minuteman and Poseidon programs and is used today in the Space Shuttle booster motors. Each of the latter contains 1,107,000 lb of propellant. A list of Thiokol-developed liquid hydrocarbon polymers is presented in Table II, and Table III shows the progress made in solid propellants resulting from their use.

At some point in the late 1950s, the Chemical Division of Thiokol reviewed the work of the Rocket Division on the PBAN polymer, with an eye toward producing it for sale to the Rocket Divisions. After due consideration, the decision was made to go one step beyond PBAN to the development of a carboxyl-terminated polybutadiene (CTPB). Because of this, the production of PBAN has remained with ASRC (later renamed Kentucky Synthetic Rubber Corporation) to this day. This carboxyl-terminated polybutadiene (CTPB) polymer was used to develop solid propellants with even better mechanical properties than the PBAN polymer, but it never fully supplanted the latter, partly due to its higher cost, and partly due to the emergence of an even better polymer, known as HTPB (hydroxyl-terminated polybutadiene). This polymer became available in the late 1960s, as a lower viscosity, lower cost polymer that has become the standard for the industry.

In 1955, seeing more Air Force business in the offing, Thiokol finally transferred an experienced cadre of managers and engineers from Huntsville back to Elkton, and this division began to grow also. Among those transferred were John Higginson (who was appointed general manager), Bryce Wilhite (who formed and headed a previously nonexistent Engineering Department), Horace "Buddy" Bomar, and Anthony Guzzo. In October of 1955, a meeting of the Board of Directors took place where a request for the money to build a large new plant was placed before the Board.[29] This request was the result of an internal decision that a much bigger site than Huntsville or Elkton was needed if Thiokol was to "stay in the business."[30] Bryce Wilhite recalls a Thiokol meeting in early 1956 held at Mount Tremblant in Canada where he gave Mr. Crosby an estimated cost of $2,000,000 for building a large motor plant.

In those days, a large part of the financial support of Thiokol was provided by the Bankers Trust bank in New York, and the initial Board response in the morning of the meeting was not very encouraging, despite an excellent presentation by Dr. Ritchey. One of the Board members (Bill Spencer) groused that he had never heard of a company that wanted to build a plant without a single order.[31] Spencer and Otto Schweng argued that Thiokol should put its scarce capital into commercial ventures. However, by the afternoon session, the Board relented and approved an effort to raise funding of nearly $2 million to build the plant. Thiokol's total sales for the previous year (1955) were $21,053,000 and the 3,750,000 shares of stock possessed a book value of $1.18 per share, so the $2 million approved was a sizable fraction of the total stockholder equity. The final figure of $1,950,000 was obtained by stockholder subscription, and was available by early 1956.[32]

<u>Minuteman and the Move to Utah</u>

Now came the task of locating a site that had sufficient acreage, and, more important, could be bought at an affordable price. After reviewing many sites over a two-month period, the decision was made to purchase 11,000 acres of a cattle ranch just north of the Great Salt Lake in Utah, at a price of $2.95 per acre (about $32,000 in total). The rancher would continue to graze his cattle on 90% of the land, while Thiokol would use the other 10% to build the new plant. The Board gave formal approval for the $2 million in February 1956, and the Utah site in Brigham City (known locally as Lampo Junction, Fig. 11) was selected by May of the same year. Eventually, this site was expanded to 22,000 acres. In August, a bid was selected from the architectural firm of Ashton, Evans, Brasier, and Monroe, and design began. By 1965 this arid hilly site north of The Great Salt Lake had become a small city with several thousand employees and hundreds of buildings for designing, manufacturing, and testing large solid rocket motors (Fig. 12).

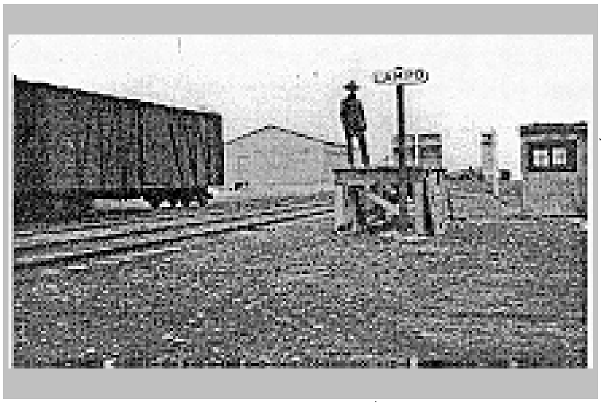


Figure 11. Lampo Junction Before 1956

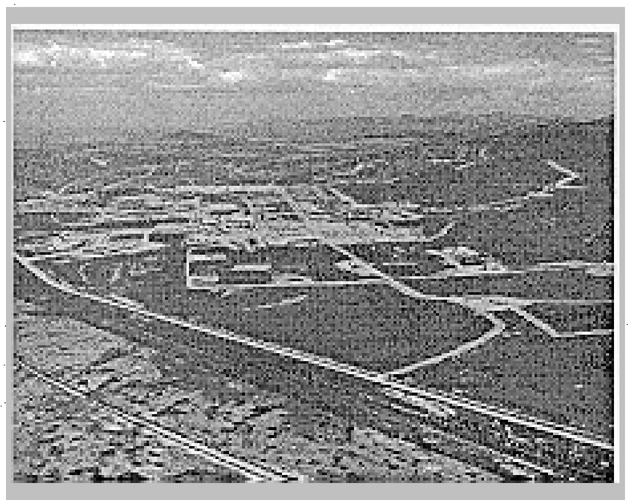


Figure 12. Thiokol at Lampo in 1965

Ground was broken by November 1956, with construction starting on the test area first, and the first buildings were completed by February 1957. The site began requiring so much concrete (3000 cubic yards for test bays) that a small concrete plant was built on the site.

