How a Tiny Laboratory in Kansas City Grew Into a Giant Corporation

A History of Thiokol and Rockets
1926 - 1996

E. S. Sutton

Forward

In the summer of 1989 I received a telephone call from Tom Davidson asking if I would be interested in preparing a paper on "The History of Thiokol" for presentation at the 26th Joint Propulsion Conference sponsored by the American Institute of Aeronautics and Astronautics (AIAA) in July of 1990 at Orlando, Florida. I quickly agreed, as I always had to any request from Tom, and as usual, I failed to realize how this apparently small task would grow over the years into a larger and larger mountain of work. The Orlando requirement was met by giving an oral presentation of the essence of the paper and by showing a 15 minute video of significant events in the history of Thiokol, ably put together by Jerry Capute of the Elkton Division.

Both of these were very well received at Orlando. Then came the much harder task of putting it all down on paper, and getting it approved by many of the other participants in the exciting early decades of Thiokol's existence. In particular, I am indebted to Dr. Harold W. Ritchey, who sent me five pages of detailed suggestions for improvements and corrections of my errors, and also to Mr. Joseph Crosby, who gave me two long interview sessions in 1990 and 1991 shortly before his death at the age of 95.

Among the many others who contributed significantly to this final version are Griff Jones, Billy Hunter, Jim Powers, Arnie Irwin, Phil Dykstra, Joe Pelham, Ed Dorsey, Tony Guzzo, Jack Buchanan, Bruce Brooks, and the originator of the request, Tom Davidson, who contributed the section on Ordnance in its entirety.

I am also indebted to Marie Shanahan of the Elkton Division for careful editing of the original draft and to Carole Barrios Lapine of the Thiokol Corporate Office in Ogden, Utah for providing a copy of her booklet entitled "Thiokol History 1926-1992". And finally, but not least to Anne Menaquale who typed the final version, and to my wife, Lois Sutton, without whose support and gentle prodding this history would never have been finished.

I realize that even this version still contains undetected errors and does not contain the names of a larger group of people who were responsible for the success of Thiokol than those who are mentioned. I also realize that this narrative covers Elkton in somewhat more detail than its small size deserves, but that is the result of the 35 years I worked at that one location.

Perhaps the next edition will be able to rectify these faults, but it will have to be done by someone with a fresher approach to this important subject than I have at present.

Are there any volunteers? I have a large collection of assorted literature to pass on to the next historian, whomever he or she turns out to be. I believe it is important to leave a good record of the events that caused Doc Patrick's small laboratory in Kansas City to grow into today's propulsion giant.

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INTRODUCTION

During the second half of the twentieth century, scientists and engineers made a steady series of technological advances that succeeded in taking the field of rocket propulsion from the status of a science-fiction curiosity to the level of a recognized and sophisticated major branch of engineering. As a result of these advances, in the past three decades voyages have been made to the Moon, to the planets of our solar system, and to their many moons by rocket-propelled space probes. In addition, telephone and television signals are being transmitted world-wide from commercial satellites. Also, a vast array of tactical missiles, and submarine-launched and silo-launched ballistic missiles capable of traveling thousands of miles in half an hour are in the arsenals of several nations.

Rocket propulsion has provided the motive power for all of these advances in technology. These and many other rocket applications have resulted from discoveries, inventions and engineering developments that created an entire industry in a very short time. This article describes the history of Thiokol -- one of the major companies that grew with this industry -- and some of the pioneers who brought about the growth of this company.

The first two sections of this brief history of Thiokol cover the period from 1926 to 1958 in chronological order. After 1958, the technological history of Thiokol became so complex that it has been described in five separate sections that each cover the period from 1959 to 1992. These sections are entitled Big Motors, Space, Missiles, Ordnance, and Technology.

1.0 ORIGINS

For hundreds of years, since the Chinese developed gun powder rockets in 1232 A.D.,[1] to the 1920s, it was accepted that rockets were an interesting component of aerial pyrotechnic displays, or "fireworks", and not useful for other purposes, except for a few scattered military applications. Two of the most famous exceptions were the bombardment of the city of Copenhagen in 1807 by the British, who fired 25,000 Congreve rockets in that campaign, and the use of rockets in the American-British War of 1812. This resulted in the mention of "the rockets red glare" in the national anthem, "Star-Spangled Banner", written in 1814 by Francis Scott Key.

After this brief flurry of activity, the use of rockets languished for nearly a century, while the competing technology of guns made continuous progress in increasing both range and accuracy. Then, in 1903, the Russian writer and scientist, Konstantin Eduarovich Tsiolkovsky, published a theoretical article entitled "Exploration of Cosmic Space by Means of Reaction Devices" that outlined the first principles of rocket technology, and their use in space. Unfortunately, none of his work was translated into English until the late 1940's.[2]

The next and more physical advance came from an American physicist, Robert H. Goddard, who received his training at Worcester Polytechnic Institute and Clark University. Unaware of Tsiolkovsky's work, he developed the mathematics of rockets independently, and began experimenting in 1909. In 1917, after completing his education, he received a grant from the Smithsonian, publishing a report on his solid-fuel work in 1919, entitled "A Method of Reaching Extreme Altitudes". However, in 1920, he changed his experimental efforts to liquid fuels, and he continued working with these for the rest of his career.

In 1926, Dr. Goddard reported to the Smithsonian on his liquid fuel experiments:

"On November 1, 1923, a rocket motor operated in the testing frame; using liquid oxygen and gasoline, both supplied by pumps on the rocket... The first flight of a liquid oxygen-gasoline rocket was obtained on March 16, 1926, in Auburn, Massachusetts, and was reported to the Smithsonian Institution May 5, 1926... The rocket traveled a distance of 184 feet in 2.5 seconds as timed by stop-watch, making the speed along the trajectory about 60 miles per hour."[3]

In one of those incredible coincidences that make human history so fascinating, another American scientist only a few days later in 1926, made a discovery that was to link up with Dr. Goddard's pioneering work on rockets a little more than 20 years later.

"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 black strap molasses and smelled like rotten eggs... Cleaning his laboratory the next morning, Dr. Patrick found the mixture had solidified. When he chopped it

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[1] *Rockets, Missiles and Space Travel*, by Willy Ley, Viking Press, 1952.

[2] F.H. Winter, *Rockets Into Space*, Harvard University Press, 1990.

[3] *Liquid Propellant Rocket Developmen*", Smithsonian Publication 3381, Dr. R.H. Goddard, March 16, 1936.

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..."[4]

At this point, like his predecessor, Charles Goodyear, nearly 100 years before him, he realized he had stumbled on a potentially useful discovery. He had found a route to the first synthetic rubber to be manufactured in the United States. The chemistry of this reaction is described in an article on the life of Dr. Patrick as follows: "He observed an unusual reaction, however, when he attempted to use a solution of sodium polysulfide as the hydrolyzing agent... As his interest in the product grew, Patrick established the stoichiometry of the reaction, showing that it was evidently a simple condensation:

$$(CH_2)_2\,Cl_2 + Na_2S_x = C_2H_4S_x + 2NaCl$$ "[5]

The first patent issued on this invention was granted in 1927 to Dr. Patrick and his co-worker, 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.[6]

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 Figure 1 and the two founders of the company are shown in Figure 2. The story of how they got together was described by Dr. Patrick as follows:

"During 1928, the Industrial Testing Laboratory had undertaken a quite successful development for the Western Salt Co. (the development was a process for producing smoky-flavored salt; another case where Patrick's results were well in advance of public taste), and through this work I had become acquainted with Mr. Bevis Longstreth, president of the salt company, whose headquarters were in Kansas City.

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

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[4] Brill, Franklin E., *The 'Gunk' That's Out of This World*, True Magazine, March 1959.

[5] *Joseph C. Patrick (1892-1965) Goodyear Medalist, 1958*, by J.B. Patrick and S.M. Martin, Jr., Rubber Chemistry and Technology, 1960.

[6] J.W. Crosby, Personal Reminiscence, Oct. 15, 1990.

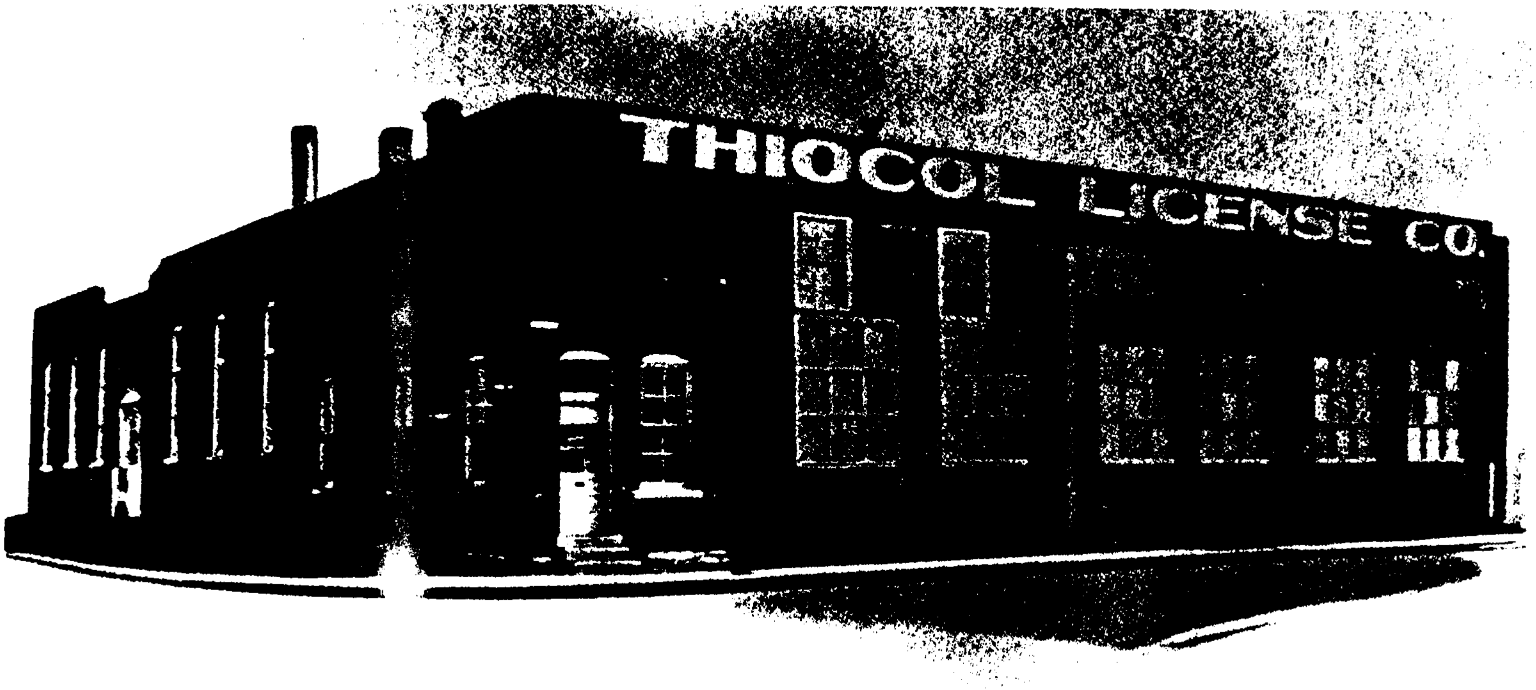

Fig. 1
The Kansas City Laboratory

Dr. Joseph C. Patrick

Bevis Longstreth.

Fig. 2
Dr. Joseph C. Patrick
and
Bevis Longstreth

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.[7]

Unfortunately for the new fledging corporation its main product continued to emit odors that not only offended the local law-abiding citizens of Kansas City, but also the local bootleggers as well. Since the latter felt the Thiokol odors would contaminate an already poorly distilled product, they exerted pressure through the local head politician, Tom "Boss" Pendergast. The "Boss" gave Thiokol an order they couldn't afford to refuse. "Get out of town."[8]

And so they left.

This description of Thiokol's departure from Kansas City is given in a less colorful but undoubtedly more accurate version in the biography of Dr. Patrick.

"Boss Tom" Pendergast found jobs for many of his supporters by sending them to local industries with the suggestion that they be hired or given work. One day a young lawyer showed up and informed Dr. Patrick that "friends" in the local government had told him that Thiokol needed legal help. When Dr. Patrick said he didn't need any, the young man said, "I hope you know what you're doing", and left. Shortly thereafter, "inspectors of every variety known to municipal government descended on the little factory, and as fast as one violation of some city code or other could be disproved, two more were alleged". Eventually these tactics forced Thiokol out of Kansas City.

In 1930 they moved to Yardville, New Jersey, on the outskirts of Trenton, where their odors were tolerated because of the many other small rubber factories operating in Trenton at that time. By this time, the name was now spelled "Thiokol". The 1930's 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 or weather, or electrical arcing.

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[7] *Joseph C. Patrick (1892-1965) Goodyear Medalist, 1958* by J.B. Patrick and S.M. Martin, Jr., Rubber Chemistry and Technology, 1960.

[8] *The Rocketing Fortunes of Thiokol,* by E.T. Thompson, Fortune, June 1958.

The first industrial application was with West Chester Lighting Co., which provided Mt. Vernon with electricity using Thiokol insulated cables. The first user of Thiokol sealants for aircraft wing tanks was Pan American World Airways, in the Pan Am Clippers that flew regular routes from San Francisco to Manila in the 1930s.[9]

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

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. The chemistry of this process is shown in Figure 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".[10] 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. The 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 8 years before in 1936, becoming Sales Manager in 1941. (Fig. 5).

For the year of 1944, the total sales of the corporation were a modest $1.2 million, with an even more modest profit of $11,995.[11] 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..."

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[9] *From Rubber to Rockets*, circa 1957.

[10] ibid.

[11] Thiokol Annual Report, 1944.

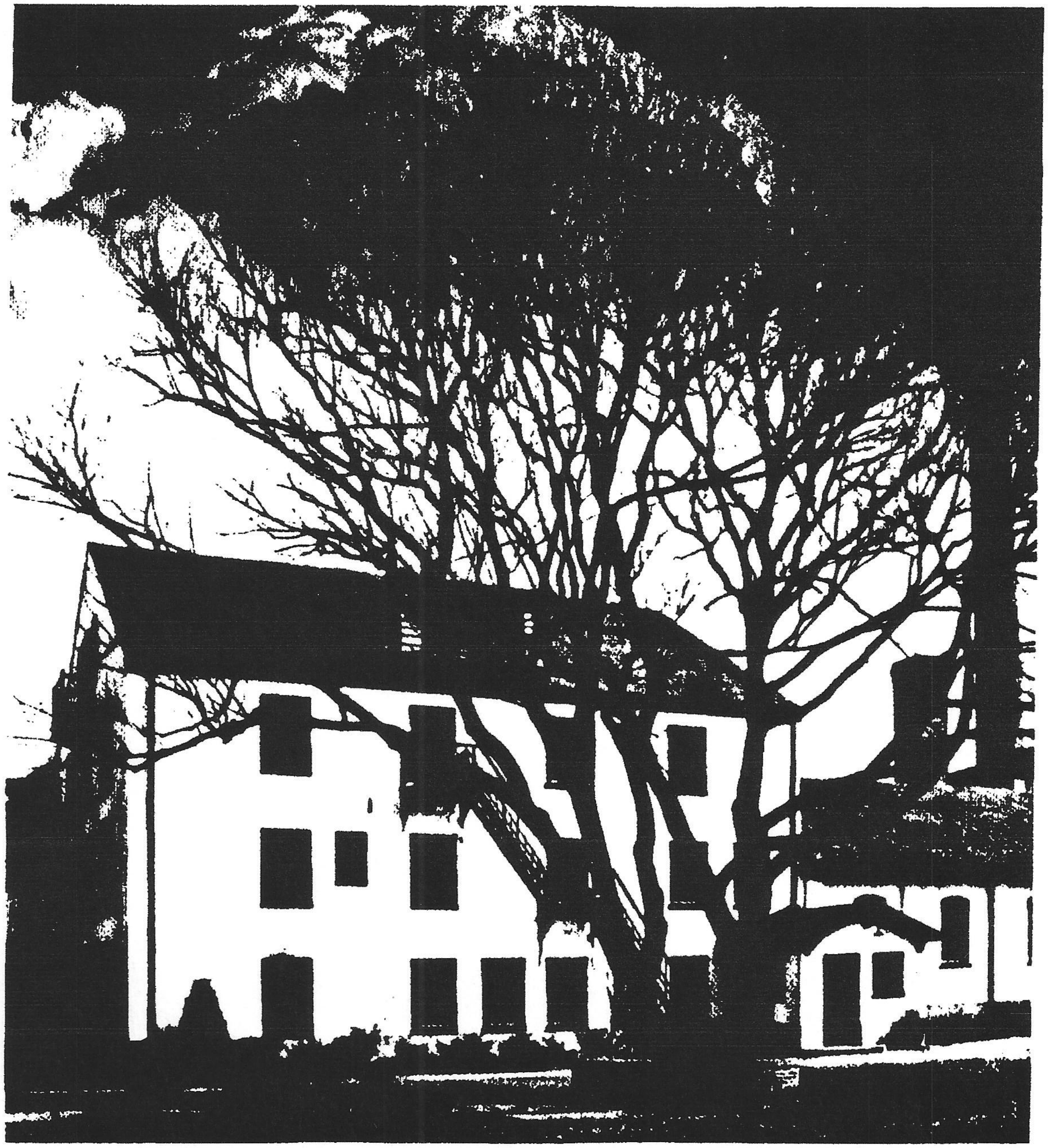
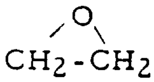


Fig. 3

Equations for the Manufacture of Ethyl Formal Polysulfide Polymer

5-1.  + HCl $\longrightarrow$ $ClCH_2CH_2\text{-}OH$

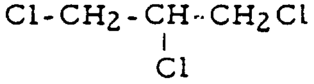
ethylene oxide (I) — ethylene chlorohydrin (II)

5-2. 2 II + HCHO $\longrightarrow$ $Cl\text{-}CH_2CH_2\text{-}OCH_2O\text{-}CH_2CH_2\text{-}Cl$

formaldehyde (III) — dichloro ethyl formal (IV)

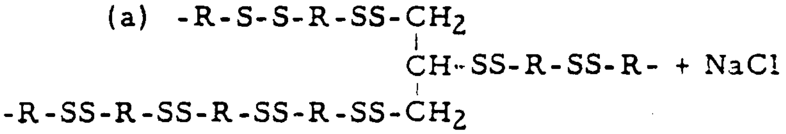
5-3. 2 NaOH + nS $\longrightarrow$ $Na_2S_n(Na_2S_{2.25})$

sodium polysulfide (V)

5-4. IV + V + 

$$Cl\text{-}CH_2\text{-}\underset{\displaystyle Cl}{\underset{|}{CH}}\text{-}CH_2Cl \longrightarrow$$

trichloropropane (VI)



$$\begin{array}{l} \text{(a)}\ \text{-R-S-S-R-SS-}CH_2 \\ \qquad\qquad\qquad\quad | \\ \qquad\qquad\qquad\quad CH\text{-SS-R-SS-R-} + NaCl \\ \qquad\qquad\qquad\quad | \\ \text{-R-SS-R-SS-R-SS-R-SS-}CH_2 \end{array}$$

ethyl formal polysulfide polymer (VII)

5-5. -R-SS-R-SS-R-SS-R-SS-R-SS-R-SS-R- + NaSH $\longrightarrow$

-R-SS-R-SH + NaS-R-SS-R-SS-R-SS-R-

liquid polymer (before coagulation with $NaHSO_4$)

5-6. -R-SSS-R-SS-R-SS-R- + Na_2SO_3 $\rightarrow$ -R-SS-R-SS-R-SS-R- + $Na_2S_2O_3$

(a) **R** = $\text{-}CH_2CH_2\text{-}OCH_2O\text{-}CH_2CH_2\text{-}$

Note: From “Ten Years of Thiokol Propellants” by J. M. McDermott, 1958

Fig. 4

Fig. 5
Joseph W. Crosby

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.[12] Thiokol chemists, hoping to find as-yet unknown applications for the new type of polymer, began circulating technical information on the new material.

