The Development of U.S. Missiles During the Cold War

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Background

During World War I the United States and Russia fought as allies against Germany and Japan. After the war, the U.S., tired of the ravages of international conflict, greatly reduced its armed forces while Russia kept the bulk of its huge army active and forced Eastern European nations to join the Communist bloc. The term "Cold War" was used to describe the relationship between the U.S. and Russia because, although they regarded each other as enemies, there was no open warfare between the two. Behind the scenes both governments engaged in intense scientific research in the development of nuclear weapons and the means of delivering them over the vast distances that lie between the two countries. It was for this reason that in October 1945 the U.S. Army Air Force requested industry proposals for missile systems to deliver warheads as far as 6000 nautical miles (5200 statute or land miles).

Introduction

This course is intended to provide introductory information on ballistic missiles developed by the United States military. The flight of a ballistic missile resembles that of an artillery piece where the projectile is given an initial thrust out the barrel and then coasts in an arced trajectory to its target. A ballistic missile used for military purposes is given an initial thrust from its engines and then coasts to its target in a similar curved path. Initially, U.S. missiles were designed after the German V2 rockets whereby a kerosene-like fuel and a liquid oxygen oxidizer were used as the propellants. Later, more advanced liquid and solid propellants were developed. The long range ICBMs have the capability of reaching most targets anywhere on the globe from bases in the U.S. The Medium Range Ballistic Missiles (MRBM) have the capability of hitting enemy targets from bases located in friendly countries in Europe. Short Range Ballistic Missiles (SRBM) were issued to combat troops for use on the battlefield. There is good reason to believe that ballistic missiles had a large part in preventing the outbreak of World War III.

Rocket Engines

A rocket is an engine that produces more power than any other engine known. The word "rocket" is also used to describe the vehicle that is powered by a rocket engine. The Chinese used rockets against enemy soldiers in the 1200s. In the war of 1812, British soldiers used rockets to attack Fort McHenry, Maryland. Francis Scott Key, while watching the battle, wrote "the rockets' red glare" which is contained in "The Star-Spangled Banner", the United States National Anthem. “Missile” is also used to describe the vehicle that is powered by a rocket engine. Missiles are used for military purposes as well as to carry people and scientific equipment into outer space for peaceful means.

Rocket engines are internal combustion engines that rely on the production of high pressure gases from the chemical reaction of a fuel component and an oxidizer component to provide propulsive force. There are two kinds of rockets that are used on most missiles and spacecraft today: liquid propellant and solid propellant. Liquid propellants require proportionately large tanks, pumps, and plumbing systems to store and deliver the contents to a combustion chamber where the fuel and oxidizer are mixed and ignited by an electric spark. In the case of hypergolic (self-igniting) liquid propellants, the two components ignite on contact. Solid propellants have the fuel and oxidizer mixed in granular form. The grains are packed inside a cylindrical casing that has a hollow core extending down the center where the combustion takes place. The high temperature gases from the combustion of the grains flow into a nozzle which converts high temperature, high pressure gas into very high velocity gas; the reactive force which propels the vehicle. (See Figures 1 and 2.)