By early 1956, the Air Force, after reviewing the Navy's Lockheed/Aerojet Polaris program, and designs from Thiokol and the other solid propellant manufacturers, was able to obtain approval to start a new, solid-fueled ICBM program that would be a significant step beyond Polaris in range, and also would reduce the hours-to-days times required to reach flight readiness for the liquid-fueled Atlas, Titan, and Thor programs to a grand total of 60 seconds. Initially, in October 1956, Thiokol began work on the feasibility programs; one on propellant development, and another on motor design and development.

Because of the 60-sec objective, the new system received the name of Minuteman, backed up by a logo that was reminiscent of the Minutemen of the American Revolution. This program was to provide Thiokol with a set of technical and financial challenges that could have swamped a less determined, less technically capable small company.

During the summer of 1957, some of the same cadre, John Higginson, Bryce Wilhite, and Anthony Guzzo, who had moved from Huntsville to Elkton in 1955, moved again -- this time to Utah. Higginson, who had been the second general manager of the reactivated Elkton plant, became the first general manager of the new Utah plant and Wilhite became the first technical director (Fig. 13). Other personnel including Jack Dieter and Bill Kelly were transferred directly from Elkton and Huntsville, and the race began.

Figure 13. John Higginson, Utah Governor Clyde, and Bryce Wilhite With an Early Horizontal Baker Perkins Mixer

By December 1957, the new plant had manufactured its first large engine, containing more than four times as much polysulfide propellant as the RV-A-10 (22,000 lb), and, in February 1958, this first large motor was tested successfully, as the TU-110. Soon after, a similar motor was loaded with polybutadiene acrylic acid (PBAA) propellant and tested successfully as the TU-111. This motor advanced the industry's technology for several reasons -- it was the first scaleup of a propellant that contained the new PBAA binder, and it proved again that a solid-fueled ICBM was within grasp in both technology and cost.

The Air Force let two propulsion contracts for each of Minuteman's three stages, and Thiokol was successful in winning one for each of the three stages, the only propulsion contractor to do so. Not only was the new Utah Division heavily involved in these development operations, but Huntsville and Elkton were also assigned significant portions of the effort. In order to coordinate this multifaceted program, Thiokol set up a program management office on the 12th floor of a building in downtown Ogden, Utah, and sent John "Jack" Buchanan, formerly head of the Test Department at Huntsville, and John "Mac" McDermott, head of the Propellant Development Laboratory at Huntsville out to coordinate phases of the program between Utah, Huntsville, and Elkton. When office space became available, they moved out to the plant site. At the Utah Division, some of the key people involved in running the Minuteman program were Ed Garrison and Phil Dykstra.

By the end of 1958, the original small chemical company with sales of $1.1 million in 1948, had grown in 10 years to a large solid propulsion contractor, still combined with a chemical company, and its sales for that year were $89 million with $77 million of this from its propulsion activities. The first decade of Thiokol as a rocket motor developer, designer, and manufacturer was over, with record growth.

But even more growth lay just a year away, and even more diversity in the types of rocket motors it was supplying to the Department of Defense and the newly formed National Aeronautics and Space Agency (NASA). By now it was a recognized power in solid rocket motors for tactical missiles and large ICBM motors, and it was soon to become preeminent in a third area – Space.

Big Motors for Big Launch Vehicle

Wasatch, because of its huge area, soon became the lead division for big motors. In 1958, the Army had lost its Army Ballistic Missile Development Agency (ABMDA) to the newly formed NASA. With this shift went Dr. Von Braun, all of the large liquid engine programs, and most of the German scientists and engineers. The objective of this new agency, created by adding ABMDA to the old National Advisory Council on Aeronautics (NACA), and adding the Jet Propulsion Laboratory (JPL) as an advisor to the new organization, was nothing less than the conquest of space. The Air Force would have the responsibility for land-based intercontinental ballistic missiles (ICBMs) and the strategic bombers. The Navy would have the sea-based ICBM responsibility, and the Army was given the task of developing all land-based tactical support missiles like the Pershing, with a 300-mile range, and a host of smaller tactical weapons. The Huntsville Division, occupying an Army facility, followed this path as well.