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 seconds, 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 JATO's. Despite this early success, JPL's emphasis continued to be placed on liquid rockets.[13]

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.[14] 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.

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[12] Personal Communication, J.W. Crosby, June 12, 1991.

[13] *JPL and the American Space Program,* Yale University Press, 1982, by Clayton R. Koppes, p.11.

[14] ibid, p.12.

In the period July 1, 1944 (the official birth date of the JPL organization), to April 1, 1945, JPL operated an internal program known as JPL-4 (ORDCIT) with the objective of developing a guided missile capable of carrying a 1000-pound warhead a distance of 150 miles. As the first step in this direction, JPL planned to develop a rocket nicknamed the Private, as a small unguided missile using the GALCIT 61-C propellant. This unit provided 1000 pounds of thrust for 34 seconds.

Despite this progress, one of the founders of the American Rocket Society, G. Edward Pendray, made the prediction in 1944 that solid propellant rockets will "never give the power and sustained performance needed for high altitude sounding rockets...or long-range military or trajectory rockets."[15]

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."[16]

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."[17] 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.

"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.

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[15] ibid, p.36.

[16] Dr. H.W. Ritchey, Memoirs, circa 1980.

[17] Koppes, Clayton R., *JPL and the American Space Program,* Yale University Press, 1982, p.36.

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."[18]

About 1946, Army ordnance personnel became interested in the new development, and they funded a project with JPL to develop the Thunderbird, a 6-inch-diameter 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 burn-out. It was a 10-point internal-burning star design.

"Rocket researchers in Great Britain and the Allegheny Ballistics Laboratory in West Virginia had conducted extensive tests on small-scale solids using a star-shaped charge but for various reasons had abandoned the star idea. JPL researchers learned of the star-shaped grain design almost by accident, through an appendix to another report being circulated among military laboratories."[19]

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.[20]

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,[21] 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.

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[18] J.W. Crosby, Personal Reminiscence, Oct. 15, 1990.

[19] Koppes, Clayton R., *JPL and the American Space Program,* Yale University Press, 1982, p.36.

[20] Thackwell, H.L., Jr., and Shafer, J.L, *The Applicability of Solid Propellants to Rocket Vehicles of V-2 Size and Performance,* JPL (c) Memorandum 4-25, July 1948.

[21] H.G. Jones, Personal reminiscence, 1992.

Table 1. T-10 propellant

Composition	
	Wt, %
Ethyl Formal Polysulfide (LP-3)	32
$KClO_4$	47
NH_4ClO_4	21
	100
Properties	
Density, lb/in.^{3}	0.0665
Specific Impulse, secs	190
Burning Rate, in./sec at 1500 psi	1.0
Problems	
. High modulus, low elongation . Burn rate very sensitive to oxidizer particle size . High pressure exponent . Poor aging (less than 12 months at 110°F)	

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.

The details of these early events have been contributed by H. Griffith Jones, who was working in the Pentagon in 1947 as an engineer, reporting to then Col. (later Major General) H.N. Toftoy. He remembers:

"I got in touch with Mr. Crosby in 1947 and asked if Thiokol would be interested in working on rockets. Mr. Crosby said yes, and so a meeting was arranged in Trenton in the spring of 1947. Dr. Colin M. Hudson traveled from the Rocket Branch of Army Ordnance Research and Development to Trenton and discussed the project with Joe Crosby, Harry Ferguson, Sam Martin, Al Raws, Joe Jorczak and others.

Ferguson and Raws then went to the Pentagon, and a young lawyer, whose name I believe was Kramer, drew up a contract, working in General Barnes' office. This document was signed (probably in late 1947) and Thiokol began work." This account is confirmed in Thiokol's Annual Report for 1948, which stated, "Work on the contract with the United States Army Ordnance relating to propellants, which was initiated in 1947, continued through out the year at Elkton, Maryland."[22]

At about this same time Thiokol bought a prospective site for its rocket activities outside of New Brunswick, N.J., 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. All three remained with the company throughout their long and productive careers, willingly moving from one location and responsibility to another many times. A partial list of the early employees is given as Appendix A. Jack Buchanan remembers those early days:

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[22] ibid.

“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.[23]

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 over from World War II made Elkton much more attractive than New Brunswick.

On top of this, an Army Colonel 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.

What happened within the Army to cause such a reversal of plans? These details have again been supplied by "Griff" Jones. A photograph taken in July of 1949 of some of the principals in these early activities is shown in Fig. 6.

"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 is shown in the Army Ordnance document reproduced as Appendix B, 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.

Also in 1948, the Army began to refurbish Redstone Arsenal in Huntsville, Alabama, as a site for its other rocket activities. The German V-2 engineers and scientists, who had been

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[23] Jack Buchanan, Personal Reminiscence, June 1996.

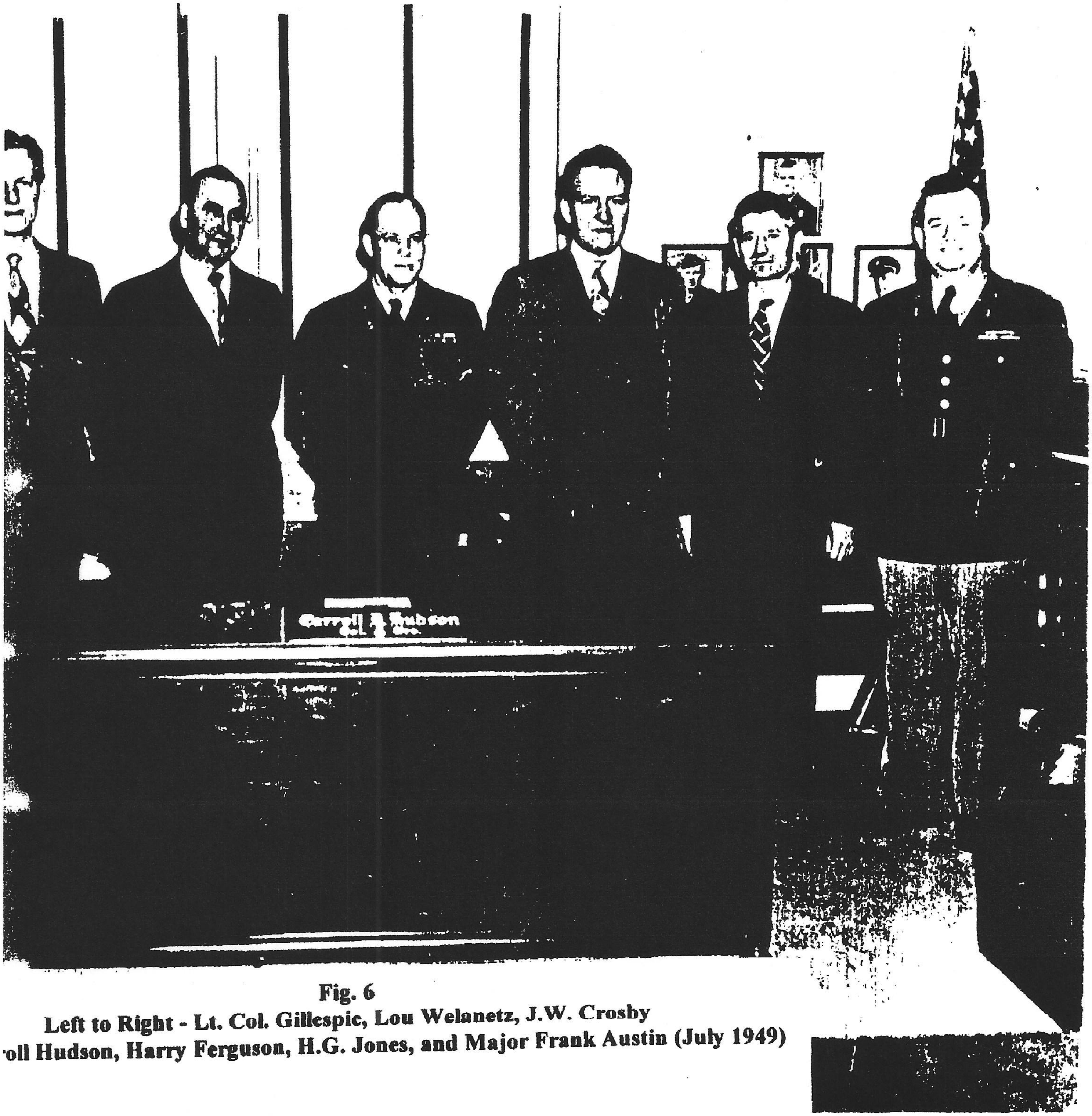

Fig. 6
Left to Right - Lt. Col. Gillespie, Lou Welanetz, J.W. Crosby
oll Hudson, Harry Ferguson, H.G. Jones, and Major Frank Austin (July 1949)

collected by the Americans from Peenemunde under Operation Paperclip at the end of World War II and sent to Ft. Bliss, Texas, were to be transferred to Huntsville to pursue the development of large liquid rockets under the leadership of Dr. Werner von Braun. The Army recognized that the JPL site in Pasadena, hemmed in more and more by the residential growth of the area, could never be more than a research facility. They also recognized that JPL's experience with the new polysulfide composite had shown that most of the technical problems were entwined with the complex chemistry of the polysulfide polymer and its curing reactions.

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.[24] 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.

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[24] Thiokol Annual Reports, 1948 and 1958.

2.0 EARLY PROPULSION HISTORY (1948-1958)

In early 1948, actual operations began at the Elkton site. Figure 7 shows a picture of that early building, taken in 1958, but the Thiokol logo is still visible. 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 Figure 8 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 Division of Thiokol Corporation. Kershner was later to become general manager of the Elkton Division when it was reactivated in 1951.

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. Colonel Hudson had been recalled from duty on Okinawa to become the first Commanding officer of the newly activated Redstone Arsenal. A copy is shown in Appendix C. 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. (Figure 9). Dr. Ritchey had unquestionably one of the best possible backgrounds for assuming technical direction of Thiokol's infant rocket activities.

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 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 4 years later, on Easter Sunday of 1949, Mebane sent him a telegram offering him the job of

FIRST PROPELLANT LABORATORY

Fig. 7

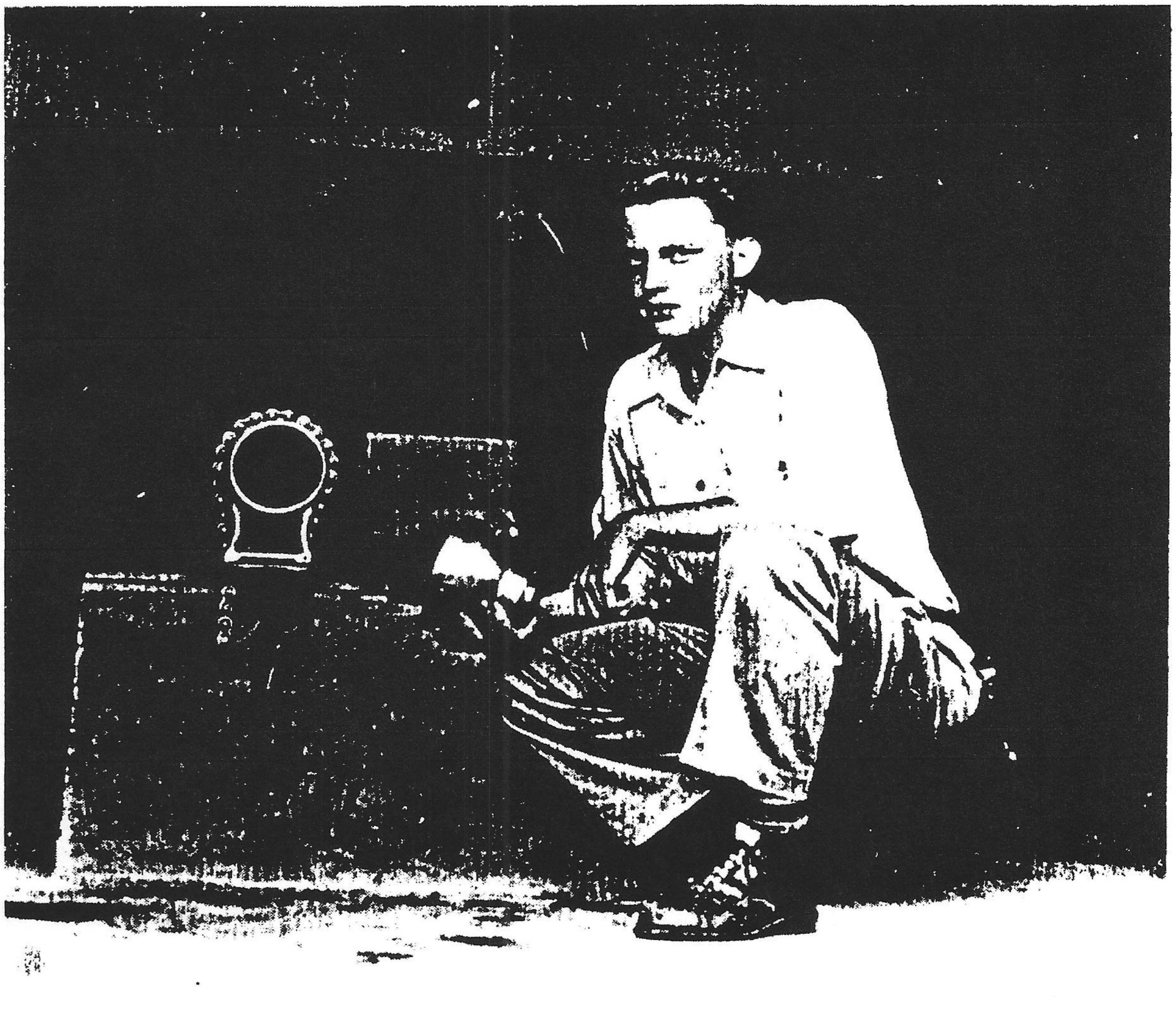

Fig. 8

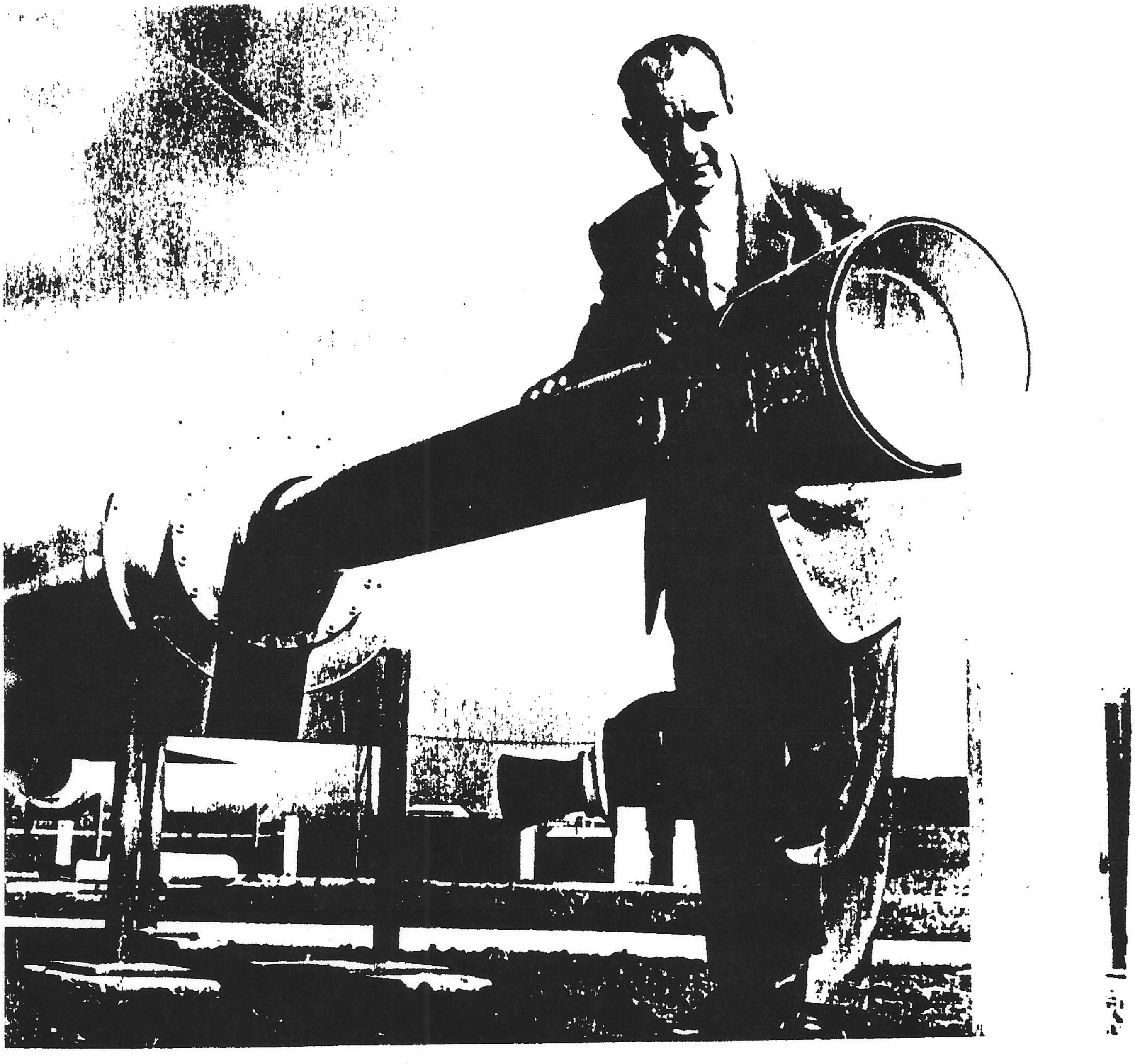

Fig. 9

technical director of the newly formed Thiokol Rocket Operations. At that time, he was in Hanford, Washington, where he was working for General Electric in the Nuclear Reactor Design Group. 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,[25] 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-inch motor case-bonded design with approximately 10 pounds of propellant to an 8-inch-diameter case-bonded motor containing 100 pounds 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.[26] T-131 and T-41 (the first Falcon design) motors were also being tested at this time). A short summary of the T-40 motor is given in Appendix D.[27] This scale-up 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.

Operations at the Elkton plant continued while the move was being made to Huntsville, and the final mix made at Elkton in 1949 was Number 369. From this, 21 T-131 motors were loaded. Although a 50 gallon mixer had been ordered and received at Elkton, it was never used there, and was reshipped to Huntsville. The largest mixer used at Elkton was the 20 gallon Baker-Perkins mixer.[28]

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.

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[25] Huntsville Division History, July 1969.

[26] Martin, G.L., Jr, *Final Report on Development of JATO, G-KS-3000, T-40*, Thiokol Report 7-51, March 1951.

[27] Wiggins, J.W., *The Earliest Large Solid Rocket Motor - The Hermes*, Thiokol Chemical Corporation, AIAA 9th Annual meeting, January 8-10, 1973.

[28] Personal reminiscence, Anthony Guzzo, June 1996.

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."[29]

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 Figure 10.

From about April to July 1949, Thiokol personnel were working at both Elkton and Huntsville, and they got their first taste of what was to become a way of life - long working hours broken up sporadically by air travel. In those pre-jet days, a trip to JPL on the west coast from Huntsville seemed to take forever, and days were for working, so much of the travel took place at night.

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.[30] 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."[31] 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.

The bearing seals of this design operated under the surface of the propellant during mixing, causing safety problems, and eventually it was replaced by the vertical rotor design in the late 1950s. A photograph of this early Baker-Perkins mixer is shown in Figure 11.