Figure 1: Schematic Rocket Engine - Liquid Propellant

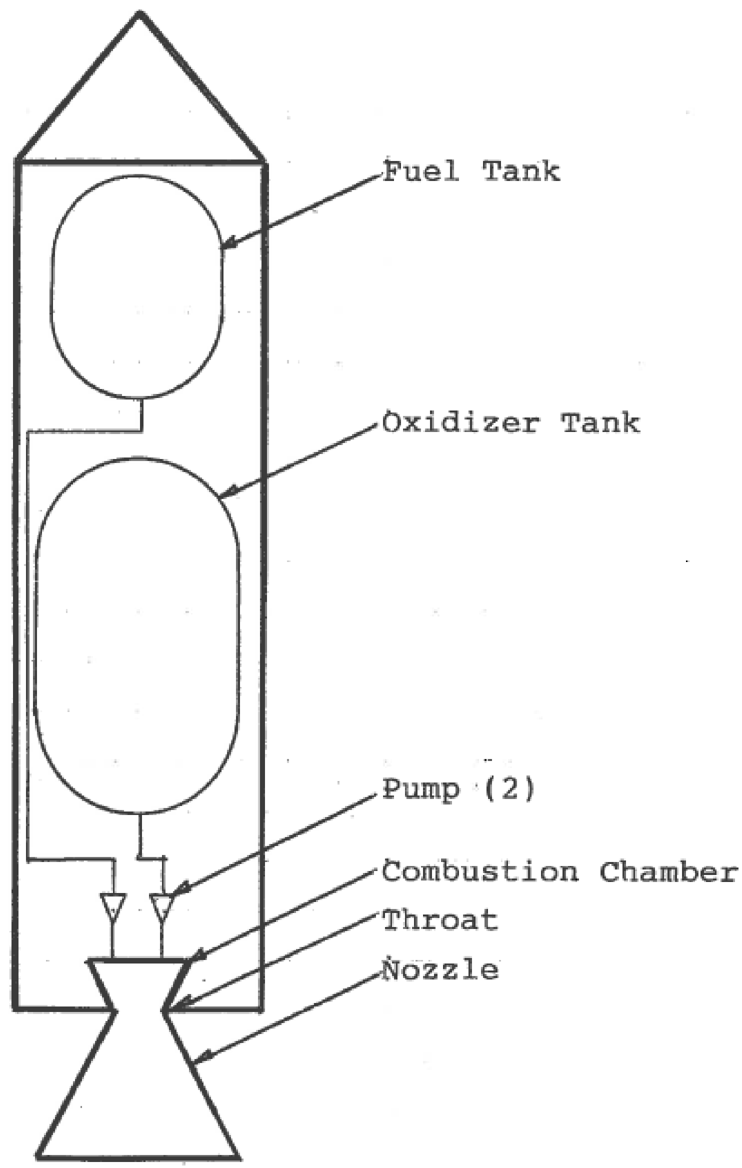
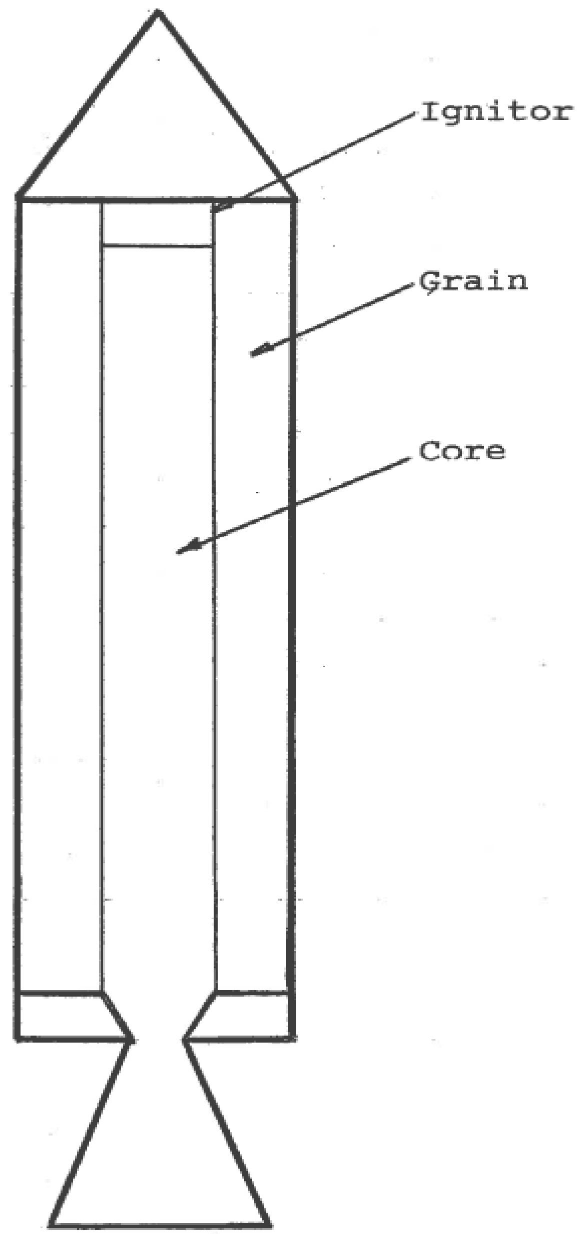