Progress on the Minuteman was unbelievably rapid. In May 1959, only 20 months after the official dedication of the Wasatch plant on October 17, 1957, the first full-scale Minuteman first-stage motor was successfully fired in a single nozzle test. On February 1, 1961, Minuteman made its first flight, and it was a resounding success. In 1962, the first Minuteman came off the production line and was delivered to the Air Force a full year ahead of schedule. By 1964, there were 100 Minutemen placed in silos across the U.S. By the end of the second decade of Thiokol's existence as a rocket motor manufacturer in 1968, it had produced a total of 2000 Minutemen first-stage units. A young engineer named U. E. ("Ed") Garrison who transferred from Huntsville to Utah, was intimately involved in the Minuteman program as the program manager. Fig. 14 shows an early Minuteman and Fig. 15 summarizes the outstanding progress made on this important program. Garrison later became the President and CEO of Thiokol in 1982.

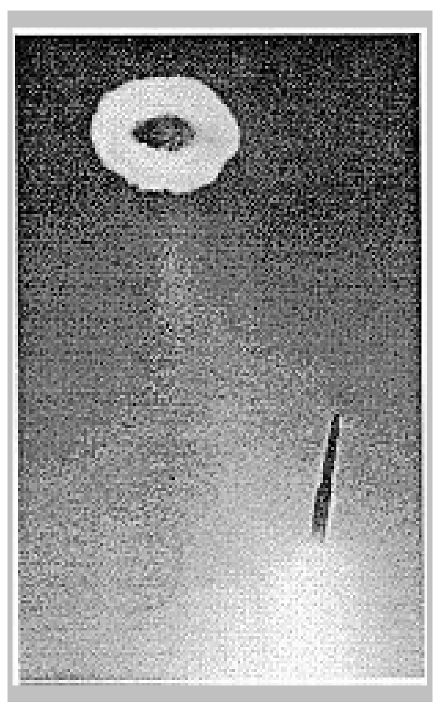


Figure 14. Early Minuteman Launch

A Model Program

1957

- AF contract – feasibility study

1958

- Successful demo motor tested 63-in. dia, 22,000 lb

1959

- AF contract - first-stage development
- First motor loaded in January
- Successful test in April
- First silo test in September

1960

- First movable nozzle test in October
- First PFRT test

1961

- Completed PFRT test in January - 12 for 12
- First Minuteman flight - February 1, 1961

One Year Ahead of Schedule

1962

- First MM I production motor accepted in April

1964

- First MM II production motor accepted in May

1966

- 1,626 motors loaded; more than 1,000 delivered for installation or testing

Figure 15. Minuteman Program Summary

Thiokol was now clearly the leader in the industry for the production of large motors, but even larger solid rocket motors were in the works. On May 25, 1961, President John F. Kennedy proposed to Congress – and the nation – that an American program be begun to place humans on the surface of the moon.

NASA was now three years old, and this new organization was given the task of mobilizing and managing the American aerospace industry so that President Kennedy's goal would be achieved by the end of the 1960s.

The overall design for the Apollo program (as the voyage to the moon became known) called for a cluster of liquid engines as the main approach to the propulsion system, but large solid motors were to be demonstrated also.

So, in 1963, Thiokol began yet another big motor scaleup effort, at the instigation of the Air Force. This time, the motor diameters were 156 inches and 260 inches. This latter unit was to be 65 times larger than the Minuteman first stage. Joe Crosby and the Board of Directors once again gritted their teeth and came up with $10.5 million in funding. This time the full-scale motor would be so large it could not be shipped over the U.S. railway or highway systems, so yet another new Thiokol plant was designed and built, this time in Brunswick, Georgia, with access to the Atlantic Ocean. The plan was to put the motor on a barge and tow it down to Cape Canaveral for vehicle assembly and launch. At the same time, the Wasatch Division began work on the 156-in. dia land-transportable motor, while construction of the Georgia plant was under way. This time, the land cost $1.5 million, a sizable increase over the $32,000 paid for the Utah plant site. The buildings were completed in early 1964, and design and manufacture of these biggest-ever solid motors began.

In December 1964, Wasatch successfully tested a 156-in. motor and in February 1965, the Georgia Division tested its version of a 156-in. design. The test was successful, and it produced a total of 3 million lb of thrust – the largest solid propellant motor ever fired in the free world up to that time.

On Palm Sunday of 1965, the maraging steel case for the 260-in. motor manufactured by Newport News Shipbuilding Corporation was hydrotested, and, for the first time, Thiokol's unbroken string of successes in scaling up solid rocket motors to bigger and bigger dimensions came to an end. The 260-in. case failed in hydrotest at about 50% of the design pressure due to a pre-existing flaw in the parent metal of the 0.75-in.-thick case in the cylinder membrane adjacent to a longitudinal weld. The flaw was too small for the inspection techniques of that day to detect reliably. NASA soon after decided to cancel both Thiokol's and Aerojet's programs, and the Apollo program proceeded with liquid rocket motors for the main moon rocket propulsion system. Thiokol did eventually provide a total of thirteen small motors for the Apollo system.

In the 1965 Thiokol Annual Report, there is a brief mention of the adverse financial effect of the cancellation of the 260-in. space booster motor contract. The Georgia plant was placed on standby status, except for a small group who attempted vainly for a few years more to find other profitable applications for the land and the facilities; the most striking item among these was a reinforced concrete pit more than 260 inches in diameter and more than 100 feet deep that was intended to serve as a combination casting pit and curing oven. A photograph of this pit in shown in Fig. 16. In the 1970s, the Georgia facility was sold to Union Carbide.