By the end of 1949, 18 mixes had been made in the 50-gallon mixer, and several new projects had been added and 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. Dr. Ritchey remembers the problems in making the transition from the T-41 Falcon to the improved T-42 Falcon:

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[29] Personal communication, Dr. H.W. Ritchey, Jan. 14, 1991.

[30] Wiggins, J.W., *"The Earliest Large Solid Rocket Motor-The Hermes"*, Thiokol Chemical Corporation, AIAA 9th Annual Meeting, Jan. 8-10, 1973, p.345.

[31] Dr. H.W. Ritchey, Video Reminiscence, 1989.

FALCON – THIOKOL'S FIRST PRODUCTION SOLID ROCKET MOTOR

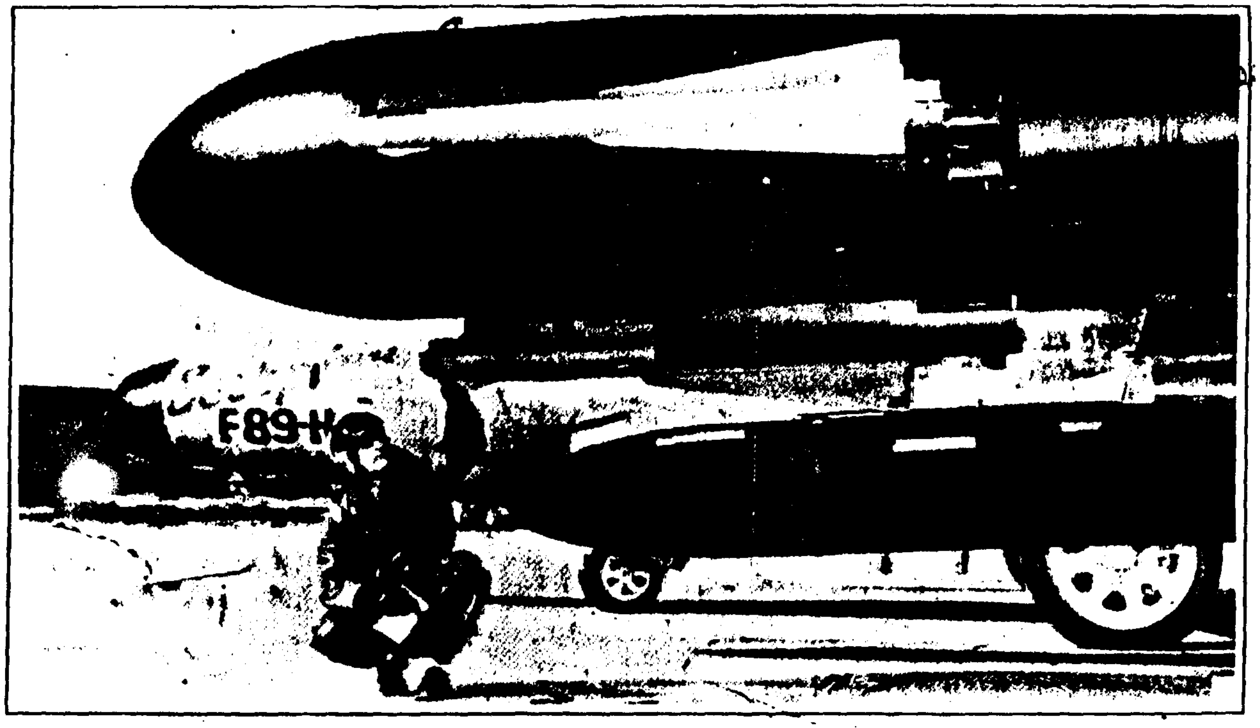

Fig. 10

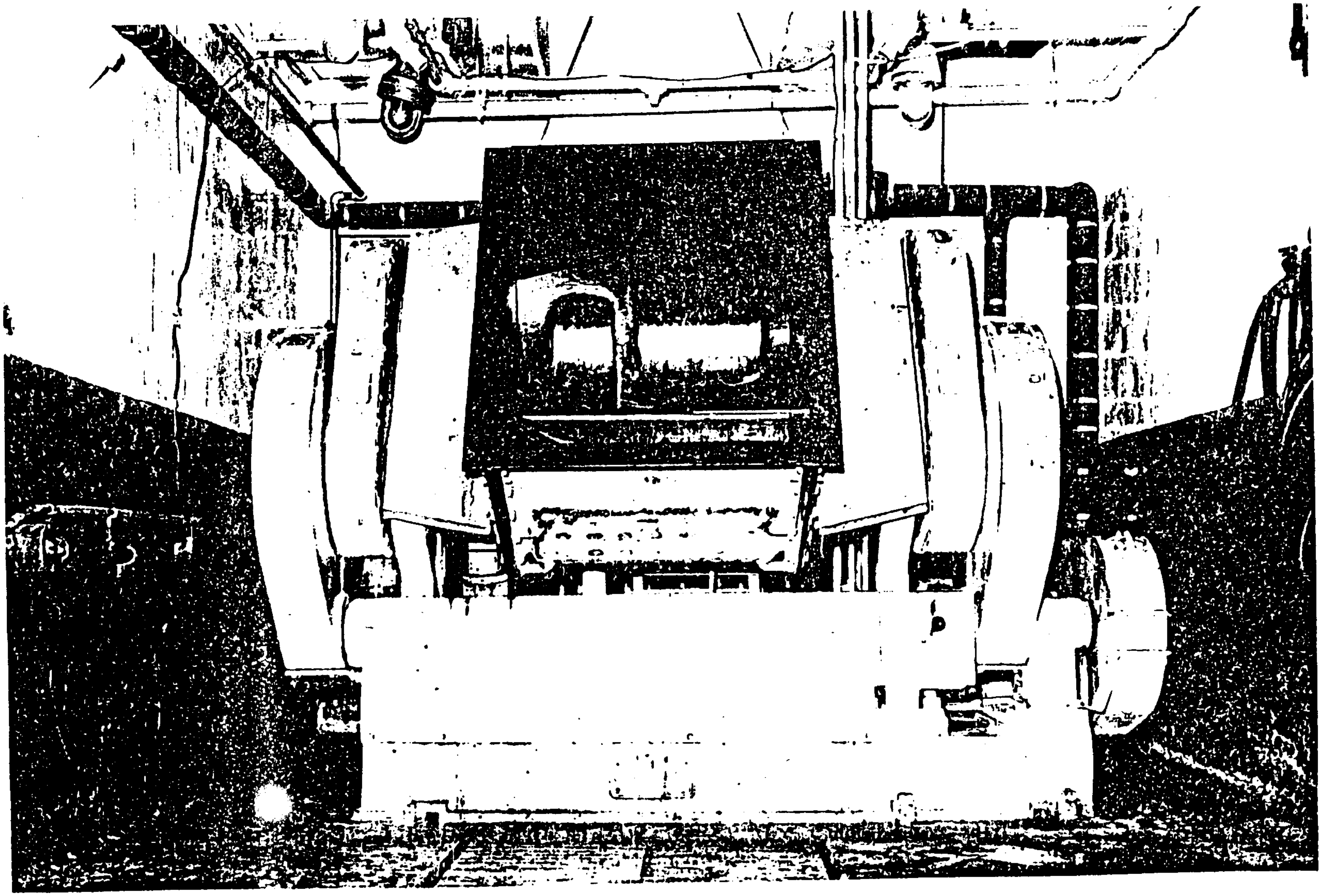

Fig. 11
100-Gallon Mixer

"LP-bonded propellants gave me one of my greatest lifetime headaches because of the cure exotherm and resulting shrinkage on curing - just before it became solid. Propellant voids from shrinkage and from (air) bubbles were at first two of our greatest problems. I initiated the temperature-programmed cure cycle and also the slit-plate casting system to remove mixing bubbles." Later on, pressurized curing was introduced to allow propellant to flow back into the motor from the head-cap area.[32]

"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, 1950, in an unairconditioned office in Huntsville, before the administration building was built, with a ten-cent compass and ruler, I designed ... the 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 break through!" 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.

In the meantime, during 1949, JPL had been struggling unsuccessfully to scale up the technique they had originated to a 15-inch-diameter 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 1940's, 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 post-war 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.

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[32] A.T. Guzzo, letter, July 29, 1996.

In December 1945, Bush assessed the state of the art, and pronounced that "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."[33] 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, a total of sixty-seven V-2's 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-inch-diameter rocket motor. JPL would also be involved in the program. In February 1949, JPL began static testing of a 15 inch diameter motor as the initial step to the design of a 31 inch diameter motor.

Two stories emerge from the available sources about the selection of the 31-inch-diameter motor. The original program called for a 26-inch-diameter motor; this was calculated to be the optimum diameter for carrying a 500-pound payload a distance of 75 miles. One version has it that the diameter was changed to 31 inches because this was the diameter of the then-current atomic bomb designs.[34] The other (and much more plausible) version was that 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-inch-diameter rolled and welded steel tubes.[35] In any event, the payload requirement was increased from 500 to 1500 lbs, and this increased the optimum diameter from 26 to 31 inches.

The entire Thiokol funding for this pioneering project was slightly less than $2,000,000. The design called for a 5000-pound propellant charge and a length of 108 inches. 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.[36] 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)

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[33] McDougall, W.A., *The Heavens and the Earth*, Basic Books, 1985, p. 98.

[34] Koppes, Clayton R., *JPL and the American Space Program*, Yale University Press, 1982, p. 72.

[35] Ritchey, Dr. H.W., "Memoirs", p. 26.

[36] ibid., pp. 25-26.

change was to use a thicker case wall (0.200 inch) 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. It is shown as Type A in Figure 12. 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 motor length.

Effort on "The Thing," as the combination of the Hermes A-2 rocket motor and its transporter was referred to by Thiokol engineers, started in May of 1950, and the first full-scale static test was made eighteen months later in December of 1951. And it was successful.

This first scale-up 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 pounds, including 4,786 pounds of T-14E1 propellant, in a 31-inch-diameter by 118-inch-long case with a 0.25-inch wall thickness of 4130 steel. It burned for 41.2 seconds, delivering an average thrust of 17, 172 pounds, with a total impulse of 795,000 pound-seconds. Photos of this first static test are shown in Figures 13 and 14. Also, a photo of the Huntsville Engineering Department taken at about this time (August, 1951) is shown in Figure 15. This photo was supplied by Dr. John Osborne, who left Thiokol to become Professor of Aerospace Engineering at Purdue.

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 regards 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-inch diameter x 108-inch length), long-duration (41.2 seconds), 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 pounds 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 scale-up factors as high as 50 to 1.

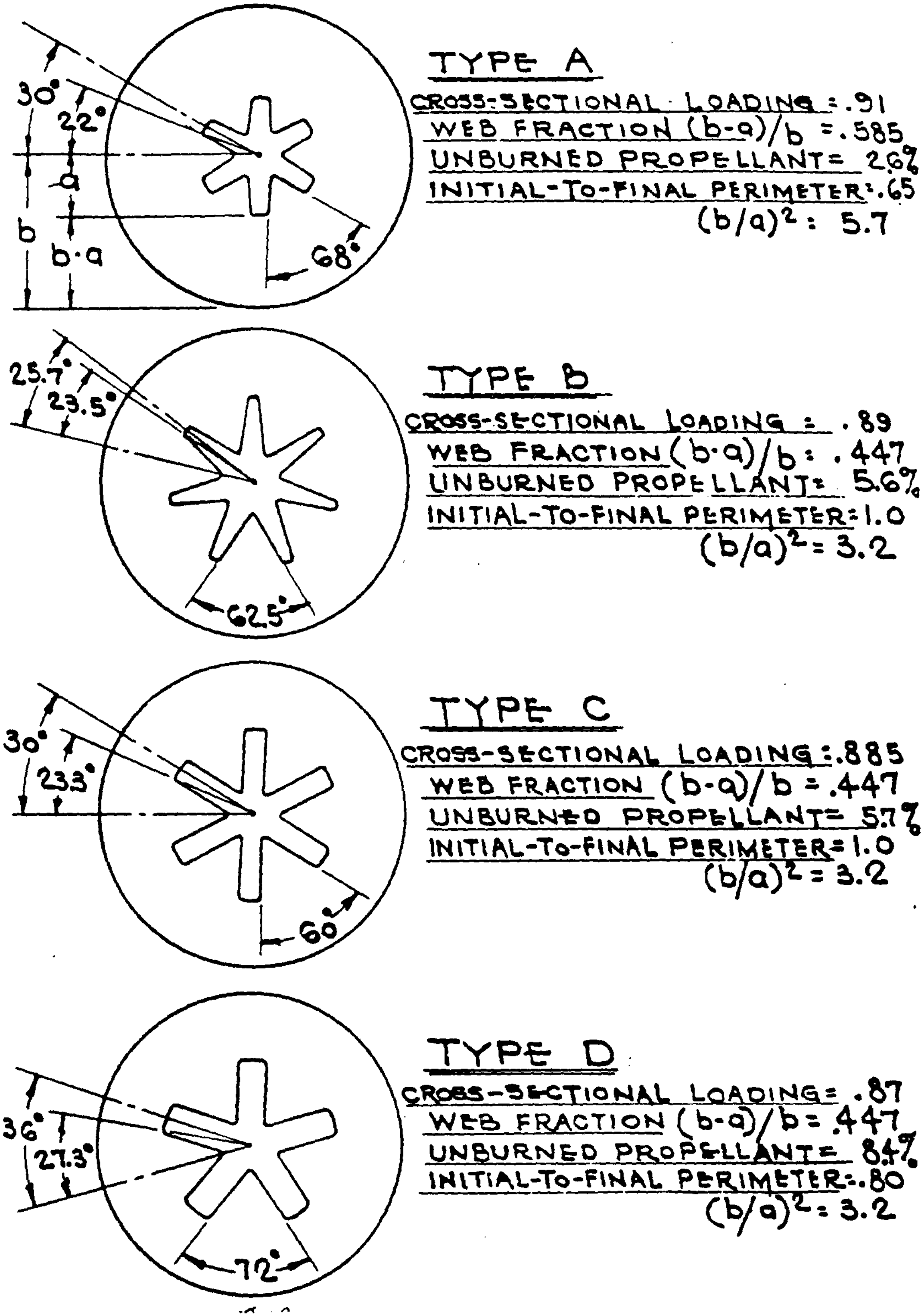

Fig. 12
Star-Shaped Grain Cross-Sections
for Hermes A2-S Test Motors

HERMES ROCKET MOTOR - "THE THING"