Figure 2: Schematic Rocket Engine - Solid Propellent



Most U.S. missiles use RP1 and liquid oxygen (LOX) as the propellants; the same used in the German V2 rockets. RP1 is similar to kerosene which is distilled from crude oil and is a mixture of various hydrocarbons. Hydrocarbons, as the name suggests, are hydrogen-carbon compounds which when mixed with LOX and ignited produce heat, carbon dioxide, and water. Liquid oxygen is obtained from distilled liquid air. Air is liquefied by lowering its temperature to minus 310F. The most powerful liquid propellant combination is liquid hydrogen (LH2) and LOX. Bulk quantities of LH2 are produced from natural gas. LH2 and LOX burn clean giving off only water and heat as the by-products. The chemical equation is:

$$2H_2+O_2 \dashrightarrow 2H_2O+\text{heat}$$

This combination results in an extremely large amount of high temperature gas making it the most powerful of all propellants used today. The missile that put the men on the moon and the space shuttle both use this combination. It was first pioneered on the Centaur upper stage vehicle which was previously used on many spacecraft.

An advantage of liquid propellants is that engines can be stopped and restarted in space while some of the more advanced engines can even be throttled (power output raised and lowered). A disadvantage of liquid propellants is that LH2 and LOX are potentially dangerous cryogenic (very low temperature) substances that pose severe storage and handling problems. Oxygen liquefies at -316F while hydrogen liquefies at -423F, just 37F above absolute zero (-460F). Liquid hydrogen is very volatile and hard to contain while liquid oxygen reacts violently when in contact with any hydrocarbon.

Solid fuel propellants have the fuel and oxidizer mixed together in granular form. The grains burn with an explosive power that is greater than gunpowder. The grains are packed inside a cylindrical shaped casing. There is a hollow core extending down the length of the grain pack in which the combustion occurs. The cross-section shape of the core can be configured to produce the desired thrust versus time schedule. The big advantage of using solid propellants is that the engine is simple. It doesn't require large storage tanks with elaborate pumping and plumbing systems. The disadvantage of using solid propellants is that they don't burn as efficiently as liquid propellants and they can't be stopped and restarted in space. They essentially burn until all the fuel is consumed.

Another advantage of using liquid propellants over solid propellants is that liquid propellants have a higher "specific impulse" than solid propellants. Specific impulse can be defined as how long a rocket engine can produce a given amount of thrust using a given amount of fuel. Pound thrust is a measure of how powerful a rocket engine is while specific impulse is a measure of how efficiently it operates. An analogy can be made to an automobile engine where horsepower is a measure of engine power and miles per gallon is a measure of how efficiently it operates. In an automobile, a high powered engine is not too practical if it gets only a few miles per gallon of fuel. The specific impulse of some of the more advanced solid propellants is 265 seconds while the specific impulse of RP1/LOX is 330 seconds and the specific impulse of LH2/LOX is 450 seconds.