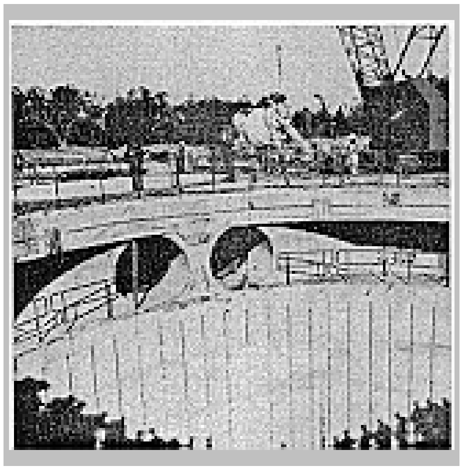


Figure 16. Georgia Division Casting Pit

For six years or more, big motor activities at Thiokol were limited to the ballistic missiles of the time – Minuteman and Poseidon – the Navy's successor to the Polaris.

By 1971,[33] interest in large solid motors had revived to the point where pictures and data on the long-dormant 156- and 260-in. program were supplied again to NASA as a first step in designing the Space Transportation System (STS), or Space Shuttle, as it became popularly known. A schematic design from 1972 shows a pair of very large solid rocket motors (SRMs) strapped on the sides of the liquid engine and tankage core vehicle. In 1973, NASA conducted a proposal competition for these new large motors, and Thiokol was successful in winning it. Once again, Thiokol began work at the same time on both the design of these motors and a plant to manufacture them. Unlike the earlier ill-fated efforts that called for motors that were so large they could only be transported by barge to the launch site, this time the design called for segmented rocket motors that were 146 inches in diameter, and because of this design, the segments were able to be transported by rail individually to the launch site and assembled there. Because of this, Thiokol was able to construct the SRM manufacturing facilities on the Wasatch site and this addition made possible the description of Wasatch as the "largest development and manufacturing facility for solid rocket motors in the free world."

Design of the SRMs for the Shuttle was completed in three years, and the first full-scale firing of a Shuttle booster motor was conducted in July 1977. It was slightly more than 12 feet in diameter and 125 feet long, and it contained more than one million pounds of propellant in each motor. Two of these were attached to the Shuttle. The metal casing segments were designed to be recovered and reused up to 19 times to reduce the costs per Shuttle launch. A photo of the assembled Shuttle with its two SRMs (solid rocket motors) attached is shown in Fig. 17. Some of the key people involved in these efforts were Ed Dorsey, John Thirkill, Joe Pelham, and Joe Kilminster. At this point in time, the total number of people working at the Wasatch Division was more than 6,000.

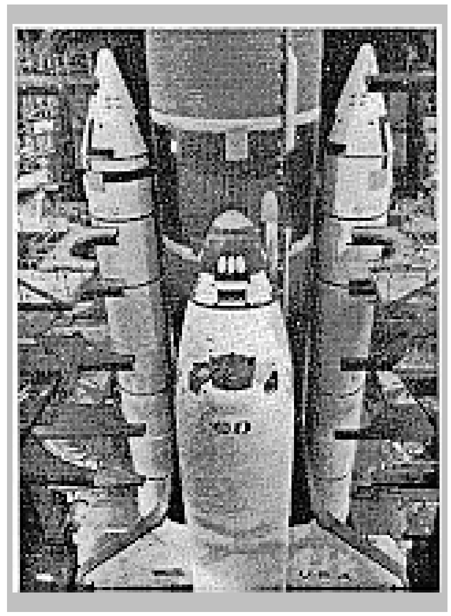


Figure 17. Space Shuttle Boosters

A tabulation of large rocket motor scaleup chronology is shown in Table IV, including the progression from loading a motor (the T-40 JATO) from one batch of propellant to loading the 156-in. motor with 160 batches of 5000 lb each.

<u>Space Motors for Satellites and Space Probes</u>

Near the end of Thiokol's first decade of designing and building solid rockets, a program was conceived by the Air Force named Project Farside, which had the specific objective of setting a new altitude record.

This required a four-stage vehicle, consisting of two stages of Thiokol Recruit rockets and two stages of Grand Central-produced Loki rockets.