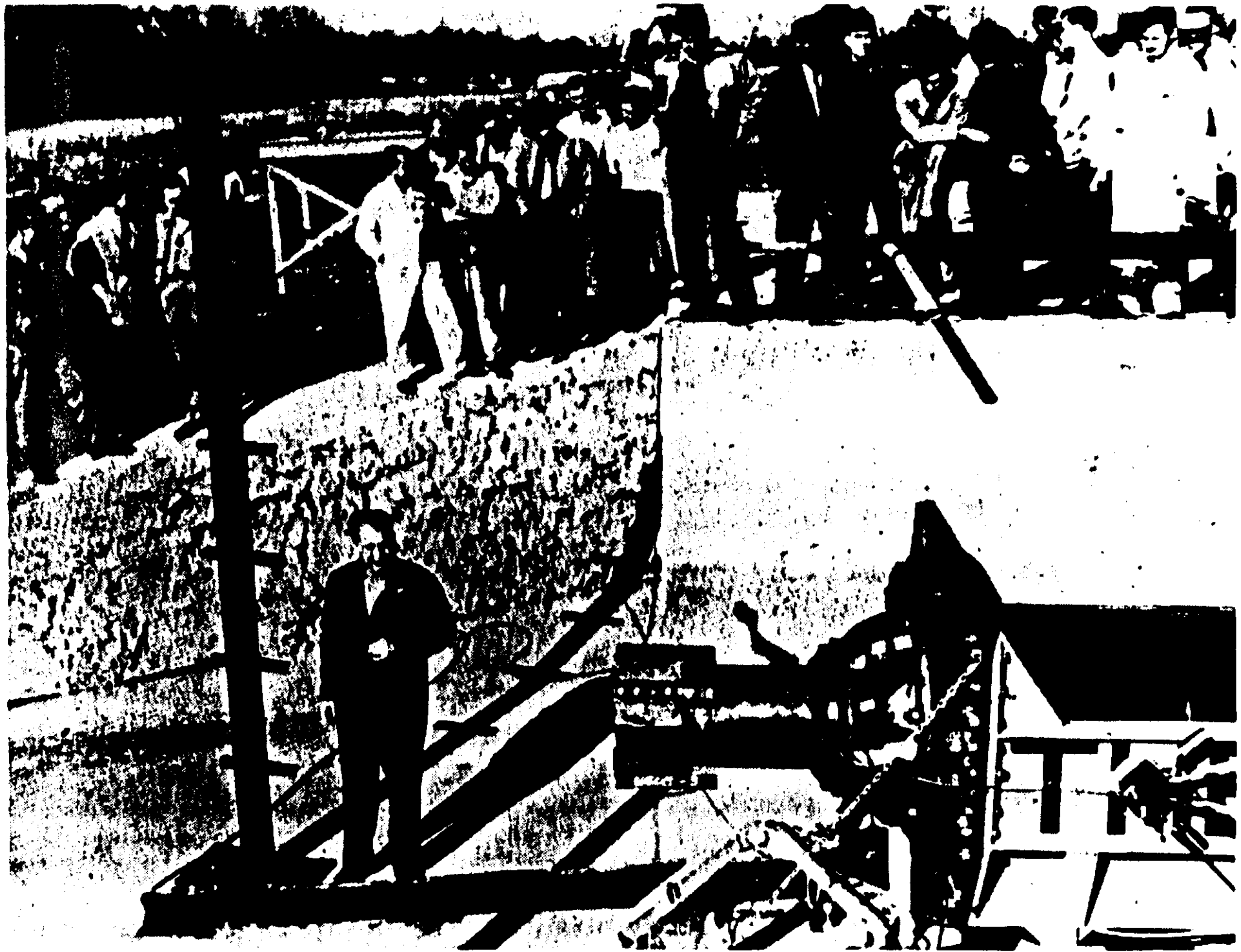

Fig. 13

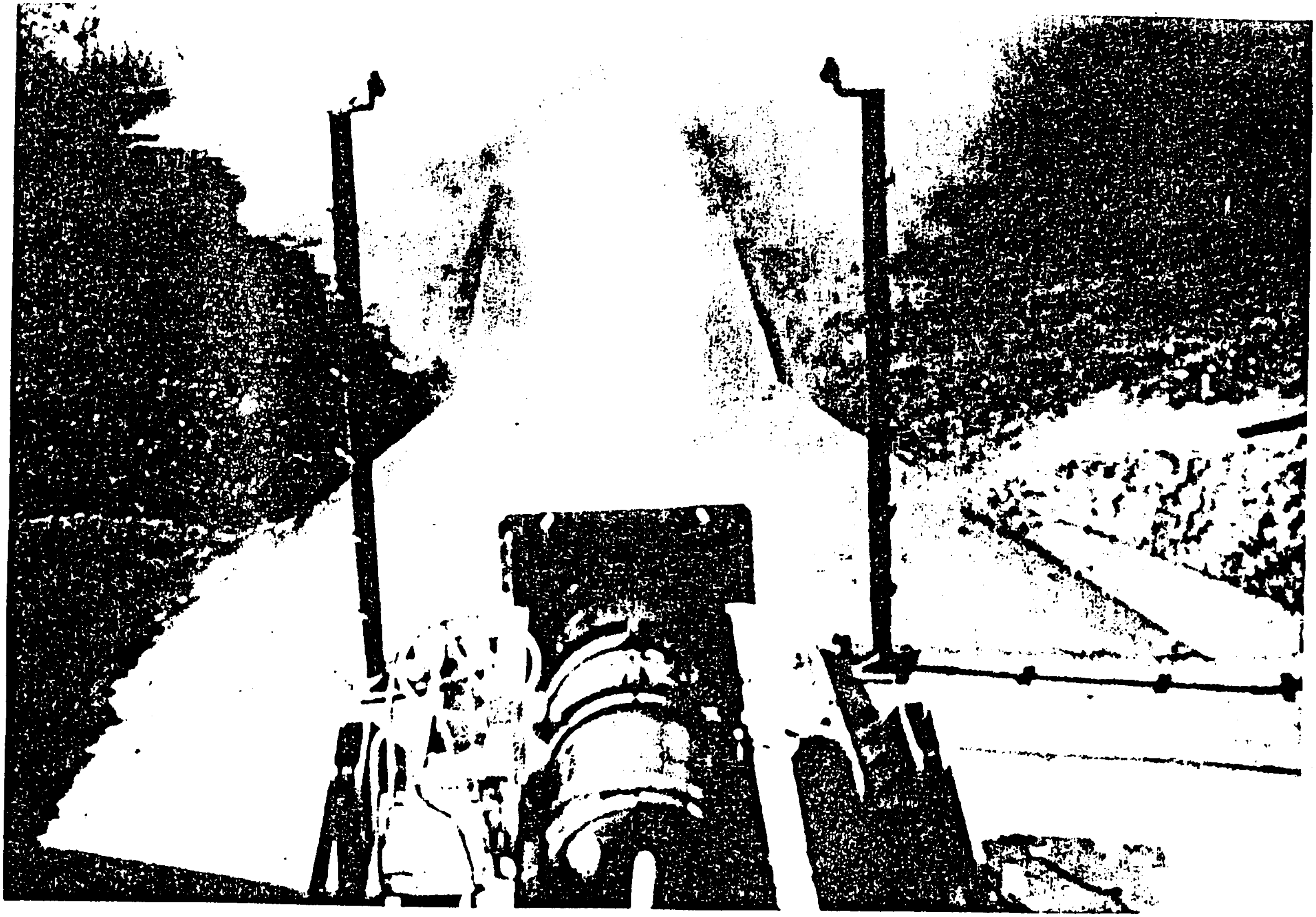

Fig. 14
Static Test of First Full-Scale (31-Inch Diameter) Motor

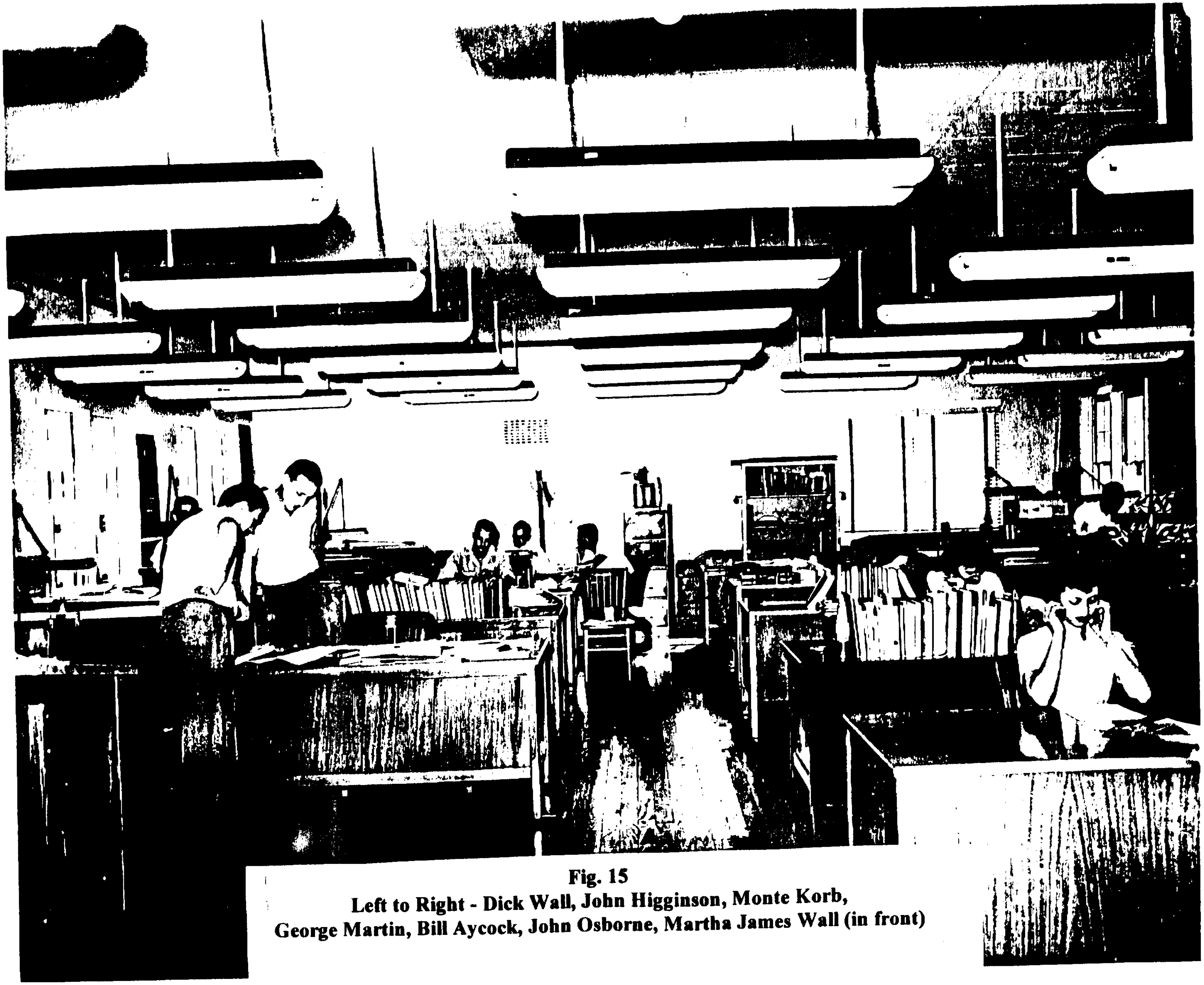

Fig. 15
Left to Right - Dick Wall, John Higginson, Monte Korb,
George Martin, Bill Aycock, John Osborne, Martha James Wall (in front)

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 at the request of the Army, 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 Rand 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 take off, 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 ...."[37]

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[37] P.R. Dykstra to J.P. King, 20 February 1991.

In the period from 1951 to about 1955, the reactivated Elkton Division worked almost exclusively on ammonium nitrate propellants, but eventually the low burning rate and the low specific impulse 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[38] 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 2 years ahead of its original schedule. It provided lighter weight, greater mobility, and greater range than the liquid-fueled Corporal.

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 pounds of solid propellant in its three stages, the X-17 proved still further the reliability of solid motors; the program had only one failure 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. Although Thiokol had 70% of the available solid rocket motor business at the time, the main Polaris solid motor development program had previously been awarded to its West Coast competitor, Aerojet.

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[38] Ulanoff, S., *Illustrated Guide to U.S. Missiles and Rockets*, Doubleday & Co., 1959.

"The Polaris program went to Aerojet because Aerojet already owned sizable development facilities at Sacramento, and work could begin without delay. Thiokol's Elkton plant was far too small for rockets the size of the Polaris engine. Also, Aerojet, whose president [was] former Secretary of the Navy, Dan Kimball, had been closely associated with the Navy for years."[39] In addition, the Navy would have had to route its contracts through the Army to work with Thiokol.

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 ICBM's but the only suitable propellant was the polysulfide type, with an Isp of less than 200 seconds because of the low fuel value of its sulfur content ...

After about two years of work on propellant binders with nitro or nitrate-groups, we switched to efforts on a high fuel value hydrocarbon liquid polymer binder ... The first tests measured Isp's around 240 seconds - ICBM range! Joe Wiggins and I flew all one night in 1955 to take the good news to Air Force BMD, then located temporarily in an abandoned convent in Inglewood, California."

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 non-existent Engineering Department), Horace "Buddy" Bomar, and Anthony Guzzo. In October of 1955, Dr. Ritchey recalls a meeting of the Board of Directors where a request for the money to build a large new plant was placed before the Board.[40] This request was the result of Ritchey telling Crosby that a much bigger site than Huntsville or Elkton was needed if Thiokol was to "stay in the business."[41] 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.[42] 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 that 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.[43]

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[39] Thompson, Edward T., *The Rocketing Fortunes of Thiokol* Fortune, June 1958, p. 114.

[40] Dr. H.W. Ritchey, Memoirs.

[41] J.W. Crosby, Personal Reminiscence, 1991.

[42] ibid.

[43] Thompson, Edward T., *The Rocketing Fortunes of Thiokol*, Fortune, June 1958, p. 114.

Now came the task of locating a site that had sufficient acreage, and more importantly, could be brought at an affordable price. After reviewing many sites over a two month period the decision was made to purchase 11,000 acres of a sheep 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 sheep 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) was selected by May of the same year. The bleakness of the terrain can be seen in Figure 16, compared to only four years later in 1960. Later on, 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.

Ground was broken by November, 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 second 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 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. Other personnel were transferred directly from Elkton and Huntsville, and the race began.

By December 1957, the new plant had manufactured its first large engine, containing over four times as much propellant as the RV-A-10 (22,000 pounds), and in February 1958 this first large motor was tested successfully. This motor known as the TU-110, was nicknamed the "Big B" motor,[44] and it advanced the industry's technology for several reasons - it was the first scale-up of a propellant that contained the new polybutadiene acrylic acid (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,

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[44] A politer version of "It's a big bastard".

1960

Fig. 16
Lampo Junction in 1956 and 1960

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, the feisty head of the Propellant Development Laboratory at Huntsville out to this new Rocket Operations Center, or ROC office, to run the program. 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 three major areas:

- Big Motors
- Tactical Missiles
- Technology

and it was soon to become preeminent in a fourth area -- Space.

Many changes and additions to the corporate structure had occurred in the 30 years between 1928, when the corporation was formed, and 1958, when this first decade of rocket activities had ended. Some of the important changes are listed in Table 2, and others carrying this corporate chronology up to 1990 are included.

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CORPORATE CHRONOLOGY

Year	Event
1928	Thiokol incorporated in Kansas City, MO
1930	Moved to Yardville, NJ
1948	Rocket operations begun in Elkton, MD
1949	Original rocket group moved to Redstone Arsenal, Huntsville, AL
1951	Elkton reactivated
1952	Thiokol began operation of Longhorn in Marshall, TX
1957	Utah (later Wasatch) Division formed
1958	Reaction Motors liquid rocket operations acquired
1962	Georgia Space Booster plant started
1965	Georgia plant put on standby
1972	Reaction Motors ceased operations
1975	Louisiana Division operations began
1982	Thiokol merged with Morton Salt
1989	Morton Thiokol split into Morton International and Thiokol Corporation

Table 2

3.0 Big Motors (1958 - 1990)

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. On Feb. 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. Figure 17 summarizes the outstanding progress made on this important program. Garrison later became the President and CEO of Thiokol in 1982.

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. Here are his words:

> "If we are to win the battle that is now going on around the world between freedom and tyranny, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere..."[45]
> "We will put men on the moon in this decade and bring them back alive."

He was, of course, referring to the recent suborbital flights of Yuri Gagarin and Alan Shepherd. NASA was now 3 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.

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[45] McDougall, W.A., *The Heavens and the Earth*, Basic Books, 1985, p. 303.

MINUTEMAN

A Model Program

1957	• AF contract – feasibility study
	• Successful demo motor tested 63-in. dia, 22,000 lb
1958	• AF contract – first-stage development
1959	• 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

Fig. 17

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 scale-up effort, at the instigation of Air Force and NASA officials. 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 of 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-inch diameter 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-inch motor and in February 1965, the Georgia Division tested its version of a 156-inch design. The test was successful, and it produced a total of 3 million pounds of thrust -- the largest solid propellant motor ever fired in the free world up to that time.

Later on in 1965, the maraging steel case for the 260-inch motor manufactured by Newport News Shipbuilding Corp. 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-inch case failed in hydrotest at 15% of the design pressure, probably due to improper heat-treatment of the welds in the finished assembly. 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.

In the 1965 Thiokol Annual Report there is a brief mention of the adverse financial effect of the cancellation of the 260-inch 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-like pit over 260 inches in diameter and over 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. 18. In the 1970s the Georgia facility was sold to Union Carbide.

For 6 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.

GEORGIA DIVISION
156-IN. CASTING PIT – 50 FT ACROSS X 120 FT DEEP

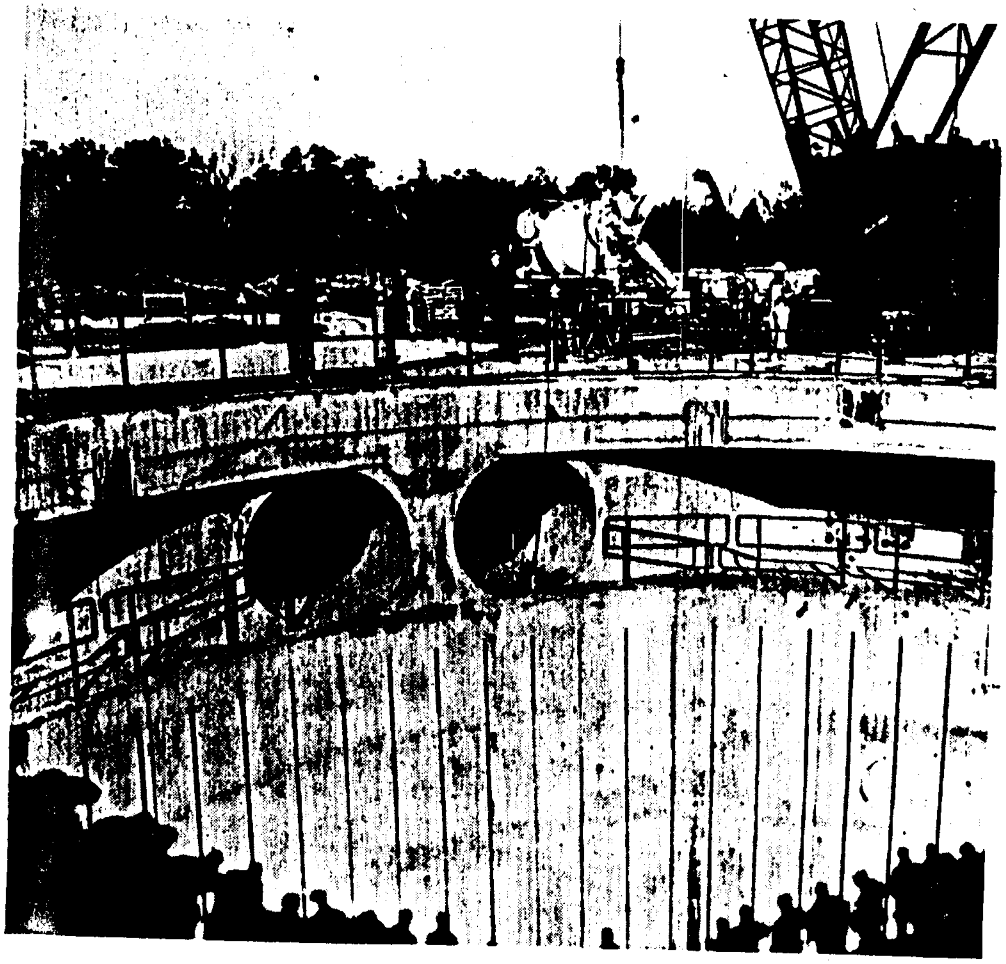

Fig. 18

By 1971,[46] interest in large solid motors had revived to the point where pictures and data on the long-dormant 156- and 260-inch 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 3 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 1 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. 19. Some of the key people involved in these efforts were Ed Dorsey, John Thirkill, Joe Pelham and Al McDonald. At this point in time, the total number of people working at the Wasatch Division was over 6,000.

After a total of 11 successful full-scale static tests (7 development and 4 qualification), and a total of 24 successful Shuttle flights, for a grand total of 59 firings of full-scale Shuttle SRMs without a mishap, a tragic failure occurred on January 28, 1986, with the loss of the Challenger and seven brave astronauts. It was with a personal sense of loss that Thiokol engineers and other program personnel undertook a 24-hour-a-day, 7-day-a-week schedule for many months until the safety margin of the seal at the joints between the segments had been increased to the point where launches could be safely conducted over a wider temperature range than the old seal design, but not as low as the 8°F recorded for the right SRB by the MSFC ice inspection team on January 28.[47]

A tabulation of large rocket motor scale-up chronology is shown in Table 3, including the progression from loading a motor (the T-40 JATO) from one batch of propellant to loading the 156-inch motor with 160 batches of 5000 pounds each.

As a part of the redesign, development and requalification process, six full-scale RSRM motors were successfully tested, with one of them enduring exposure to +120°F and firing at this temperature. The Shuttle resumed flights on September 29, 1988, after 2-1/2 years of intense redesign effort on the SRMs, with a successful flight of the Discovery. As of the end of 1995, 44

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[46] Thiokol Annual Report, 1972.

[47] Presidential Commission Report on the Space Shuttle Challenger Accident, page 110, June 6, 1986.

SPACE SHUTTLE BOOSTERS

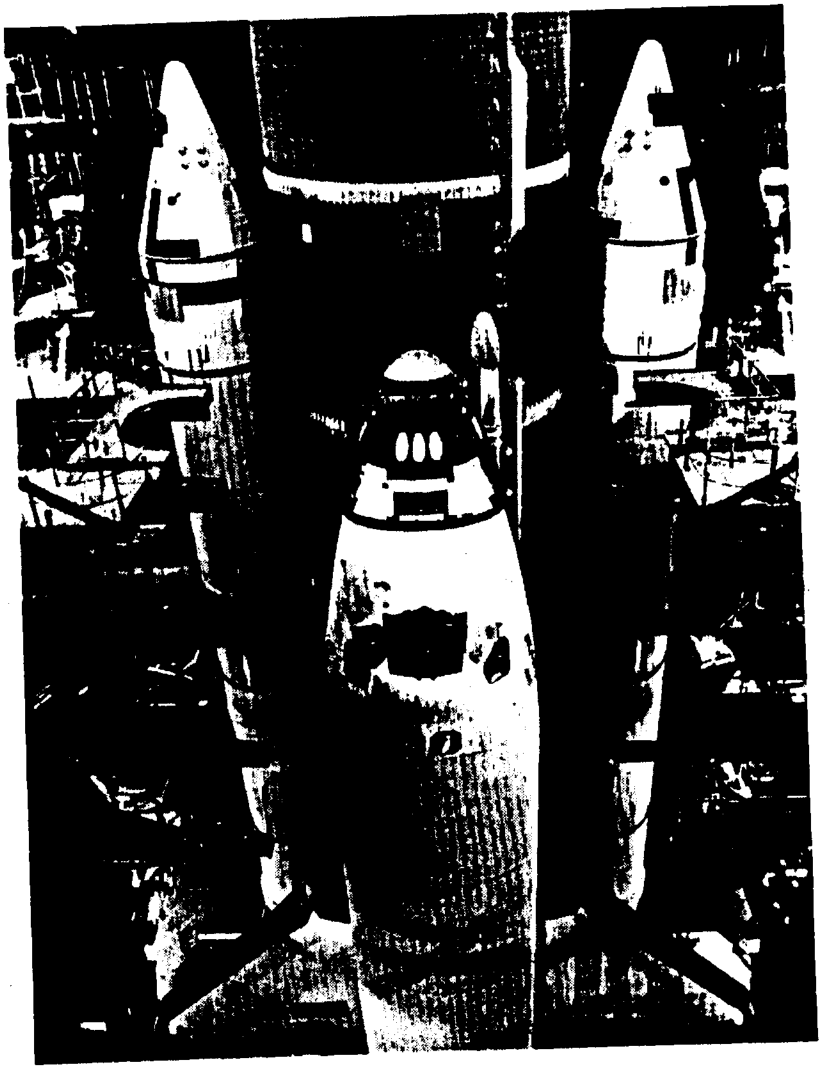

Fig. 19

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	798,000	160
1977	Shuttle SRM	146	1,107,000	160
1978	Peacekeeper Stage I	92	90,000	17

Table 3

4.0 SPACE (1957 - 1990)

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.[48]

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 3 weeks earlier on October 4.[49]

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.[50] [51] 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. (Figure 20). 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.