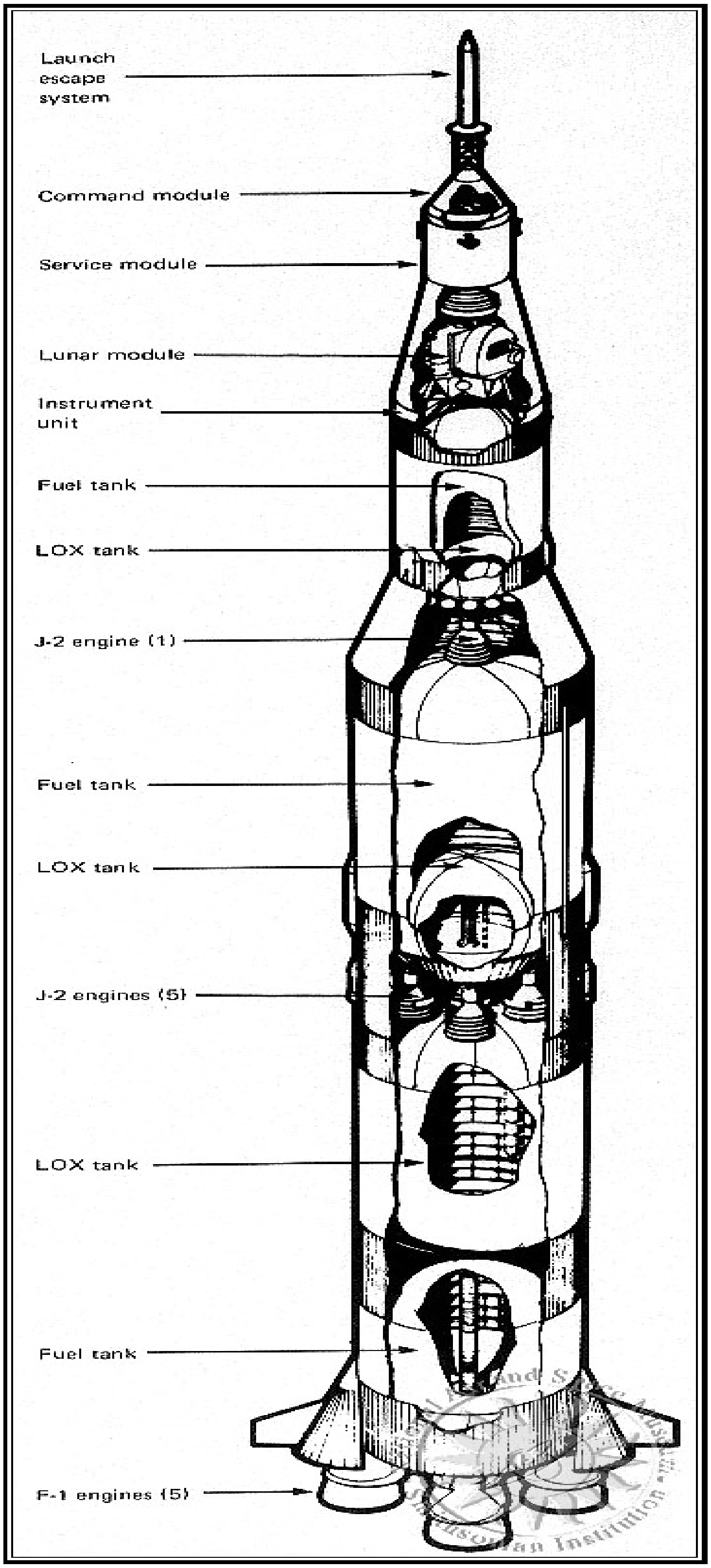
Missile Types

Missiles are classified according to range, type of propellant, and number of stages. A stage is an independent engine/fuel tank section that, after its use, is jettisoned (separated) from the missile during flight. Most missiles have one to three stages. The first or lower stage is ignited at launch and burns until all its fuel is consumed. It is then jettisoned and the second stage ignited, etc. Generally, each succeeding stage is smaller than the preceding one. Staging is a means of keeping the missile thrust-to-weight ratio high enabling the accommodation of heavier payloads. (See Figure 3.) There are a number of ways that are used to classify missiles. The following is one of the ways used in this publication that has been established by the U.S. Department of Defense.

- Intercontinental (ICBM) - over 5000 kilometers (over 3400 miles)
- Intermediate (IRBM) ---- 3000-5000 kilometers (1860-3400 miles)
- Medium (MRBM) -------- 1000-3000 kilometers (0600-1860 miles)
- Short (SRBM) ----------- under 1000 kilometers (under 0600 miles)

The Atlas, Titan, and Minuteman ICBMs; the Thor and Jupiter MRBMs; and the Redstone SRBM are among the topics discussed in this publication.

Figure 3: Three Stage Missile - Saturn V Moon Rocket



Missile Launch Sites

Cape Canaveral, Florida is where most of the military and civilian missiles are launched. Located on a strip of land that juts out into the Atlantic Ocean, Cape Canaveral is an ideal location to establish missile launch pads as missiles are launched east over the ocean making it safe for communities on the mainland. Also, missiles launched from the east coast of the United States near the equator get an extra boost of speed from the rotation of the Earth. The tangential velocity of the Earth at the equator equals approximately 1000 miles per hour. Missiles launched west over the Pacific Ocean lose velocity from this effect. Vandenberg Air Force Base in California has been used to launch missiles northward into polar orbit where the spinning of the Earth has little effect on velocity. (See Figure 4.)