The first stage was a cluster of four Recruits, with one more as the second stage. This assembly would be lofted to a height of several miles by a plastic film balloon. The cluster of four would be fired, penetrating the balloon, and, after burnout, the final rocket would be fired, raising the payload to an altitude of 4000 miles above the surface of the earth, well beyond the earth's atmosphere.[34]

The helium-filled balloon, with a capacity of 3 million cubic feet, carried the rockets to 100,000 feet, at which point the first rocket stage was ignited. This first space probe rocket system was launched in October 1957 at Eniwetock Atoll in the Pacific. This launch came on October 22, 1957, but it was eclipsed by the successful Sputnik launch by the USSR three weeks earlier on October 4.[35]

Soon after this initial effort, Thiokol began a series of space-oriented programs that involved the Elkton, Huntsville, and Wasatch Divisions. In addition, in 1958, Thiokol acquired one of the early pioneers in the liquid rocket engine field in the form of the New Jersey firm Reaction Motors, Inc. This group had begun operations near Denville, New Jersey, incorporating in December 1941, only a few months before the incorporation of Aerojet on the west coast in March 1942.[36,37] At the time of the merger, Reaction Motors was deep into the development of a liquid rocket engine (the XLR-99) that would power a series of experimental space planes. These efforts reached an early peak in 1961, when this engine powered NASA's X-15 to a speed of four times the speed of sound near the edge of space (Fig. 18). The forerunner of the X-15 was the Bell X-1, powered by Reaction Motors 6000 C-4 liquid engines. In October 1947, this aircraft was the first to exceed the speed of sound.

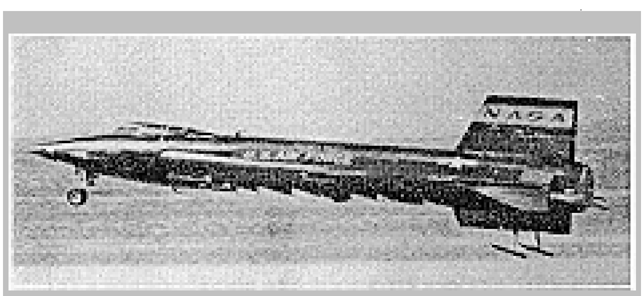


Figure 18. The X-15 Rocket Plane

Also, during these early years, Huntsville was modifying its Hermes experience into a NASA test bed motor nicknamed "Little Joe," which would provide some of the essential data for the design of Project Mercury, the first manned space program by the U.S. This vehicle used four Castor® I motors and four Recruit motors. It was a modification of the Air Force X-17 test vehicle.

Now these popular and reliable motor designs began to be picked up and used in many different programs. In 1959, NASA began the development of a new launch vehicle called the Scout, and it also used the Castor® I (another descendant of the Hermes) as the second stage of this four-stage vehicle. All four stages of Scout were solid propellant motors, and it represented a low-cost route to low earth orbits for small payloads for more than 30 years after its first launch in 1960.

Because of its availability and reliability, the Castor® I was used as the first solid rocket motor to be attached to a liquid-engine-powered launch vehicle. This hybrid vehicle made use of the natural advantages of both types of rocket propulsion. The short duration and high thrust of the solid "strap-ons," combined with the longer duration and lower thrust of the liquid systems, imposed relatively low g-levels on the sensitive electronic payloads carried aloft by these expendable launch vehicles, or ELVs as they became known.

The Air Force's Thor liquid-fueled propulsion system was converted to the Delta ELV by the addition of a set of Castor® motors attached to its sides. The first flight of the thrust-augmented Thor (TAT), as the Delta was originally known, took place in 1964. This began as three Castor® motors attached to the Delta 1300 ELV, then increased to six Castors® for the Delta 1600 series, and finally nine in the Delta 1900 series. A combined total of more than 900 Castor® I and II motors were flown successfully on the Delta series ELVs. Over the years, these designs were enlarged to include a Castor® IV (flown in 1985), a Castor® IVA (flown in 1988), and a Castor® V (flown in 1991). A photograph of the Delta with Castor strap-ons is shown in Fig. 19.

The solid motor strap-on designs continued to expand in size and eventually evolved into the Shuttle SRMs, the largest strap-on solid motors.

While the strap-on booster motors were being developed, Thiokol was at the same time pioneering in another important type of space motor – high mass fraction upper-stage motors, for eventual use in providing satellite payloads with the precisely programmed thrust patterns that placed them in their final orbital position.