Also, during these early years, Huntsville was modifying its Hermes experience into a NASA test bed motor nicknamed "Little Joe," that 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 1 motors and four Recruit motors. It was a modification of the Air Force X-17 test vehicle. Also, about 1959, the X-17 was used to launch an atomic bomb into the stratosphere[52] launched from a ship off the South American coast as an EMP (electromagnetic pulse) experiment. It disrupted radio and phone communications for hours.

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[48] *The Space Encyclopedia,* A Guide to Astronomy and Space Research, New York, 1960.

[49] Emme, E.M., *An American Chronology of Space and Technology in the Exploration of Space,* NASA, 1961.

[50] Reaction Motors, Incorporated, F.H. Winter and F. I. Ordway, paper IAA-82-277, Sept. 27, 1982.

[51] *JPL and the American Space Program,* C.R. Koppes, p. 16.

[52] H.W. Ritchey, letter, Jan. 1991.

more successful Shuttle launches have taken place; one of the most significant ones (April 1990) placed the Hubble Space Telescope into the highest earth orbit yet attained by the Shuttle. The overall number of flights to date is 69, for a total of 138 SRMs.

The Shuttle RSRM represents the convergence and culmination of two of Thiokol's major areas of long-term achievements -- large motors and space. In the section that follows, the history of Thiokol's space efforts is examined in more detail, tracing them from their early beginnings through more than three decades to the present time.

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THE X-15 ROCKET PLANE

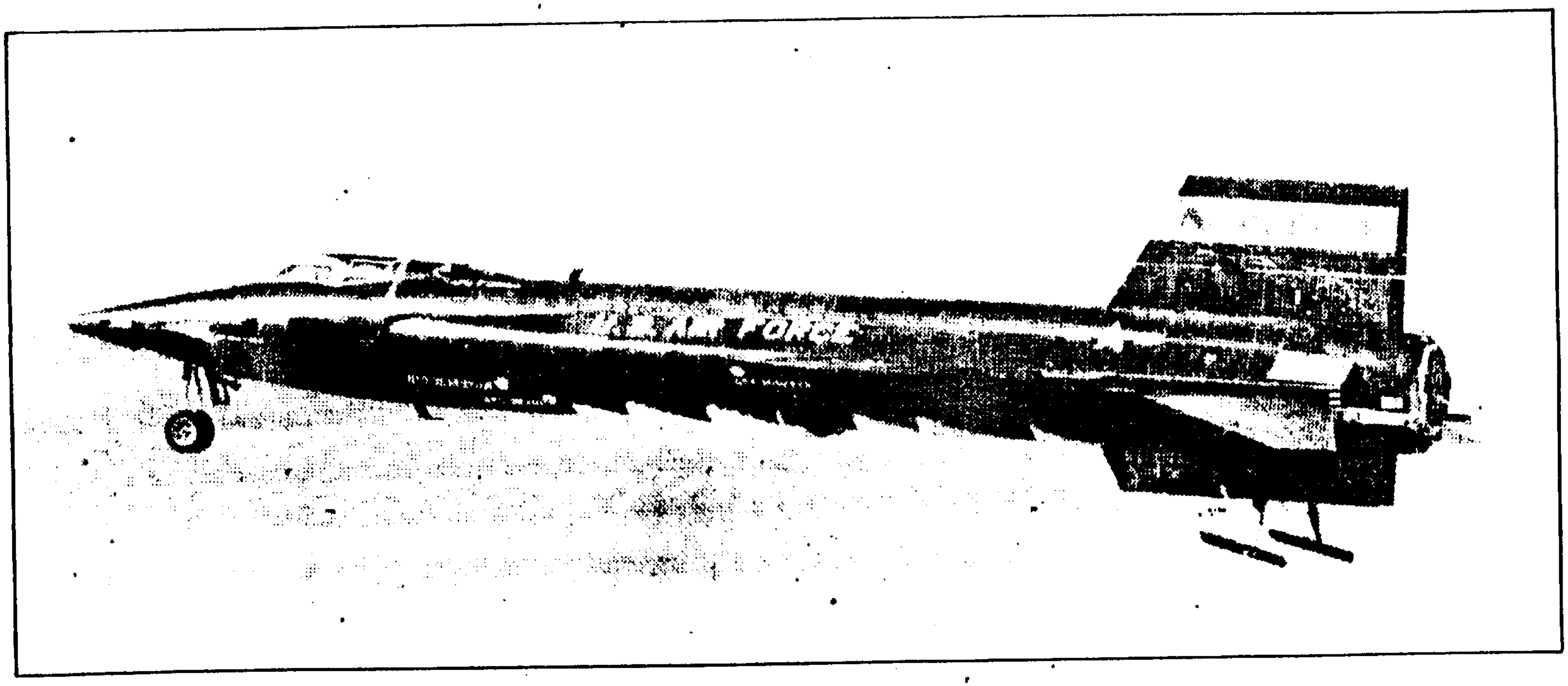

Fig. 20

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 over 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 Castors 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 was 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).

The solid motor strap-on designs continued to expand in size and eventually evolved into the Shuttle SRMs, the largest strap-on solid motors. The SRMs and their designs have been covered earlier, in the section on large 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.

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-inch-diameter 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-inch-diameter "ball" was soon followed by a larger, 40-inch-diameter 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 soft lunar landing system. 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 Figure 21 with the design engineer (Bob McCafferty) using his sliderule for the design calculations in that pre-computer era. Thiokol followed this program by supplying the retro motors for the Gemini program, returning each of the astronaut pairs to earth successfully.

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 been heretofore been possible. The Surveyor design was slightly reduced in size from the 40-inch spherical, becoming a 37-inch-diameter 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 inches up to 75 inches 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. Over 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.

Some of the people connected with the development and production of these motors were Arnie Irwin, who suggested the STAR name, R.L. "Dick" Davis and Jim Pletz, who managed many of the STAR programs, Les Dyson, John King, Tom Kirschner and Don Lushis, the STAR motor engineers, Dr. Winston Brundige, the space motor aging expert, and Jack Gottemuller, who cast many of these motors in production.

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.

Thiokol also supplied a total of 13 solid rocket motors for use on the large liquid Saturn rockets that launched the Apollo spacecraft on its flights to the moon.

A selection of some of the most important dates in Thiokol's space motor history is presented in Table 4. A more complete history of space milestones from 1957 to 1986 is included as Appendix E.

Figure 21

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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	First 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
Apr 1985	Aged Motor Flight	Castor I	Lance Geophysics (23 years)
Nov 26, 1985	First Flight	STAR 63D	PAM Delta/RCA Sat Com
Jan 1989	Final Qualification Test — Redesigned Motor	Shuttle RSRM	Space Transportation System (+20°F)
Aug 1989	First Neptune Flyby	STAR 37E	Voyager II (1977 launch)

Table 4

5.0 MISSILES (1949 - 1990)

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 over 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 given in Table 5. The year in which development or production of the unit began is given to provide a chronology of these missiles. The two original tables used to form this combined table are given in their original format as Appendix F.[53] [54] Included are reliability data on space and strategic motors as well as tactical missile motors. For the tactical missiles, the flight reliability is calculated as 0.998% at a 99% confidence level. This is a remarkable achievement over a 42-year period 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 long-standing relationship with Hughes and the Air Force on these important tactical weapons. The first flight of the Maverick took place in 1969,

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[53] Examples of Flight Reliability, Table 12-5, Huntsville Proposal 108-86, March 31, 1986.

[54] Morton Thiokol Reliability Summary, October 21, 1987, supplied by R. K. Lund.

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CASE-BONDED TACTICAL ROCKET MOTORS
(as of 10/31/87)

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-10	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	4
1974	Harm	—	300	250	7
1976	Hellfire	TX-657	22	362	0
1985	Standard Missile	Mk-70/104	1500	401	4

Table 5

along with the first flight of a hypervelocity rocket being developed by Thiokol, known as the Zap.

By the year 1970, Thiokol had become the supplier for a very long list of solid rockets for weapon systems. The following were included on this list:

Table 6. Thiokol Weapons Propulsion Systems in 1970

- Production
  - 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
- Development
  - TOW
  - Hellfire
  - HVAR (high-velocity antitank rocket)

By 1971, the list was increased by the addition of the navy Agile and the Air Force SRAM missile programs, 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, from 1974 through 1990, 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 standard Missile Fleet Defense rockets, HARM and AAAM advanced sub-launched Ballistic Missiles. Newer systems included the helicopter-launched Hellfire 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.

By 1985, some new initiatives had begun on missile systems, including the High-Speed Anti-Radiation Missile (HARM), the Standard Missile, and early work on Strategic Defense Initiative (SDI) Technology had begun. During the next 5 years, the HARM and Standard Missiles were to go into production, and significant development programs in the important SDI area were initiated. Also, development programs for the Trident II SLBM, the MX Peacekeeper missile and the Small Intercontinental Ballistic Missile (SICBM) moved to the front of Thiokol's efforts on missile systems. These efforts continued as Thiokol moved into the decade of the 1990's.

6.0 Technology (1949 - 1990)

From the beginning, Thiokol's greatest contributions have been in the field of solid rocket motor technology, with the emphasis on developments that are translatable into the production of effective high-performance rocket motors with high reliability -- in other words, rocket motors that work and that can be delivered in large quantities at a reasonable cost. Extracting the last fraction of a percent of performance by the use of overly sophisticated designs has generally been avoided, with a more conservative approach to technology generally paying dividends in the form of shorter development schedules and fewer production problems.

Table 7 lists some of the most important technology items Thiokol has contributed to the industry. Many additional items could be added to the list, but these are seen as either significant firsts, or significant contributions, and frequently both.

Liquid Polymers and Solid Propellants

Thiokol has been synonymous with liquid polymers for nearly 50 years, and the number of patents and research papers issued in this area is too large to count. Table 8 summarizes some of the most important liquid polymers developed by Thiokol chemists over the years. The work on the original liquid polysulfide polymer, the LP3 ethyl formal type, was begun in 1942, by Dr. Patrick and Harry Ferguson. The history of how it drew Thiokol into the design and manufacture of rockets has been described earlier.

Because of the usefulness of this type of polymer as an aircraft fuel tank sealant, the Department of Defense provided funds to Thiokol from 1948 to 1949 to research polymer modifications that would improve the low temperature flexibility of these polymers. Out of this work by Edward Fettes, Eugene Bertozzi, and others working in the Thiokol laboratories in Trenton, New Jersey, came two new liquid polymers. In these the disulfide linkages were separated at first by butyl formal segments (LP-205) and later by butyl ether segments (LP-270). These polymers did in fact improve the low temperature performance of sealant compositions, although at the expense of increased cost. In the early 1950s, the chemists in the rocket side of the corporation, led by Dr. William Arendale and John McDermott of the Redstone (later Huntsville) Division, developed propellants based on mixtures of these three polysulfide polymers to improve low temperature properties. Table 9 lists examples of these early propellants.

The numbering system for propellants began in 1948 as the letter "T" (for Thiokol), followed by a sequential number that appears to have started with the number "10". T-10, a composition of potassium perchlorate and LP-3, was the same as JPL composition JPL100L, but the T indicated that is was manufactured by Thiokol. About 1952, the system was adjusted to indicate the division of origin; this resulted in designations such as TRX-135, signifying Thiokol Redstone Experimental propellant. About 1957, Dr. Ritchey, who was now technical director for all of Thiokol's rocket activities, was being bombarded with compositions from several different divisions, with several different types of binder/polymers. In order to expand and codify the system, he outlined the system that is still in use today:

SIGNIFICANT TECHNOLOGICAL CONTRIBUTIONS TO SOLID PROPULSION

- Liquid polymers
- Solid propellant compositions
- Case-bonded rocket motors
- Large rocket motors and multiple mix technology
- The pyrogen ignition concept
- Case-on-propellant techniques
- High-performance space motors
- Thrust vector control (TVC) systems for use in air, space, and under water
- Segmented-case rocket motors
- Strap-on solids for launch vehicles
- Strategic missile propulsion
- Integral rocket-ramjet boosters
- Solid pulse motors
- Carbon / Carbon exit cones
- Non-asbestos insulation compounds
- LOX hybrid motor
- On-demand gas generators (dual chamber and other types)
- Deep space ignition systems
- Continuous propellant processing
- Clean exhaust propellants (reduced smoke and minimum smoke types

Table 7

THIOKOL LIQUID POLYMERS

Year	Polymer	Designation	Specific Gravity, g/cc	Heat of Combustion, cal/gm
1942	Ethyl Formal Polysulfide	LP3, LP33	1.27	5,300
1948	Butyl Formal Polysulfide	LP-205	1.15	7,100
1949	Butyl Ether Polysulfide	LP-270	1.12	7,500
1954	Polybutadiene Acrylic Acid	PBAA	0.90	10,300
1954	Polybutadiene Acrylonitrile	PBAN	0.93	9,900
1955	Carboxyl-terminated Polybutadiene	CTPB	0.91	10,500
1987	Polyglycidyl Nitrate	PGN	1.45	3,240

Table 8

TP - for Thiokol propellant
E - A code letter signifying the binder polymer type
1000 - a four-digit sequential number that also indicated the division of origin

The letter "E" indicated the original ethyl formal polysulfide was the binder, while the letter "L" indicated a mixture of the three polysulfide polymers. H, signifying hydrocarbon, was selected to indicate a propellant based on the new polybutadiene-based liquid polymers. Research on these had begun, not in the Trenton chemical laboratories, but in the Redstone 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.

In 1952, Thiokol, as part of its Army-funded research program, began searching for ways to increase the specific impulse and to lower the low temperature limit of its polysulfide propellants. One of the approaches taken involved reducing or eliminating the sulfur content of the polysulfides by preparing liquid hydrocarbon polymers. 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 that could be cured easily to these polymers. 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-ounce Coca-Cola bottles, since these were the right capacity and size (and cost) to fit the home-made polymerization cabinet used to produce sufficient quantities for characterization in experimental propellants.[55] 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 it was eventually scaled up in 1958 to produce the "Big B" motor with 22,000 pounds of propellant. 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 pounds of propellant.

At some point in the late 1950's, 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

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[55] Personal reminiscence, W.E. Hunter.

became available in the late 1960s, as a lower-viscosity, lower-cost polymer that has become the standard for the industry. It used isocyanate compounds as curing agents, and eventually resulted in higher performance solid propellants like TP-H-1202, due mainly to its ability to disperse higher percentages of solid oxidizers and fuels. A representative list of Thiokol solid propellants is given in Table 9.

In the late 1970s, other non-Thiokol-developed polymers became important, such as the polycaprolactone (PCL)types. These oxygenated polymers had good compatibility with energetic liquid plasticizers such as TMETN (trimethylolethane trinitrate) and NG (nitroglycerin), and permitted the development of energetic propellants that had little or no particulate solids in their exhaust products, such as TP-Q-7012. Dr. David Flanigan and others in the Huntsville laboratories were heavily involved in these early composite minimum smoke propellants. This work evolved into the use of mixed nitratoplasticizers (TMETN and BTTN) in place of nitroglycerin. These minimum smoke propellants are in use in such systems as TOW II and Hellfire. In the late 1980s work was undertaken on "clean propellants" to drastically reduce or eliminate HCL in motor exhaust products. This work, spear-headed by Dr. Ron Carpenter, his coworkers under the direction of Dr. Grant Thompson, , resulted in two "scavenged" propellants ready for end item development.

Thiokol has continued to research new liquid polymers over each decade since the 1950s, however. An example of just one of these is listed at the end of Table 8; this is polyglycidyl nitrate, or PGN. It is interesting to note that this material, of considerable interest to Thiokol and the industry in 1990, was the subject of a research project at the Jet Propulsion Laboratory in the 1950s. Today's sophistication in polymerization techniques and analytical instruments has aided greatly in this new review of an old material.

Another indicator of recent technology trends being investigated by Thiokol is the use of thermoplastic elastomers in the formulation of solid propellants. For example, the use of alternating hard block/soft block polymer chains, such as the SBS-TPE polymer (stryene-butadiene-styrene thermoplastic elastomer), gives promise that the several-days-long curing cycles in common use with the HTPB and other older butadiene polymers will eventually be replaced by a melt-and-pour-and-resolidify cycle that is only a few hours in length. The comparison of this processing technique with the original asphalt binder developed by Parsons in the early 1940s is striking, and once again shows how old ideas can be revitalized with new polymers.

In the 1990's, Thiokol is still pursuing vigorous research programs on new liquid polymers and new solid propellants based on them. Liquid polymers were responsible for Thiokol's entry into the field of rocket propulsion, and it is clear that the company does not intend to forget this fact.

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SOLID PROPELLANTS

Year	Type	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	0.0632	263
1977	HTPB/AP/Al/HMX	TP-H-1202	0.0666	267
1978	PCL/TMETN/HMX	TP-Q-7012	0.0636	250
1989	SBS-TPE/AP/Al	TP-T-3007	0.0650	265

Fig. 7

Case-Bonded Rocket Motors

While the chemists at Thiokol were busy developing new polymers and new propellants, the engineers were even busier developing new rocket motors. During the 1950s and 1960s, the list of rocket motors under development and in production was increasing in length every year, with a corresponding increase in the number of project engineers and program managers. In those turbulent years, the average age of the technical staff was in the neighborhood of 30, and it seemed to outsiders visiting Thiokol for the first time that the organization was in a constant state of turmoil, with people rushing back and forth rapidly, yelling at each other constantly. This frequently gave outsiders the impression that communication with the customer was less important than experimental work on the design.[56]

The comment was more accurate than not; Thiokol developed an early reputation for designing and producing simple, rugged, and producible rocket motors, as the flight history data cited earlier in Table 5 demonstrates. At the same time, this concentration on making certain the motor "worked," frequently led to delays in getting out necessary reports; at one point (about 1954), the Falcon program was over 12 months behind in issuing monthly status reports. This did not mean that the Air Force and Hughes were not fully aware of the status of the program; they were in weekly, sometimes daily contact by telephone, and this made documenting progress with written reports a lower priority task than it would have been otherwise. Given a choice between spending his workday writing reports and getting ready for another static firing test of the newest design change, the project engineer and program manager always opted for the latter. It was more exciting, particularly in the days when the outcome of a test had not been predicted in advance by a large, sophisticated computer program. Over the years this early attitude of putting reports at a low level of priority was replaced by a much more professional approach toward documenting progress in a timely fashion, and meeting report deadlines is now part of the job.

By the end of the first decade (1958) of Thiokol's rocket motor development, however, agreement had been reached on sound engineering design practices in many areas, and the first computers had been inserted into the process of designing new motors.

Assessing the situation in 1960, Dr. Ritchey felt that knowledge of Thiokol's technical capabilities was somewhat spotty among the major contractors in the aerospace industry. As a way of correcting this, he ordered a generalized presentation to be assembled and taken out to the prime contractors of the day. For several weeks during the summer of 1960, a team of both liquid and solid rocket engineers and chemists crisscrossed every region of the U.S. giving this presentation sometimes two and three times a day. A set of notes for the solid rocket motor segment of this presentation has survived to the present day, and in an attempt to preserve an historic "snapshot" of Thiokol's rocket motor status over 30 years ago, the following excerpt

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[56] One Government employee at Wright Patterson Air Force Base in 1958 described the company in those days as follows: "Thiokol is the kind of company where you give them a one-year contract to develop a rocket motor, and for twelve months you never hear a word. Then, on the last day of the contract, some young guy in shirt-sleeves rushes in with a rocket motor under his arm, yelling that he's delivering the motor and it works. And it does." (Attributed to Don Hart, Director of the Rocket Propulsion Laboratory, EAFB).

from the beginning of this review of the "Development and Production-Solids" section is included here. These notes are attributed to Bill Savelle, who gave most of the solid motor presentations.