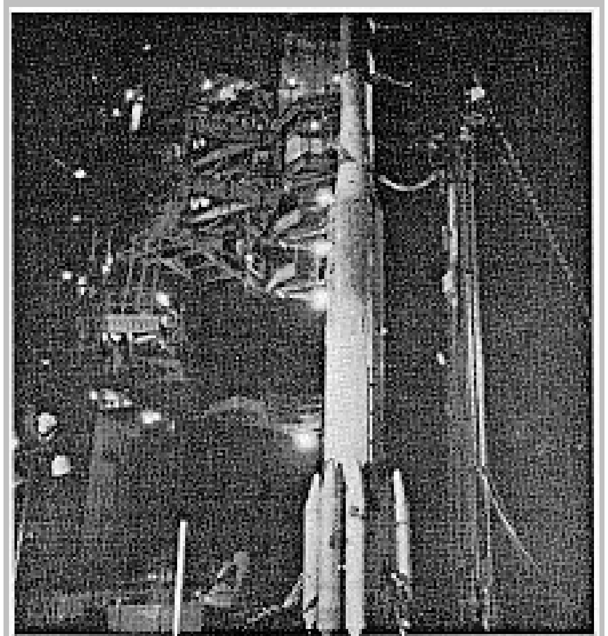


Figure 19. Delta With Castor Strap-Ons

This work began with a small NASA contract that started at Elkton in 1960. The moving force behind this program was a small, energetic NASA engineer from Louisiana with a name that advertised his Cajun heritage – Guy Thibideaux. Guy insisted that extremely efficient, spherically shaped rocket motors not only could be developed, but also would find an application in the future. The first of these motors was a 25-in.-dia metal ball, with a nozzle attached to it. After 30 years of continued development and use of these designs, it is difficult to recapture and understand the skepticism this type of motor met with in some quarters. Everyone knew up to this point that all solid rocket motors were supposed to be cylinders, with the nozzle firmly attached to one end of the cylinder – just like the rockets the Chinese had made 700 years before, and just like every solid rocket motor that had been designed and made to that time. Since spherical cases exhibit only about half the stress levels found in cylindrical cases during pressurization, spherical motors with very high mass fractions (~0.95) are possible.

This 25-in.-dia "ball" was soon followed by a larger, 40-in.-dia design, and both of these early spherical motors were successfully made and tested during 1962. After this design was shown to be feasible, it was quickly picked up and incorporated into the Surveyor program as the most efficient design for the solid retro rocket on the lunar landing system. Reaction Motors also supplied a small throttleable liquid vernier engine for the final soft landing on the surface of the moon.

Thiokol had already developed a retro rocket design for the Discoverer surveillance satellites and carried it through modifications into the retro rockets for the Mercury man-in-space program, with the successful return of John Glenn on February 20, 1962. The design of the Mercury retro is shown in Fig. 20 with the design engineer (Bob McCafferty) using his sliderule for the design calculations in that early computer era. Thiokol followed this program by supplying the retro motors for the Gemini program, returning each of the astronaut pairs to earth successfully.

Figure 20. Bob McCafferty and the Mercury Retro Motor

The Surveyor retro was a much larger motor than these early retro rockets, but it used the same principle of applying a large amount of controlled thrust, with more precision in both nozzle alignment and control of the total impulse than had heretofore been possible. The Surveyor design was slightly reduced in size from the 40-in. spherical, becoming a 37-in.-dia design that has been in use ever since 1964, in many modifications and with many changes in length. Both larger and smaller diameter spheres and elliptically shaped motors have evolved from it, ranging in diameter from 6 in. up to 75 in. with so many applications as perigee and apogee kick motors for placing satellites into orbit that only a few of the most important ones can be mentioned here. More than 2000 satellites have been successfully placed in orbit by the family of Thiokol STAR™ motors, as they became known. The most frequently used STAR™ motors have been the STAR™ 37 and the STAR™ 48 designs. A photo of a satellite emerging from the Space Shuttle bay with a STAR™ 48 motor attached is shown in Fig. 21.

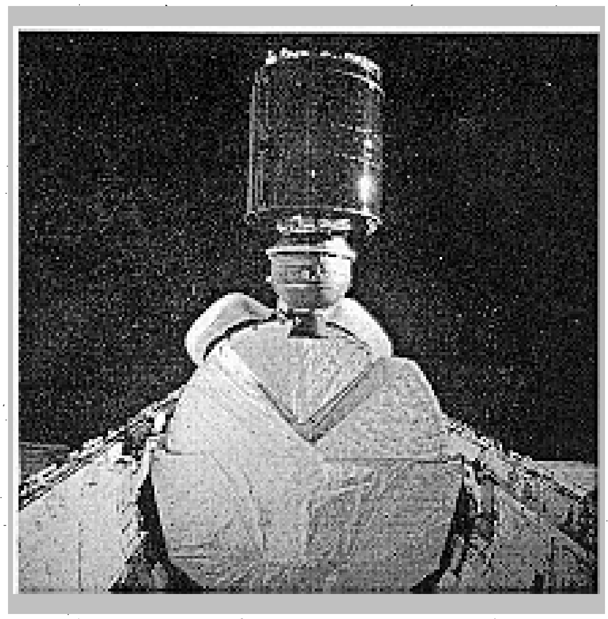


Figure 21. STAR 48 with Satellite Payload Emerging from Shuttle Bay

Perhaps the most scientifically significant use of these motors has been in the planetary space probes that have been used to explore our solar system in the kind of detail that was unimaginable to astronomers only a few decades ago. The Pioneer and Voyager probes have explored Venus, Jupiter, Saturn, Neptune, and Uranus, and all of the moons of these planets, using Thiokol's space motors to provide the final boosts in velocity for the spacecraft.

Because the Thiokol rocket motor cases continue to travel with these probes after burnout, the first four man-made objects to leave our solar system (Pioneers F and G, and Voyagers I and II) contain spent rocket motor cases that originally came from Thiokol.

A selection of some of the most important dates in Thiokol's space motor history is presented in Table V.

Tactical Motors for Missiles

The number of missile system programs Thiokol has been a part of for more than 40 years is so long that only a few of the more significant ones can be discussed here. The earliest of these were the long-lived Falcon Air Force air-to-air missile program, with Hughes Aircraft as the prime contractor, and the T-131 artillery round for the Army described earlier. The Falcon propulsion unit went through many modifications, with improvements being added each time, and was in production at three different Thiokol locations – Huntsville, Elkton, and Longhorn. M-58 Falcon polysulfide motors achieved a wider operating temperature range (-65 to + 165°F) by 1959 than any other tactical weapon system of its day, and field-stored units demonstrated satisfactory performance more than 22 years after manufacture. Many of the details of the case-bonding process were developed under this program, and eventually the entire industry came to accept this type of design as the most efficient one for solid propellant rockets.