"In discussing our current 1960 programs, it is important to emphasize that the work we performed in 1953 and prior years enables us to point to our present accomplishments ... As the pioneer in high performance case-bonded rocket engines Thiokol has been associated with ... an impressively large number of programs..."

The next few slides of the presentation listed the programs shown in Tables 10 and 11.

Table 10. Engines in Research and Development - 1960

Designation	Prime Contractor	Service
Minuteman	BMC	USAF
Subroc	Goodyear	USN
Pershing	Martin	USA
Zeus	Douglas	USA
Sphericals	NASA	NASA

Table 11. Programs in Production - 1960

Designation	Prime Contractor	Service
Mercury Retrograde	McDonnell	NASA
Discoverer Retrograde	General Electric	USAD
Little Joe, XM33	North American	NASA
Scout, XM33	Chance Vought	NASA
WS609A, XM33	Aeronautronics	USAF
Recruit	Various	All
Cajun	Various	All
XM20	Various	All
Bomarc Booster	Boeing	USAF
Mace	Martin	USAF
Lacrosse	Martin	USA
Nike Hercules Sustainer	Douglas	USA
Honest John Spin	Douglas	USA
Sergeant	Sperry	USA
Falcon	Hughes	USAF
Jupiter Spin	ABMA	USA
Jupiter Vernier	ABMA	USA
X7B Booster	Lockheed	USAF

And the list continued to lengthen in the years after 1960. Table 12 shows the program additions year-by-year up through 1988.

By 1960, Thiokol now had five rocket divisions at five separate locations, all pursuing new programs at a furious rate. The liquid rocket division was Reaction Motors in Denville, NJ, which had begun as an independent corporation in December of 1941[57] and had been acquired by Thiokol in April of 1958. The other four -- Redstone in Huntsville, Alabama; Longhorn in Marshall, Texas; Elkton in Elkton, Maryland; and the Wasatch Division in Brigham City, Utah -- were all engaged in various aspects of the solid rocket field, and competing against one another to some degree.

Table 12. Thiokol Rocket Motors After 1960

Year	Rocket Motor Name/Function	Division
1961	Surveyor Retro/Space Motor	Elkton
	Dynasoar (X-20)	Elkton
1962	Nike Ajax	Redstone (Huntsville)
	Hawk	Redstone (Huntsville
	Mobile Medium Range Ballistic Missile (MMRBM)	Utah (Wasatch)
1963	260-in. Dia./NASA Booster	Georgia
	156-in. Dia/NASA Booster	Georgia
	156-in. Dia/NASA Booster	Utah (Wasatch)
1964	Genie (STAR 37)	Utah (Wasatch)
1965	Burner II/Space Motor	Elkton
	Improved Delta/Space Motor	Elkton
	Apollo/Tower Jettison	Elkton
	Recruit/Sounding Rocket	Elkton
	Apache/Sounding Rocket	Huntsville
	Maverick	Huntsville
	Improved Zeus	Huntsville
	Air-Augmented Rocket	Huntsville
	Poseidon	Utah (Wasatch)
	Patriot	Huntsville
1967	Sentinel/Anti-Ballistic Missile	Huntsville
	Castor I / Booster	Huntsville
1972	Trident I - First and Second Stages	Wasatch
	Minuteman Third Stage	Wasatch
1974	Shuttle SRM	Wasatch
	Sidewinder	Huntsville
	STAR 48	Elkton
	Harpoon	Elkton
	HARM	Wasatch

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[57] Winter, F.H., and Ordway, F.I., *Reaction Motors, Incorporated, from December 1941 through April 1958*, IAA-82-277, October 1982.

1975	Standard Missile	Wasatch
1978	Peacekeeper First Stage	Wasatch
1980	TOW II	Huntsville
1981	Hellfire	Huntsville
1982	Trident II First and Second Stages	Wasatch*
1983	SLAT Ramjet Booster	Huntsville
1986	Shuttle RSRM	Space (Utah)
1987	Vertical Launch Assoc.	Elkton
1988	AAAM	Tactical (Utah)

* Joint Venture with Hercules

To bring some order into this chaotic situation, Thiokol established a Rocket Operations Center in Ogden, Utah, in the spring of 1960, and put Dr. Ritchey in charge.

Two of the most significant steps taken by Dr. Ritchey and his staff were to set up a proposal assignment system and to call for the issuance of a Standard Handbook of Rocket Engineering. Volume 1 of this document issued in January of 1961, and it codified much of the solid rocket design information and techniques developed in the 13 years since Thiokol had entered the field.

These two actions moved Thiokol along a path that eliminated much of the confusion that had caused one industry executive[58] to remark somewhat facetiously that he didn't mind competing with the five little companies that made up Thiokol; they weren't that much competition for his large single-location rocket company.

By 1965, this coordination of various locations was working so well that Thiokol joined with Hercules, Incorporated (another major supplier), to pursue the Poseidon, the next Navy SLBM (sub-launched ballistic missile). This was a longer-range missile that would eventually replace the Polaris, won a decade earlier by Aerojet. This early success of the Joint Venture, as it became known, was extended continuously over the ensuing 25 years, benefiting both the Department of Defense and the two participants. The relationship was continued under the Trident I and II programs.

Volume II of the Standard Handbook was issued 3 years after Volume I, in January of 1964, and the differences are interesting. The table of contents of Volume II is shown in Table 13. Unfortunately there are no contributors listed for Volume I, but those for each section of Volume II are listed here, as a way of identifying some (by no means all) of the engineering specialists for Thiokol in the early 1960s.

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[58] Attributed to Dan Kimball of Aerojet, to J.W. Crosby.

While Volume I dealt primarily with theory and the mathematical equations that defined rocket motor design and performance, Volume II emphasized actual engineering data, and its application to the design of rocket motors. The growing sophistication in design, and the extension to more complex devices, is evident in such sections as the ones on Igniters and Thrust Vector Controls. In the 1961 edition, the section on the pyrogen igniter is limited to a half page of text, while the 1964 volume covers 11 pages, giving detailed drawings, data, and predictive equations. This device was originally conceived and tested in 1954 at the Huntsville (Redstone) Division by Allan E. Williams, who later became Director of Engineering at the Elkton Division.

Igniters

Prior to the invention of the pyrogen igniter, rocket motors were ignited by pyrotechnic devices of three major types:

Basket-type igniters
"Jelly-roll" igniters
Can-type igniters

The pyrogen concept was a simple one; it used a small rocket motor to ignite a bigger rocket motor. It reduced the amount of sensitive pyrotechnic mixtures to a much safer level, and it produced an easily controlled and designable pressure rise rate inside the rocket motor during the ignition phase. It also produced hot ignition gases and solid particles over a longer period of time than the three types of pyrotechnic igniters, making the problem of obtaining reliable ignition at temperatures as low as -75°F a simple one to solve. It is especially well-suited to igniting motors in space, because it makes it unnecessary to maintain pressure in the motor grain cavity.

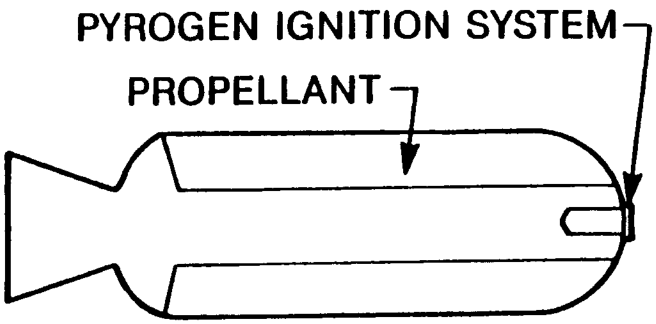
The pyrogen concept was also easily adaptable to a wide range of installation and design options. Figure 22 shows four different modes of using the pyrogen concept. This drawing is copied from the 1964 edition of the Thiokol Standard Handbook, and it shows how commonplace this attractively simple method of controlling the ignition process had become by this time period. Other variations have been developed and used in the years since 1964, as well. In the 5 years following its first test at Thiokol in 1954, the pyrogen design concept became the standard method of igniting large rocket motors for the industry

Thrust Vector Controls

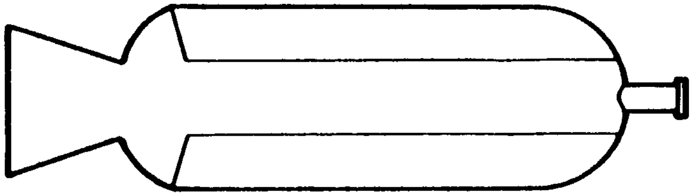
Thiokol engineers also developed and successfully tested many devices in the field of thrust vector controls. The first large solid rocket to use a steering device was the Hermes A-2; it

SA28893 (199)

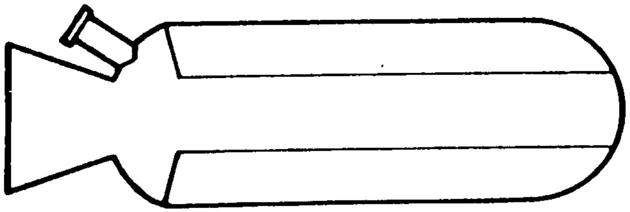
THE PYROGEN IGNITION CONCEPT



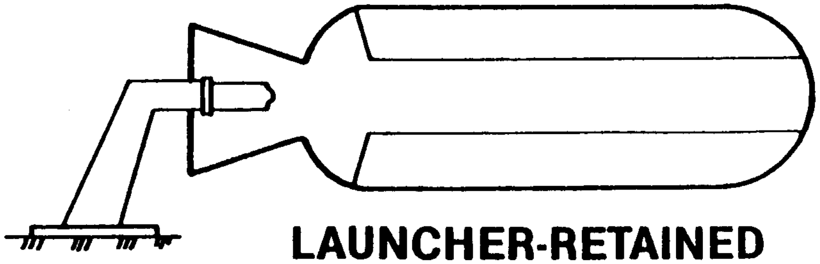
INTERNALLY MOUNTED HEAD-END PYROGEN IGNITER SYSTEM



EXTERNALLY MOUNTED HEAD-END PYROGEN IGNITION SYSTEM



EXTERNALLY MOUNTED AFT-END PYROGEN IGNITION SYSTEM



LAUNCHER-RETAINED PYROGEN IGNITION SYSTEM

Source — *Standard Handbook of Rocket Engineering* (Vol. II), Thiokol Chemical Corporation, 1963

Figure 22

Appendix A
Early Thiokol Employees (circa 1948)

			Moved From Elkton To Huntsville
Glen Nelson	-	The first employee	Yes
Lou Welanetz	-	The first General Manager	No
Henry Nocke	-	Head of Quality Control	Yes
Jack Buchanan	-	Head of Testing (started 3/48)	Yes
Bob Brooks	-	Testing	Yes
Charlie Meiser	-	Chemist	Yes
Myron Black	-	Chemist	Yes
Tony Guzzo	-	Started Sept. 1948	Yes
Bill Wyre	-	Propellant Mixing - Operator	Yes
Earl Roark	-	Oxidizer Grinding - Operator	Yes
John McDermott	-	Head Propellant Development	Yes
Frank Quinn	-	Purchasing	Yes
Dr. Harold W. Ritchey	-	Started June 1949	Yes
Jim Boyd	-	Moved back to Elkton and started Boyd's Motel	Yes
George Martin	-	Testing - Engineer	Yes
Irv Schneider	-	Engineering	Yes
Bill DeKnight	-	Testing	Yes
Al Snyder	-	Accounting	Yes
Jane Dutcher	-	Lab	No
Don Kershner	-	Summer Employee	No (spent 6 weeks in Huntsville)
_________ Day	-	Shipping & Receiving	Yes
Andy Fossum	-	Shipping & Receiving	Yes
Jim Alley	-	Operator	Yes
Mike Toomey	-	Testing	No
___________	-	Welder	No

Notes: (1) This list of 25 of the original group was provided by Anthony Guzzo and Bob Brooks

(2) Bob Brooks remembers the total number of original Elkton employees as 27. This number is confirmed in an early Huntsville listing.

Appendix B

TU2-31

RECORD
HGJones/Im/6427

ORDTU

3 March 1949

SUBJECT: Research and Development of Thiokol Propellants
TU2-16, Contract No. W-36-034-ORD-7709

TO: District Chief
Philadelphia Ordnance District
Building 11, Frankford Arsenal
Philadelphia 37, Pa.

1. 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.

2. You are requested to advise Thiokol Corporation to prepare for the deactivation of the Elkton location, the transfer of all the equipment and other property to Redstone Arsenal, and the installation of the necessary equipment and laboratory facilities at that location. Mr. J. W. Crosby, President of Thiokol Corporation has been contacted by this office and his willingness to continue operations at the new site has been ascertained.

3. Tentative schedule for transfer of operations has been set as follows:

a. Negotiate a separate CPFF contract for the transfer as soon as possible.

b. Transfer operations on a phase basis to avoid interruptions as far as possible to present activities.

c. Transfer personnel and begin operations at Redstone not later than 1 October 1949, and have sites at Elkton cleaned up and lease terminated not later than 1 February 1950.

The transfer contract will be prepared in Washington, and the Commanding Officer at Redstone Arsenal will be designated as the contracting officer.

COPY

It is not contemplated that this move will affect the present operating contract, but the renewal of this contract after its expiration will be accomplished at Redstone Arsenal.

4. The District is requested to assist the contractor in every manner in expediting this transfer.

BY COMMAND OF MAJOR GENERAL HUGHES:

H. N. TOFTOY
Colonel, Ord Dept.
Assistant

cc; Major Frank Austin
Thiokol Corporation

ORDGL-OCO

COPY

Appendix C

Employee News Bulletin

April 11, 1975

Thiokol / HUNTSVILLE DIVISION

FIRST CONTRACT FOR THIS DIVISION SIGNED 26 YEARS AGO THIS MONTH

Interested in history???? Below are some actual excerpts from our first contract dated April 15, 1949.

Contract No. W-01-021-Ord-333

RAD ORDER NO. ORDTU 9-10932

Negotiated

RELOCATION CONTRACT

DEPARTMENT OF THE ARMY - ORDNANCE DEPARTMENT

CONTRACTOR: Thiokol Corporation

ADDRESS Trenton, New Jersey

CONTRACT FOR: Relocation of facilities for research and development on rocket propellants from Elkton, Maryland to Redstone Arsenal, Huntsville, Alabama.

AMOUNT: Estimated Cost: $34,369.00
Fixed-Fee : 2,405.00

LOCATION: Redstone Arsenal, Huntsville, Alabama.

PAYMENT: To be made by the Finance Officer, U. S. Army,
Ft McPherson
Atlanta, Georgia

The supplies and services to be obtained by this instrument are authorized by, are for the purposes set forth in, and are chargeable to the following procurement authorities, the available balances of which are sufficient to cover the cost of the same:

938-5559A 2191005 P610-01 S 01-021

This contract is authorized and entered into under the Armed Services Procurement Act of 1947 (Public Law 413 - 80th Congress) and Paragraph 3-210 of the Armed Services Procurement Regulation.

THIOKOL CORPORATION
CONTRACT NO. W-01-021-Ord- 333

This CONTRACT entered into this 15thday of April 1949, by and between THE UNITED STATES OF AMERICA, hereinafter called the Government, represented by the Contracting Officer executing this contract and

THIOKOL CORPORATION

a corporation organized and existing under the laws of the State of Delaware, with its principal office and place of business in the City of Trenton, in the State of New Jersey, hereinafter called the Contractor, WITNESSETH THAT:

WHEREAS, the parties hereto entered into Contract No. W-36-034-Ord-7709 for research, development and related activities in connection with rocket propellants, the same being performed by the contractor on certain leased premises at Elkton, Maryland; and

WHEREAS, the Government desires to have the contractor continue such work on the Government property known and designated as Redstone Arsenal, Huntsville, Alabama and to transfer all facilities from Elkton thereto; and

WHEREAS, the required relocation can be performed by this contractor concurrently with his performance under the aforesaid Contract No. W-36-034-Ord-7709,

NOW, THEREFORE, in consideration of the premises and obligations herein made and undertaken, the parties hereto, intending to be legally bound hereby, do mutually agree as follows:

ARTICLE I. Description of the Project:

1. The relocation, herein provided for has reference to the movement of all the materials, tools, machinery, equipment, supplies, utilities and other things comprising the total facilities now in the custody of the contractor for engaging in research, development, design and study of polysulphide perchlorate propellants, the manufacture of such propellants and any and all work incidental or related thereto. The said facilities, hereinafter referred to as the "Plant", are now located at the Contractor's leased premises at Elkton, Maryland, and the movement thereof to the Redstone Arsenal, Huntsville, Alabama, is undertaken by the Contractor pursuant to the terms of this contract.

2. The facilities and equipment, comprising the "Plant", are of such a character and in such quantity that movement thereof can be effected piecemeal up to a point where a complete operating line can be assembled therefrom at Redstone, without materially affecting operations at Elkton. The Contractor shall utilize and employ his personnel

2. For the original signing of this contract or any modification thereof the term "Contracting Officer" as used herein shall be deemed to include the Contracting Officer appointed by the Chief of Ordnance. For all other purposes, the term "Contracting Officer" shall mean the Contracting Officer appointed by the Chief of Ordnance, his successor or duly authorized representative.

ARTICLE XXIV - Alterations:

The following alterations were made in this contract before it was signed by the parties hereto:

"Article VIV" on page 10 should read "Article IX"

Article XVIII on page 12 should read as follows: "No claim under this contract shall be assigned."

"Article XVIII" on page 15 should read "Article XXIII"

****

IN WITNESS WHEREOF, the parties hereto have executed this contract as of the day and year first above written.

THE UNITED STATES OF AMERICA

BY Carroll D. Hudson

CARROLL D. HUDSON
Col., Ord Dept
Contracting Officer

Two Witnesses:

(1) Irene M. Breen
148 Concord Ave.
Trenton, N.J.
(Address)

(2) A. Dorothy
2056 S. Broad St.
Trenton, N.J.
(Address)

THIOKOL CORPORATION
(Contractor)

BY J W Crosby
(Name and Official Title)
J. W. Crosby, President
780 N. Clinton Ave.
Trenton, N.J.
(Business Address)

I, S. C. [illegible]rley, certify that I am the Secretary of the corporation named as Contractor herein; that J. W. Crosby who signed this contract on behalf of the Contractor was then President of said corporation; that said contract was duly signed for and, in behalf of said corporation by authority of its governing body and is within the scope of its corporate powers.

IN WITNESS WHEREOF, I have hereunto affixed my hand and the seal of said corporation this 1st day of April, 1949.

B. C. Earley
Secretary
B. C. Earley

(Corporate Seal)

Appendix D

DEVELOPMENT OF THE T-40 ROCKET MOTOR[1]

Some emphasis is required on the role of the T-40 rocket motor in the development of the Hermes solid and its influence on later developments. Drawings of the Hermes and T-40 motors show a remarkable resemblance, and indeed, the T-40 was used with little change for scale development work, particularly on "star" configurations for the Hermes.

Early in the Thiokol activity, several rocket motors were selected for the application of the new technology, but initially control of the rocket technology parts of their development was in the hands of outside agencies, usually with extensive backgrounds in earlier solid propellant systems, such as the double base type. The propellant development was carried out by Thiokol, following initial guidlines set out by JPL.