A summary of many of the case-bonded tactical missile rocket motors that Thiokol has developed and/or produced over the years is presented in Table VI. The year in which development or production of the unit began is given to provide a chronology of these missiles. The flight history of these tactical missiles is remarkable. For the 12,837 flights listed, no failure is known in which the Thiokol rocket motor was the cause. This is a remarkable achievement over the period from 1950 to 1987 and indicates once again the superiority of the case-bonded solid rocket motor design as applied by Thiokol. The histories of some of the more important tactical missile programs over the years are summarized below.

In 1959, Thiokol/Huntsville began work on a large Army solid-propellant-powered missile system known as the Pershing. In this same year, Longhorn was producing solid rocket motors for the Falcon, Lacrosse, Sergeant, and Nike Hercules programs that had previously been developed at Huntsville. By 1960, Thiokol/Elkton had embarked on a tactical nuclear weapon system for the Navy known as Subroc, a submarine-launched missile. The design of this system featured a slow-burning polyurethane propellant, a four-nozzle jetevator-control system, and a head-end blowout port thrust reversal system. The Subroc was to have as long and illustrious a career with the Navy as the Falcon was to have with the Air Force, and the Pershing with the Army.

During the second decade, from 1958 to 1968, Thiokol worked on and successfully developed solid rocket motors for the Nike Zeus, the Nike Ajax, the Bomarc B, the Genie, and a host of others. The Reaction Motors Division contributed prepackaged tactical liquid rockets for the Navy in the form of the Bullpups A and B, and the Corvus.

By 1965, Huntsville had moved on to the SAM-D (later renamed Patriot) program for the Army, with a successful launch site test during 1969. The Falcon program had become the Maverick program, and Thiokol continued its longstanding relationship with Hughes and the Air Force on these important tactical weapons. The first flight of the Maverick took place in 1969, along with the first flight of a hypervelocity rocket known as the Zap developed by Thiokol.

By the year 1970, Thiokol had become the supplier for a very long list of solid rockets for weapon systems. These are listed in Table VII. In addition, TOW, Hellfire, and HVAR were in advanced development at that time.

By 1971, the list was increased by the addition of the Navy Agile missile program, and by 1972 Thiokol had become the leading supplier of solid rocket motors in the industry. In 1974, the total amount of propellant processed by Thiokol since its beginnings only 26 years before had reached the astounding total of 200 million pounds; Thiokol was well on its way to becoming the first company in the industry to process a quarter of a billion pounds of propellant. This milestone was passed in the early 1980s.

Later on, after 1974, Thiokol developed propulsion units for other weapon systems, many of which evolved from earlier ones already mentioned. For example, the SAM-D evolved into the Army's Patriot, and the Poseidon became the Navy's Trident I and II, the advanced sub-launched Ballistic Missiles. Newer systems included the helicopter-launched Hellfire rockets and the HARM and AAAM rockets.

After 1975, the list of new systems developed became smaller, as the entire industry began to concentrate more on the production of existing weapons, and the pace of improvements, although still rapid, began to produce smaller improvements in both propellants and case designs. The emphasis began to switch from increasing performance by improvements in these areas to one of increasing sophistication in the use of advanced high-temperature materials for nozzles and insulation, and advanced designs for thrust vector control systems, so that the overall performance of the rocket propulsion system was improved.

Epilogue

In 1982, after 54 years of independent existence, the Thiokol Corporation was taken over by the Morton Salt Company of Chicago, Illinois, and the name of the merged corporations was changed to Morton Thiokol, Inc.

This history of Thiokol ends with the year 1982 because the events since then are better known and documented, and this helps to reduce an already overly long description of the rocket history of Thiokol to a more manageable length. A summary of some of the key dates in the chronology of Thiokol appears in Table VIII.

It is interesting to note that in 1989, Morton Thiokol spun off Thiokol as a separate corporation, changing the names to Morton International, Inc., and Thiokol Corporation. However, Morton took the automobile crash bag technology and business originally developed by the Wasatch Division and later passed it on to the Swedish crash bag firm, Auto-Liv. In 1998, Thiokol Corporation changed its name to Cordant Technologies Inc., and, in 1999, Morton International was taken over by the chemical firm of Rohm and Haas, Inc.

The Thiokol name still lives on as Thiokol Propulsion, a division of Cordant Technologies Inc. Doc Patrick would be pleased to know that his knowledge of chemistry and Greek produced a word that is still in existence, despite all of these changes in the American corporate scene.