Initial pilot plant operations had been established by Thiokol group, then at Elkton, Maryland, and when work had progressed to the point where propellant of three JPL formulations could be made with essentially the same characteristics as that made at JPL, Army Ordnance established Project TU2-2018A, the objective of which was to have Thiokol undertake the design and development of a general purpose rocket motor, with performance specified to fill a gap in the range of performance of existing units.

The specifications for this motor were simple and offer a startling contrast to modern statements of requirements. A quotation from the first report on the program reads:

> "The following specific requirements were given:
>
> | | |
> |---|---|
> | Thrust, lb | 3000 |
> | Burning Time, sec | 6 |
> | Total Impulse, lb-sec | 18000 |
> | Over-all Specific Impulse, lb-sec/lb, min. | 100 |
> | Ratio of Over-all Length to Diameter | about 6:1 or 7:1 |
> | Temperature Units of Operations | + 130°F to -20°F |
>
> No specifications limiting the choice of polysulfide polymer propellant, the motor case materials, or the provision for attachments were made."

---

[1] Reference 10.

At this time, three JPL formulations (JPL 100L, JPL 126, and JPL 118) were "available" and were used in preliminary design studies for the T-40. The JPL 118 (later, T-13) propellant was chosen and a test motor and a flight motor were designed. Initial tests of various grain configurations met with only partial success. Most of the failures were atributed to hardware problems; none were propellant originated, although one test motor was rejected for liner-to-propellant bond separation and one ran at high pressure for the same reason.

Only test motors (square ended, 0.375-inch walled motors with rupture discs in graphite inserted nozzles) were tested before the Thiokol group moved to Redstone Arsenal. In fact, it was not until the new facilities had been occupied for four months (October 1949) that the flight weight design was completed and parts ordered. The first psuedo-flight weight motor (1/8 case wall, instead of 1/16) was tested at the end of February 1950, just three months before the Hermes program started.

In its final design, the T-40 was one of the most efficient motors made to that date. The fact that the requirements stated that an impulse-to-weight ratio of 100 was required is indicative of the state-of-the-art at the time. In fact, however, the T-40 was the first as far as is known to have an impulse-to-weight of over 150. The performance of the final version, taken from Thiokol Report 4-51, "Notes on Development of JATO, 6KS3000, T-40" were:

Time, seconds	6.26
Average Thurst, lb	3000
Average Pressure, psia	633
Impulse, lb-sec	20,296
Specific Impulse, lb-sec/lb	198
Overall Specific Impulse, lb-sec/lb	152

The weights and dimensions were:

Overall Length, in	47.69
Outside Diameter of case, in	8.25
Maximum outside diameter (Thrust Ring), in	8.64
Weight complete (approx.), lb	133
Weight of Propellant (approx.), lb	102

A total of 62 static tests were made during development, of which 22 were with flight weight cases; 3 static tests were successful at -10°F.

The program was terminated before complete temperature limit tests were made.

The T-40 was a step forward for Thiokol, just beginning in the rocket business, and for solid propellant rocketry. Its development was terminated, primarily because there was no pressing need for such a unit. The basic design, and the specific hardware, however, saw extensive use in the Hermes program. During the Hermes program, units that differed very little from the T-40 were flight tested at Wallops Island, by NACA.

Appendix E

Space Milestones

1957–1990

Thiokol Corporation has provided reliable propulsion for spacecraft, upper stages, and boosters for space launch vehicles for more than 33 years. Our STAR motors have flown from virtually all of the major launch vehicles in the free world. Thiokol has designed and manufactured rocket motors that have provided propulsion for most of the space exploration and commercial satellite programs. The major milestones of these achievements are summarized below:

April 18, 1957: First static test of the Huntsville Division's XM33 Pollux rocket motor. The XM33 was developed for early flight testing of the Polaris guidance system.

October 1957: First launch of the Project Farside deep space probe, powered by five Elkton Recruit rocket motors from a high altitude balloon, delivered one ton of instruments 40 miles above the earth to sample environmental conditions at the fringe of space. (This test was concurrent with the Russian launch of Sputnik I.)

March 17, 1959: NASA launched the first flight of a 20-inch-diameter spherical motor with 253 pounds of propellant on an Honest John/Nike/Nike vehicle.

June 3, 1959: Castor I, Huntsville; first "H" series static test.

August 21, 1959: Castor I, Huntsville; first "H" series flight – Little Joe for NASA.

January 21, 1960: Little Joe flight performance vehicle for the Project Mercury capsules with a rhesus monkey on board incorporated Recruit and Castor rocket motors.

August 11, 1960: Discoverer XIII was deorbited successfully by an Elkton TE-M-195 retro-rocket to recover the first U.S. instrument package from earth orbit.

July 1, 1960: Castor I, Huntsville; first Scout flight (second stage) XM33E5.

November 8, 1960: Castor I, Huntsville; first flight XM33E3 (straight sea level nozzle) SLV-1B Blue Scout Junior

May 5, 1961: Mercury capsule with astronaut Alan Shepard returned from first suborbital flight by three Elkton TE-M-316 retro-rockets. A similar successful test was conducted with astronaut Gus Grissom aboard on July 21, 1961.

The TE-M-316 motor was the first man-rated solid rocket motor for space applications and the first space motor to use a pyrogen igniter (small rocket motor).

February 20, 1962: Mercury capsule manned by John Glenn returned from first orbital flight by three TE-M-316 retro-rockets.

February 28, 1963: Castor I, Huntsville; first flight TX33-52 flight 50B for thrust augmented Thor (TAT)/thrust augmented Delta (TAD).

May 16, 1963: Seventh and last Mercury capsule successfully deorbited by three retro-rockets.

March 12, 1964: Castor II, Huntsville; first static test.

December 8, 1964: Sandia Corporation re-entry vehicle with an Elkton Division 26-inch-diameter (STAR 26) spherical motor successfully flown. The motor was the first qualified for use while spinning about its thrust axis at 400 rpm.

May 6, 1965: The first launch into orbit of the Massachusetts Institute of Technology Lincoln Laboratory Launch Experimental Satellite (LES) was successful from a Titan IIIA by an Elkton Division 13-inch-diameter spherical motor. This was the first flight use of the solid propellant developed for the Surveyor retro, and it became Elkton's standard propellant for space motors designed during the following decade.

May 23, 1965: First Gemini capsule successfully retrieved from orbit by operation of four TE-M-385 12.8-inch-diameter spherical retro-rockets. This motor demonstrated the first flight use of 6Al-4V titanium as a case material for solid rocket motors.

August 8, 1965: Castor II, Huntsville; first flight – Scout TX354-3, second stage, altitude nozzle.

December 18, 1965: Gemini 7 spacecraft completed 220 orbits (2 weeks) before successful re-entry operation of Elkton retro-rockets.

May 30, 1966: Surveyor I spacecraft successfully launched to the moon and, 66 hours later, decelerated from 9000 to 400 feet/second by the STAR 37 motor prior to successful landing of the first instrument package on the moon. Five additional flights were subsequently conducted through 1968. The 1380-pound motor demonstrated major advances in solid propulsion technology for space applications:

- Propellant specific impulse of 289.5 lbf-sec/lbm achieved by use of a contoured nozzle with an expansion ratio of 53:1 and a propellant containing 86-percent total solids with 16-percent aluminum.
- Light weight (propellant mass fraction of 0.90) achieved by a spherical case of D6AC steel, a carbon-phenolic nozzle, and optimized internal insulation.
- Control of thrust vector and center-of-gravity excursion within 0.040 inch during steady state burning.
- Composite solid propellant with a carboxyl-terminated polybutadiene (CTPB) binder that combined a reliable propellant structure with high performance.

July 1, 1966: First flight of a STAR 13 motor that inserted the Anchored Interplanetary Monitoring Platform into earth orbit for scientific measurements. The motor used the titanium case technology developed for the Gemini retro with low burn rate propellant developed for a spherical apogee motor. This motor was previously used in the Titan II ICBM to provide high performance with low acceleration of the sensitive spacecraft instrumentation.

August 9, 1966: Castor II, Huntsville; first TX354-5 strap-on booster for Delta, 11 degree canted nozzle, three each.

September 15, 1966: First USAF Burner II vehicle successfully launched with a STAR 37B upper stage. This motor performed successfully in 22 flights during a decade of use.

November 15, 1966: Successful recovery of the tenth and last Gemini capsule following successful docking with Agena vehicle and operation of the four TE-M-385 retro-rockets. Every vehicle returned from space by solid propulsion had been returned by Elkton Division retro-rockets. Forty motors performed flawlessly in the ten flights.

February 14, 1967: First flight of the NASA Langley Research Center's Trailblazer II vehicle with an Elkton-built, 15-inch-diameter spherical motor as the upper stage.

June 29, 1967: Secor and Aurora scientific satellites ejected from a spacecraft bus by an Elkton Division STAR 13A motor following successful delivery of scientific payload to a 2100-nautical-mile circular polar orbit by STAR 37B motor.

July 22, 1967: First spacecraft insertion into lunar orbit when the STAR 13 motor positioned the NASA Explorer 35 Anchored Interplanetary Monitoring Platform (AIMP) for scientific measurements.

January 7, 1968: Final (seventh) Surveyor flight to the moon was successfully landed by the STAR 37 motor.

July 4, 1968: First launch of the Delta 1913 vehicle with a STAR 37D third-stage motor containing 1440 pounds of propellant and a STAR 17 containing 153 pounds of propellant as the apogee motor for inserting the NASA-Goddard Radio Astronomy Explorer into earth orbit to measure radio signals from outer space.

The STAR 17 motor demonstrated that a small, 174-pound motor could provide a specific impulse of 290 lbf-sec/lbm and a propellant mass fraction of 0.88. The STAR 37D, an improved version of the Surveyor retro-rocket, was used over a decade in 20 Delta flights.

August 1968: An Elkton Division STAR 6 motor with a fiberglass case was used to increase the velocity of low flying satellites to overcome drag losses and maintain long duration orbit.

October 11, 1968: Apollo 7 first manned flight. Thirteen Elkton Division motors used in the launch: eight TE-M-424 motors to decelerate the spent Saturn first stage, four TE-M-29 motors to decelerate the spent Saturn second stage, and a TE-M-380 motor to jettison the emergency escape system after launch.

December 18, 1968: First Intelsat III communications satellite placed in transfer orbit by an Elkton Division STAR 37D motor on a Delta 1913 launch vehicle.

December 21, 1968: Apollo 8 first manned voyage around the moon used 13 Elkton motors in the launch sequence.

May 6, 1969: Castor IV, Huntsville; first static test, straight nozzle.

November 22, 1969: The United Kingdom's first Skynet I communications satellite placed in synchronous orbit by the 275-pound STAR 17A apogee motor following transfer orbit insertion by a STAR 37D motor.

The STAR 17A motor design established the feasibility of increasing performance of a previously qualified spherical motor by adding a cylindrical section between hemispheres. This concept was later used with STAR 37 and STAR 24 motors developed for NASA.

January 23, 1970: Castor I and II, Huntsville; flew three each Castor I TX33-52 and Castor II TX354-5 on Delta 76 for NASA TAD TIROS-M.

April 3, 1971: Castor II, Huntsville; first flight, Athena first stage.

August 6, 1971: STAR 13A kick motor ejected scientific package from an orbiting vehicle in STP 70-2 mission.

March 2, 1972: First flight of a STAR 37E motor (lengthened STAR 37D) with launch of Pioneer F spacecraft toward Jupiter. The new motor developed escape velocity from an Atlas-Centaur launch vehicle. The 2473-pound motor design incorporated advances in case, nozzle, and insulation technology from previous Elkton Division space motors to achieve a propellant mass fraction of 0.926. On June 13, 1983, Pioneer 10 left our solar system after traveling 2.8 billion miles.

The STAR 37E (and its off-loaded version, STAR 37C) became the standard upper stage for NASA's Delta 2914 launch vehicle, the Global Positioning Satellite System, the Defense Meteorological Satellite System, and the Japanese N-II launch vehicle, with a total of 80 flights through December 15, 1985.

March 24, 1972: First flight of USAF Burner IIA vehicle, which incorporated a STAR 26B above the STAR 37B as a tandem upper stage.

June 30, 1972: Castor IIX, Huntsville; first static test.

July 23, 1972: Castor II, Huntsville; first 9 strap-on boosters launch Delta 89, ERTS-A.

September 21, 1972: Castor II, Huntsville; first 6 strap-on boosters launch (Castor II only) Delta 90, IMP-H.

September 25, 1972: IMP-H Interplanetary Monitoring Platform earth orbit was circularized by the STAR 17A motor after transfer orbit insertion by the STAR 37C motor.

October 2, 1972: Scientific package orbited by USAF Burner IIA with STAR 37B and STAR 26B tandem upper stage.

October 29, 1972: Castor II, Huntsville; first flight – TX354-4 sea level straight nozzle.

April 20, 1973: Pioneer G launched to Jupiter and Saturn with final velocity kick provided by the STAR 37E motor from an Atlas-Centaur.

June 15, 1973: A lunar orbit achieved for the second time when Radio Astronomy Explorer B orbit was circularized by a STAR 17 motor.

March 21, 1974: Castor IV, Huntsville; first static test, 11 degree canted sea level nozzle.

March 22, 1974: Oldest Castor IV flown to date: 3 years, 3 months, first-stage Athena H.

July 13, 1974: A STAR 24 motor inserted Timation III satellite into orbit for tests that helped prove the feasibility of the subsequent Navstar satellite of the Global Positioning Satellite System.

August 30, 1974: First flight of Elkton's STAR 20 motor as the fourth stage of successful NASA Scout vehicle launch.

November 27, 1974: United Kingdom's Skynet II communications satellite placed into synchronous orbit by a 480-pound STAR 24 motor following a Delta launch with an Elkton Division STAR 37D third stage.

July 15, 1975: Final Apollo mission for Apollo-Soyuz docking launched successfully with the use of 13 Elkton Division motors.

September 9, 1975: Castor II, Huntsville; first Japanese launch N-1 vehicle, three each, ETS-1 (KIKO).

October 22, 1975: First firing at simulated altitude of 1084-pound STAR 30 motor. Advanced design features included a propellant with 89-percent solids in a hydroxyl-terminated polybutadiene (HTPB) binder, an advanced propellant grain design, and a lightweight carbon-carbon nozzle. This test established the initial data base for the motor later developed to insert the Space Business Systems and ANIK-C satellites into orbit in 1980.

December 12, 1975: Castor IV, Huntsville; first flight, strap-on booster for Delta 118 (RCA-A).

January 20, 1976: First flight of Elkton's 744-pound STAR 27 motor, which circularized the orbit of Canada's Communications Technology Satellite (CTS) following launch from NASA Delta. The motor incorporated an 88-percent solids CTPB propellant and a new, remotely located safe-and-arm initiation system (Model 2130).

May 4, 1976: NASA Lageos spacecraft inserted into final orbit by a STAR 24 motor following successful Delta launch with a STAR 37D upper stage.

September 11, 1976: First flight of titanium case STAR 37S motor to launch USAF Block 5D meteorological satellite. The motor was an improved, lightweight version of the STAR 37D Delta third-stage motor that incorporated a titanium alloy case.

December 17, 1976: Static test of experimental 48-inch-diameter (STAR 48) motor that successfully demonstrated three-dimensional weave carbon-carbon as the nozzle throat, a 2D carbon-carbon exit cone, a new propellant grain design for high performance, and an aft-end toroidal igniter. This test established the initial data base for the STAR 48 motor now used for the McDonnell Douglas Payload Assist Module for Delta- and Shuttle-launched payloads in the 1980's.

June 23, 1977: First Navstar for the Global Positioning Satellite System placed into orbit by a STAR 27 motor following launch using tandem STAR 37E motors for upper-stage propulsion.

July 14, 1977: United States placed the Geosynchronous Meteorological Satellite into orbit for Japan using a STAR 27 apogee motor following Delta launch and transfer orbit injection by a STAR 37E motor. This satellite complements earlier U.S. and later European satellites in the Worldwide Meteorological Satellite system.

August 20, 1977: First launch of the interplanetary Voyager spacecraft with a STAR 37E providing escape velocity from a Titan III-Centaur.

January 26, 1978: First flight of the 527-pound STAR 24C apogee motor when the International Ultraviolet Experiment spacecraft was inserted into orbit following a Delta launch.

January 27, 1978: Successful test of a STAR 37X motor at simulated altitude demonstrated that the high-performance design features (89-percent solids HTPB propellant, head-end web grain, submerged carbon-carbon nozzle, and aft-end toroidal igniter) previously demonstrated in the nearly spherical STAR 30 and 48 motors can be applied successfully to a longer motor containing a 14-inch cylindrical section between hemispheres. The 72.6-inch-long motor delivered a vacuum specific impulse of 297 seconds with an initial nozzle expansion ratio of 70:1.

February 11, 1978: First flight of a 2050-pound STAR 37F motor when the FLTSATCOM A communications satellite was inserted into orbit after launch on an Atlas Centaur. Ten successful flights of the motor were completed through 1982.

April 11, 1978: The U.S. placed the first Broadcast Satellite into geosynchronous orbit for Japan using a STAR 27 motor following a Delta launch that used a STAR 37E motor for transfer orbit injection.

April 13, 1978: First successful static test of completely flightweight motor incorporating Kevlar filament-wound motor case in the 3050-pound Antares III (STAR 31) motor for an advanced Scout vehicle third stage. The high-strength Kevlar filament used by the Wasatch Division to fabricate the case minimizes weight of this 30-inch-diameter, 113-inch-long motor.

May 13, 1978: One-hundredth successful use of STAR 37 series motors (since May 1966) with the launch of Navstar satellite for the Global Positioning Satellite System. Navstar was subsequently placed into final orbit by a STAR 27 motor.

September 9, 1978: First flight of a STAR 37N upper-stage motor on Japan's N vehicle launched from Tanegashima to place the first Japanese Experimental Technology Satellite in orbit.

September 13, 1978: An improved performance 37-inch-diameter space motor, STAR 37Y, with a gas deployed skirt (GDS) attached to the carbon-carbon exit cone, was tested successfully at simulated altitude in the first GDS evaluation on a flight-type motor configuration.

The GDS is a lightweight type of extendable exit cone that folds within the nozzle for stowage and deploys when motor exhaust pressurizes it during ignition. The 5-pound columbium skirt increased nozzle expansion ratio from 76:1 to 109:1 to increase specific impulse by 1.5 percent.

December 4, 1978: A STAR 24 motor aboard the Pioneer-Venus orbiter operated successfully to place the spacecraft into orbit around Venus following the 6 1/2-month transit from Earth to Venus.

December 15, 1978: A prototype STAR 62 motor containing 5420 pounds of 89-percent solids HTPB propellant in a head-end web grain with 92-percent web fraction was tested successfully. The motor had a deeply submerged nozzle entrance on the throat insert of 4D carbon-carbon and a 2D carbon-carbon exit cone truncated for sea level operation.

February 6, 1979: Castor II, Huntsville; N-1 launch No. 5 used two each Morton Thiokol N-motors and one Nissan motor.

June 6, 1979: STAR 37E and 37S motors that were 58 months old successfully inserted the Block 5D Defense Meteorological Satellite into orbit. These were the oldest STAR 37 motors used in a satellite launch to date.

October 30, 1979: A Scout vehicle using the Castor II as second stage successfully launched the Magsat spacecraft in the first operational use of the Antares III motor (STAR 31) as third stage. The Altair III motor (STAR 20) served as the fourth stage.

February 28, 1980: The STAR 12A Super SARV motor performed successfully in the sixth firing to qualify the design as a spacecraft retro-rocket.

September 9, 1980: Castor IV. Huntsville; first flight. 7 degree canted nozzle. strap-on booster Delta 152 (GOES-D).

September 11, 1980: A STAR 27 motor successfully inserted the GOES D spacecraft into geostationary orbit following a Delta launch using the STAR 37E motor as third stage.