Table I. The First Polysulfide Propellants

Ingredient	T-10	T-13	T-14
Polysulfide polymer	30.37	30.00	40.00
Potassium perchlorate	44.34	–	–
Ammonium perchlorate	22.26	67.00	56.00
Paraquinone dioxime	2.02	2.00	2.67
Diphenylguanidine	1.01	1.00	1.33
Properties			
Density, $lb/in.^3$	0.0665	0.0600	0.0572
Specific impulse, sec	190	~200	~165
Burn rate, in/sec at 1500 psia	1.0		
Pressure exponent, n	0.82	0.34	0.34

V0699051 [430]

Table II. The First Hydrocarbon Liquid Polymers

Year	Polymer	Designation	Specific Gravity, g/cc	Heat of Combustion, cal/gm
1954	Polybutadiene acrylic acid	PBAA	0.90	10,300
1954	Polybutadiene acrylic acid acrylonitrile	PBAN	0.93	9,900
1955	Carboxyl-terminated polybutadiene	CTPB	0.91	10,500

V0699052 [430]

Table III. Solid Propellants

Year	Polymer	Designation	Density, lb/cu in.	Theoretical Specific Impulse, lb-sec/lb
1948	Polysulfide/KP/AP	T-10	0.0665	190
1953	Polysulfide/AP	TRX-135/ TP-E-8035	0.0630	227
1955	Mixed polysulfides/AP/Al	TP-L-8006	0.0629	237
1957	PBAA/AP/Al	TP-H-8009	0.0635	262
1958	PBAN/AP/Al	TP-H-1011	0.0639	262
1960	CTPB/AP/Al	TP-H-3062	0.062	263
1971	HTPB/AP/Al	TP-H-8201	0.0660	264
1975	HTPB/AP/Al/HMX	TP-H-8213	0.0666	267

Y690159 [201]

Table IV. Large Rocket Motors

Year	Rocket Motor	Dia, in.	Propellant Wt, lb	Approximate No. of Batches/Motor
1949	T-40 JATO	8.25	102	1
1951	RV-A-10/Hermes A2	31	4,786	6
1958	Big B (Segmented)	–	22,000	5
1959	Minuteman Stage I	63	44,000	8
1965	156-in. NASA Booster	156	1,020,000	182
1977	Shuttle SRM	146	1,107,000	160
1978	Peacekeeper Stage I	92	90,000	17

Y690161 [201]

Table V. Space Motor History

Date	Event	Motor	Program
Oct 1957	First Launch	Recruits (4 + 1)	Project Farside
Mar 17, 1959	First Flight	20-in. Spherical	NASA – Honest John/Nike
Aug 21, 1959	First Flight	Castor® I	NASA – Little Joe
Aug 11, 1960	First Orbital Return	SARV Retro	Discoverer XIII
Feb 20, 1962	First Manned Orbital Return	Mercury Retro	Mercury – John Glenn
May 30, 1966	Fist Soft Lunar Landing	STAR™ 37	Surveyor I
Oct 11, 1968	First Apollo Flight	TEM 424/29/380	Apollo 7
Mar 2, 1972	First Jupiter Probe Launch	STAR™ 37E	Pioneer F
Dec 4, 1978	First Venus Orbit Insertion	STAR™ 24	Pioneer Venus (6½ months)
Dec 13-15, 1982	First Shuttle Satellite Launch	STARs™ 48/30B	Anik C-3 and SBS-3

V0699056 [430]

Table VI. Case-Bonded Tactical Rocket Motors (1950-1987)

Year Developed	Name	Designation	Propellant Wt, lb	No. of Flights	No. of Failures
1949-52	Falcon	M-46/M-58	26/31	8,717	0
1954	Sergeant	XM-53	5,845	37	0
1955	Matador	M-16	1,365	105	0
1955	LaCrosse	XM-1O	489	231	0
1956	Recruit	XM-19	264	300	0
1956	Nike Hercules	M-30	2,172	1,073	0
1958	Bomarc B	XM-51	6,592	61	0
1958	Pershing	Stages I, II	4,451/2,785	34	0
1966	Spartan	Stages I, II, III	–	42	0
1967	Patriot	TX-486	1,250	211	0
1971	Maverick	TX-481/633	65	1,414	0
1974	Harm	–	300	250	0
1976	Hellfire	TX-657	22	362	0

Y690160 [201]

Table VII. Thiokol Weapons Propulsion Systems – In Production in 1970

First and third stages of Minuteman
First and second stages of Poseidon (joint venture with Hercules)
Subroc
Sidewinder/Chaparall
Bomarc
Genie
Poseidon first stage and PBCS gas generator
SAM-D (Patriot)
First, second, and third stages of Spartan

V0699057 [430]

Table VIII. Corporate Chronology

Year		Year	Event
1928	Thiokol incorporated in Kansas City, MO	1958	Reaction Motors liquid rocket operations acquired
1930	Moved to Yardville, NJ	1962	Georgia Space Booster plant started
1948	Rocket operations begun in Elkton, MD	1965	Georgia plant put on standby
1949	Original rocket group moved to Redstone Arsenal, Huntsville, AL	1972	Reaction Motors ceased operations
1951	Elkton reactivated	1975	Louisiana Division operations began
1952	Thiokol began operation of Longhorn in Marshall, TX	1982	Thiokol merged with Morton Salt
1957	Utah (later Wasatch) Division formed		

V0699058 [430]

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