November 15, 1980: Maiden flight of PAM-D powered by a STAR 48 motor was successfully launched from a 3910 Delta vehicle with a Space Business Systems (SBS) spacecraft. On November 17, the spacecraft was successfully placed into geostationary orbit by the maiden flight of the STAR 30B motor.

December 8, 1980: The first Intelsat V telecommunications spacecraft was placed into geosynchronous orbit by a STAR 37F motor following launch of an Atlas Centaur. This was the fifth flight use of the STAR 37F; the first four were for Fltsatcom.

May 14, 1981: The second Scout vehicle launch using The Castor II second stage, the Antares III third stage (STAR 31) and the Altair III fourth stage (STAR 20) orbited a NOVA I experiment for NASA.

The second stage motor was the oldest Castor II flown to date: 9 years, 10 months, 17 days.

August 3, 1981: Castor IV, Huntsville; started 6-3 launch configuration on 155 (DE satellite).

August 12, 1981: Japan completed its successful first launch of its N-II vehicle with a geostationary meteorological satellite (GMS-II) using a STAR 37E for transfer orbit insertion and a STAR 27 apogee motor to circularize the orbit at its geostationary position.

November 22, 1981: The first RCA Satcom was inserted into geostationary orbit by a STAR 30B motor following Delta launch and transfer orbit insertion by a STAR 48 motor.

December 21, 1981: The European Space Agency's first Marecs satellite was placed in orbit by a STAR 30B motor following the Ariane 1 launch from Kourou.

March 1, 1982: First use of STAR 48 and 30B motors for orbit insertion of Westar communication satellite.

August 27, 1982: First use of the STAR 48 and 30B motors for orbit insertion of Canada's ANIK satellite.

September 23, 1982: Morton Thiokol. Wasatch Division and McDonnell Douglas signed a teaming agreement and contract award for the PAM DII to include: 31 production motor deliveries, 1 development motor, and 4 qualification motors.

November 11-16, 1982: First launch of satellites from the space shuttle when SBS-3 and ANIK C3 were successfully launched using STAR 48 and 30B motors.

February 25, 1983: First static test of the Castor IVA motor for NASA. A 12% improvement in performance was obtained by changing the Castor IV propellant to HTPB.

May 22, 1983: First flight of STAR 37XF apogee motor with insertion of the sixth Intelsat V satellite into orbit.

June 13, 1983: After 11 years in space, the Pioneer 10 spacecraft passed the orbits of Neptune and Pluto to become the first space vehicle to exit our solar system. A STAR 37E motor gave the Pioneer 10 its final velocity thrust on March 2, 1972. NASA expects to track the spacecraft to 5 billion miles from earth with its deep space network.

June 19-20, 1983: STAR 48 and 30B motors placed ANIK C-2 and Palapa B-1 satellites in orbit during STS-7 flight.

June 28, 1983: First Hughes Aircraft Galaxy satellite placed in orbit by STAR 48 and 30B motors from Delta.

July 14, 1983: First flight of SGS-II vehicle which has two STAR 48 motors as tandem upper stages. This flight also launched Navstar 8 with a STAR 27 apogee motor.

July 28-29, 1983: First orbit insertion of Telstar satellite by STAR 48/STAR 30B motors.

August 30, 1983: Second static test of the Castor IVA. Both tests were very successful and were in close agreement with pretest predictions.

October 7, 1983: Second successful test of the STAR 22 air-launched booster for AFRPL. This 1,269-lb rocket motor incorporates a high performance propellant with broad temperature capability (−40 to +160°F).

October 20, 1983: Successful static test of the 104-lb STAR 13B rocket motor which incorporates a 2.2-in. stretch in the original STAR 13 motor case. The first flight of the STAR 13B was on August 16, 1984, as an AKM for the AMPTE spacecraft.

November 13, 1983: The first of a total of 8 successful static tests qualifying the 23-lb STAR 6B rocket motor was conducted. The STAR 6B provides propulsion for re-entry vehicles.

February 2-6, 1984: In their 17th and 18th flight applications as part of the Payload Assist Module (PAM) system, the STAR 48 rocket motors for Westar-VI and Palapa B-2 failed to place these satellites in their intended orbit. Since that mission a total of 13 additional STAR 48 motors with carbon-carbon nozzles have flown successfully.

May 12-16, 1984: After 103 and 99 days in space, respectively, the STAR 30B rocket motors on Westar-VI and Palapa B-2 were successfully fired to circularize the satellite orbits. These satellites were recovered by the space shuttle flight 51A in November 1984.

September 11, 1984: Successful static test of the STAR 48A rocket motor weighing 5671 lb and providing increased capability compared to the STAR 48B through an 8-in. stretch in the motor case.

November 8, 1984: Third successful static test of the 2,532-lb STAR 37FM rocket motor qualifying the motor as an AKM for Fltsatcom.

November 13, 1984: The first flight of the STAR 30BP provided the AKM for the Spacenet satellite launched from Ariane.

December 18, 1984: Completion of STAR 48B qualification for application in the PAM vehicle. The STAR 48B is a version of the regular STAR 48 with a carbon-phenolic rather than carbon-carbon nozzle.

December 20, 1984: The first carbon-carbon technology program motor (CCT-1) was static tested to characterize nozzle thermostructural response during the first 10 seconds of a STAR 48 firing. The motor was constructed to incorporate a record number of nozzle instrumentation transducers (134). In addition, nozzle components were preserved in the end-of-burn condition through the application of internal and external water quench sprays.

March 2, 1985: Completion of qualification for the STAR 30BP rocket motor. Like the STAR 48B, this motor is a carbon-phenolic nozzle version of an existing motor, the STAR 30B.

April 1985: Oldest Castor I flown to date: 22 years, 11 months. Castor / Lance vehicle for USAF geophysics program.

May 3, 1985: Successful completion of qualification of the 2110-lb STAR 37XFP, a carbon-phenolic nozzle version of the STAR 37XF.

May 9, 1985: The second carbon-carbon technology motor (CCT-2) was successfully static tested at Elkton to provide nozzle thermomechanical data from 155 transducers.

June 5, 1985: The PAM DII motor successfully completed the qualification program consisting of four motor tests.

June 17-19, 1985: The first flights of the STAR 48B rocket motor were conducted to orbit the Morelos, Arabsat, and Telstar-3D satellites from Space Shuttle Flight 51G.

August 30, 1985: The first flight of the 1369-lb STAR 30C AKM was performed to place the American Satellite Corporation's ASC-1 satellite in geosynchronous orbit. The STAR 30C is a 5-in. stretched version of the STAR 30BP motor case.

October 10, 1985: Twenty-fifth successful flight of the STAR 27 as an AKM for Navstar-11.

November 26, 1985: First flight of Wasatch's PAM DII (IPSM 63D) perigee kick motor. The PAM DII PKM placed an RCA SATCOM KuBand spacecraft into an elliptical transfer orbit.

December 1, 1985: The first flight of Elkton's STAR 37XFP apogee kick motor placed an RCA SATCOM KuBand spacecraft into geosynchronous earth orbit.

December 5, 1985: Final STAR 30E qualification test conducted. The STAR 30E is an extended version of the STAR 30BP rocket motor and weighs 1,471-lb; it will be used as an AKM for Skynet 4.

December 12, 1985: Successful test of a STAR 75 rocket motor loaded with 16,537 lb of propellant. The STAR 75 is intended to provide greatly enhanced PKM capability for larger satellites but will fit within the constraints of the Space Shuttle bay.

January 23, 1986: The third carbon-carbon technology (CCT-3) static test was successfully conducted to provide nozzle thermomechanical data from more than 160 channels of data.

February 21, 1986: The first Swedish satellite, the Viking, was placed in its final orbit by a STAR 26 AKM. The spacecraft was launched on an Ariane vehicle.

March 20, 1986: Five STAR 6B motors were utilized as propulsion for an Air Force decoy deployment system. Each motor's performance was tailored for a particular decoy configuration. A total of 10 STAR 6Bs were flown on the DDS program.

December 6, 1986: The Fltsatcom 7 spacecraft was successfully placed in geosynchronous orbit with the maiden flight of the STAR 37FM. The motor contained 2,259 lb of propellant and burned for approximately 66.2 sec.

June 2, 1987: A STAR 30B was successfully static tested in an altitude facility at AFAL, utilizing a Novoltex, woven carbon-carbon exit cone, manufactured by SEP of France.

July 2, 1987: A STAR 27 with a reversed-trapped-ball thrust vector control (TVC) nozzle was successfully static tested at the Elkton Division. The 750-lb motor burned for approximately 34 sec and demonstrated ±4 deg in the pitch and yaw directions with the hydraulically actuated TVC nozzle.

November 20, 1987: The first development static firing of the STAR 5A was conducted at simulated altitude with the motor conditioned to -4°F and spinning at 40 rpm. The test was the first of five planned to qualify the motor.

July 20, 1988: The fourth and final carbon-carbon technology motor (CCT-4) was static tested with 240 data channels recording strains, temperatures, pressures, and displacements throughout the nozzle assembly. Test objectives included the evaluation of component design and manufacturing changes resulting from the evaluation of previous test data. The results were used to validate thermal/structural analytical models.

September 26, 1988: A STAR 37S successfully placed the NOAA-H satellite into polar orbit after being launched by an Atlas E from Vandenberg AFB. The satellite provided weather and environmental monitoring capability, including information about the ozone levels at the polar caps.

December 14, 1988: First flight of the 1471-lb STAR 30E, which successfully placed the British Aerospace Skynet 4 satellite into geosynchronous orbit. The STAR 30E further demonstrated the flexibility of STAR motor designs by improving upon the STAR 30BP performance with a 7-in. stretch of the titanium case.

December 15, 1988: A STAR 37XFP, with a 19% propellant off-load, placed the GE Astra I satellite into geosynchronous orbit.

January 29, 1989: A 5½-year-old STAR 37XF placed the final Intelsat V spacecraft into geosynchronous orbit. This flight marked the last mission in which a carbon-carbon exit cone was fired on a STAR motor.

February 14, 1989: A STAR 48B and STAR 37XFP placed the first GPS Block II spacecraft into orbit. The spacecraft, which is part of a 21-satellite constellation, was launched by the first Delta II vehicle.

July 27, 1989: A STAR 30B motor case fired in space and recovered by Shuttle was reloaded and successfully static tested for lot acceptance test on the BSB and Palapa B2R programs.

January 3, 1990: A STAR 30E AKM inserted the British Aerospace Skynet 4A satellite into geosynchronous orbit following deployment from a Titan IIIC expendable launch vehicle. This launch marked the maiden flight of the commercial Titan vehicle.

April 9, 1990: A STAR 30C AKM placed the Hughes ASIASAT satellite into geosynchronous orbit following deployment from a Chinese Long March 3. This event marked the first depoyment of an American-made satellite from a Chinese launch vehicle.

April 11, 1990: An Altair III (STAR 20), normally used as the fourth stage of the Scout vehicle, was used as the orbit insertion motor for an Atlas-E payload dubbed "Stacksat." The three payloads were placed into a 400-nautical-mile circular orbit.

June 15, 1990: A second STAR 63F containing 9400 lb of propellant was successfully static tested at AEDC. The two-motor test program completed motor qualification and established the Elkton Divison as the source for Thiokol 63-in.-dia upper-stage motors.

August 10, 1990: After a 462-day trek through deep space, a STAR 48B successfully slowed the Magellan spacecraft from 24,600 mph to insert it into an elliptical orbit around Venus. The Magellan voyage began on May 4, 1989, after Magellan was deployed by the Space Shuttle Atlantis. The two Model 2134A safe-and-arm devices used to ignite the STAR 48B were electrically armed in June 1989. This mission established a new 15-month record for STAR motor exposure to space prior to firing. The record was previously held by a STAR 24 that inserted the Pioneer spacecraft into orbit around Venus after a 6½-month journey.

October 8, 1990: A STAR 48B performed successfully as the final stage to propel the European-built Ulysses spacecraft on a 5-year voyage over the poles of the sun. Spinning at 70 rpm, the STAR 48B provided an additional 13,800 ft/sec velocity increment to the 800-lb spacecraft.

November 12, 1990: A Martin Marietta Titan IV launch of a classified DoD payload served as the first flight opportunity for the recently qualified STAR 5CB retro motor. Based on the STAR 5C qualified in 1961, the new motor used a cleaner exhausting propellant. Four STAR 5CBs were used to separate the Titan IV second stage from the trans-stage.

December 3, 1990: A 12½-year-old Altair IIIA (STAR 20) motor, conditioned to 40°F, was successfully static tested while spinning at 180 rpm. The test was conducted for NASA to support shelf-life extension of the motor, used as the fourth stage of the Scout vehicle.

The CASTOR Family of Launch Motors

The Castor family of motors has enjoyed a long history of success, dating back to development of the Castor I in 1959. Ancestry of the Castor family can be traced through the XM33 Pollux, TX20, XM12 Sergeant, and Hermes A2 back to 1953. Current Castor models are:

- Castor I
- Castor II
- Castor IV
- Castor IVA
- Castor IVB

The Castor I was developed in 1959 for the Littlejoe and Scout vehicles of NASA (then NACA). The first flight was on a Littlejoe vehicle in 1959. The first strap-on application was on a Thrust-Augmented Thor (TAT) for the Air Force in 1963. Application to Delta began with Delta 25 in August 1964.

The Castor II was developed in 1964 for second-stage propulsion of NASA's Scout vehicle. The Castor II used the Castor I motor case but substituted a higher performance propellant with HC polymer for the PBAA propellant used in Castor I. The first flight was on a Scout vehicle in 1965. Strap-on application began in 1966 on an Air Force TAT vehicle, and the first launch on Delta was in 1968.

An extended length version of the Castor II motor, the Castor II-X, was demonstrated in 1972 for potential application to Delta. The Castor II-X was bypassed, and the higher performance Castor IV was selected for Delta strap-on propulsion.

The Castor IV motor was developed in 1969 to provide first stage propulsion to the Athena H vehicle of the DoD Abres program. The first flight was in 1971. The Castor IV, which uses the same PBAA propellant as Castor I, was adapted as a strap-on motor for the Delta vehicle and was first launched as a strap-on motor in 1975.

The Castor IVA was developed in 1983 using the Castor IV hardware and a higher performance HTPB propellant. It is used as strap-on propulsion for Delta.

The Castor IVB was qualified in late 1990, and the first delivery was made in early 1991. Castor IVB is the first of the Castor series with thrust vector control (TVC). TVC is a movable nozzle that permits the motor to be directed in flight by commands from a guidance computer.

Other growth versions of the Castor motor have been designed and are being considered for commercial launch vehicles.

Although Castor motor production was interrupted when Shuttle replaced Delta for orbital launch services, tooling and procedures for production were retained and production of Castor II and Castor IV motors is being reinstated for NASA Scout and Delta.

Appendix F

EXAMPLES OF FLIGHT RELIABILITY
(3/31/86)

Motor Designation		Propellant wt./lb.	Total Mtr Flight Test	Successful Flight Test	% Flight* Success
Falcon	M46	26	657	657	100.00
	M58	31	8,061	8,060***	100.00
	M60	60	137	137	100.00
Sergeant	XM-53	5,845		37	100.00
Matador	M16	1,365	105	105	100.00
Recruit	XM-19	264	300	300	100.00
Lacross	XM-10	489	231	231	100.00
X-17	XM-20	7,033	59	59	100.00
Nike-Hercules	M30	2,172	1,073	1,073	100.00
Nike-Zeus					
Booster**	TX135	9,619	153	151	98.69
Sustainer**	TX239	6,780	124	122	98.39
3rd Stage**	TX239	670	71	70	98.59
Pershing	TX172	5,715	14	15	100.00
	TX173	2,457	8	8	100.00
1st Stage	XM-105	4,451	34	34	100.00
2nd Stage	XM-106	2,785	34	34	100.00
Pedro	TX261	2,250	50	50	100.00
Unidentified Models	------	------	90	84	93.33
Bomarc	XM-51	6,592	61	61	100.00
C[illegible] I	XM-33	7,328	572	[illegible]	100.00
[illegible]	XM-35	7,033	15	15	100.00
Sounding Rocket	TX77	1,200	129	129	100.00
Castor II	TX354	8,330	752	752	100.00
Castor IV	TX526	20,600	306	305	99.67

TABLE 12-5

EXAMPLES OF FLIGHT RELIABILITY (CONTINUED)

Motor Designation		Propellant wt./lb.	Total Mtr Flight Test	Successful Flight Test	% Flight Success[*]
Spartan					
1st Stage	TX500	------	42	42	100.00
2nd Stage	TX454	------	42	42	100.00
3rd Stage	TX239	------	41	41	100.00
MLRS	TX703	201	96	96	100.00
Patriot	TX486	------	97	97	100.00
HELLFIRE	TX657	22	196	196	100.00
Maverick	TX481/ TX633	65	1,600	1,600	100.00
Standard Missile Booster (MK 70)	TX664	1,500	50	50	100.00
MK 36 Sidewinder			"C"	"C"	100.00
(Qualified Units)	------	------	15,232	15,22[illegible]	99.95

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[*] Flight success of propulsion system based on data available to Morton Thiokol/Huntsville Division.

[**] Failures occured in early development flight tests prior to PFRT and qualification and are not counted in total record.

[***] Igniter not connected to aircraft circuitry - not counted.

MORTON THIOKOL RELIABILITY SUMMARY

Motor	Number Produced	Number Static Test/Flights	Failures	Demonstrated Reliability 95% Confidence	99% Confidence
Space (52)					
Shuttle SRM(3)	71	62	1	0.953	0.943
Castor I	663	598	0	0.995	0.992
Castor II	817	766	0	0.996	0.994
Castor IV	390	327	1	0.985	0.979
STAR Motors(47)	1,908	1,886	9	0.992	0.991
Sub Total	3,849	3,638	11	0.995+	0.995
Tactical(12)					
Falcon/M58	55,937	8,060	0	0.999+	0.999
Sidewinder/M36	9,948	347	1	0.990	0.988
Nike Hercules Sustainer	18,913	1,073	0	0.997	0.996
R.S.Hellfire	8,750	231	0	0.987	0.985
M.S.Hellfire	5,000	131	0	0.978	0.973
Maverick	28,467	1,414	4	0.994	0.935
Tow 2	11,015	300	0	0.990	0.988
Patriot	1,960	211	0	0.964	0.945
VSTT	2,108	1,880	5	0.994	0.993
Std Missile/ MK 70	675	101	0	0.971	0.966
Std Missile/ MK 104	1,028	300	4	0.974	0.970
HARM	2,796	250	7	0.952	0.945
Sub Total	146,597	14,298	21	0.998+	0.998
Strategic(8)					
Minuteman F.S.	2,963	1,286	14	0.983	0.982
Minuteman T.S.	904	217	3	0.971	0.966
Peacekeeper F.S.	96	35	0	0.916	0.899
C3/TVC	1,992	543	0	0.995	0.993
C3/Mod II	682	240	0	0.988	0.985
Peacekeeper/HGG	83	51	0	0.942	0.931
Peacekeeper/TVA	118	96	0	0.969	0.963
DS/TVC	120	82	0	0.964	0.957
Sub Total	6,958	2,550	17	0.990	0.989
Grand Total	157,404	20,486	49	0.9969	0.9967

* ( ) indicates number of motor configurations,
e.g., 3 SRM and 47 STAR configurations

TABLE 7 - (Updated)

10/21/87

Motor	No. Produced	No. Static Tests/Flights	Failures	Demonstrated Reliability at 95% Confidence
Shuttle SRM(3)*	71	63	1	0.958
Titan III SRM(2)	178	169	1	0.984
Castor I	663	598	1	0.996
Castor II	817	764	3	0.992
Castor IV	390	327	1	0.992
Castor IV-A(2)	3	3	1	0.219
STAR Motors(47)	1,908	1,888	9	0.993
Total	4,030	3,814	17	0.994

* ( ) Indicates number of motor configurations