The Atlas missile which was the first ICBM developed by the U.S. occupied Cape Canaveral launch complexes 11, 12, 13, and 14. Cape Canaveral launch complexes are located in a line north and south along the Atlantic Ocean coast. Each Atlas complex includes a test stand upon which the launcher is located; a "Block House" which is a domed structure with six feet thick concrete walls where engineers remotely control the various missile systems during launch countdown operations; and a "Ready Room" where the engineering offices are located. The test stand is located two stories above ground level. There is a ramp leading up to it where missiles and equipment are transported to and from the launcher. There is a ten story high service tower that, when fully deployed, completely envelopes the missile giving engineers and technicians complete access to all mechanical and electrical systems, most of which are located in pods on each side of the Atlas missile. The service tower is mobile and is rolled away from the missile before launch. There is a small tower with a pole at the top that supports the electrical "umbilical cord" through which information is sent to and received from the missile during countdown operations. The pole at the top is pivoted away from the missile just before launch disengaging the umbilical cord plug from the missile. The "flame deflector" is a very large 90 degree duct just beneath the missile rocket engines. The duct deflects hot engine exhaust gases after engine ignition from the vertical to the horizontal just above ground level. The flame deflector walls are hollow and are filled with high pressure water from a 36 inch line. The inner walls of the flame deflector have many closely placed orifices through which water is jetted, cooling the engine exhaust gases and protecting the flame deflector from damage. (See Figures 5, 6, & 7.)

Figure 4: The Earth's Rotational Affect - Looking Down the North Pole

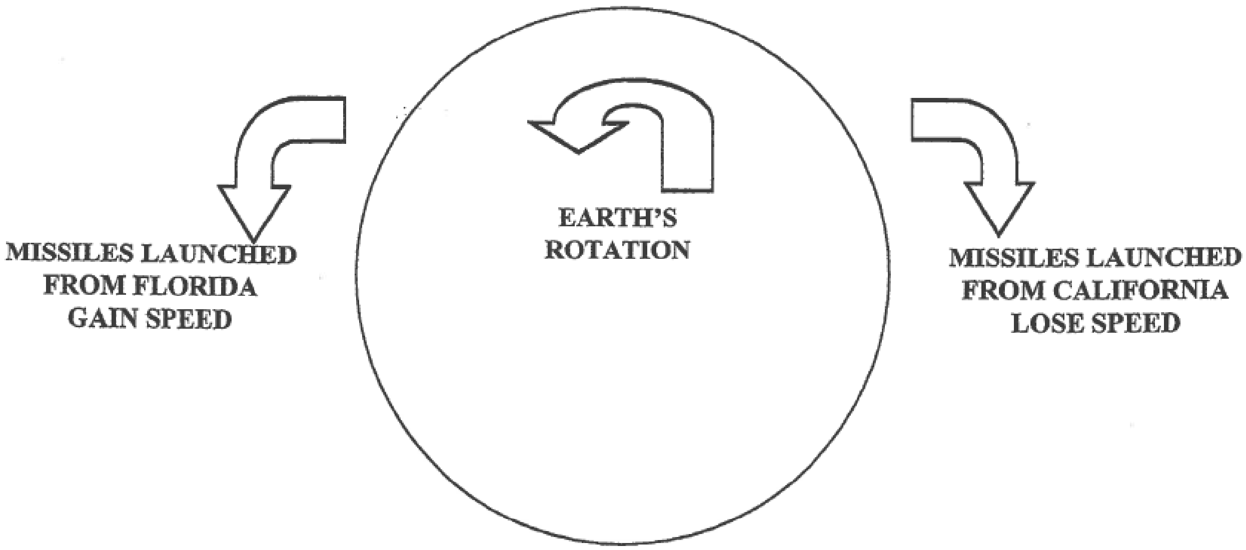


Figure 5: Atlas Missile Test Stand Service Tower

Figure 6: Schematic Flame Deflector - Water Cooled

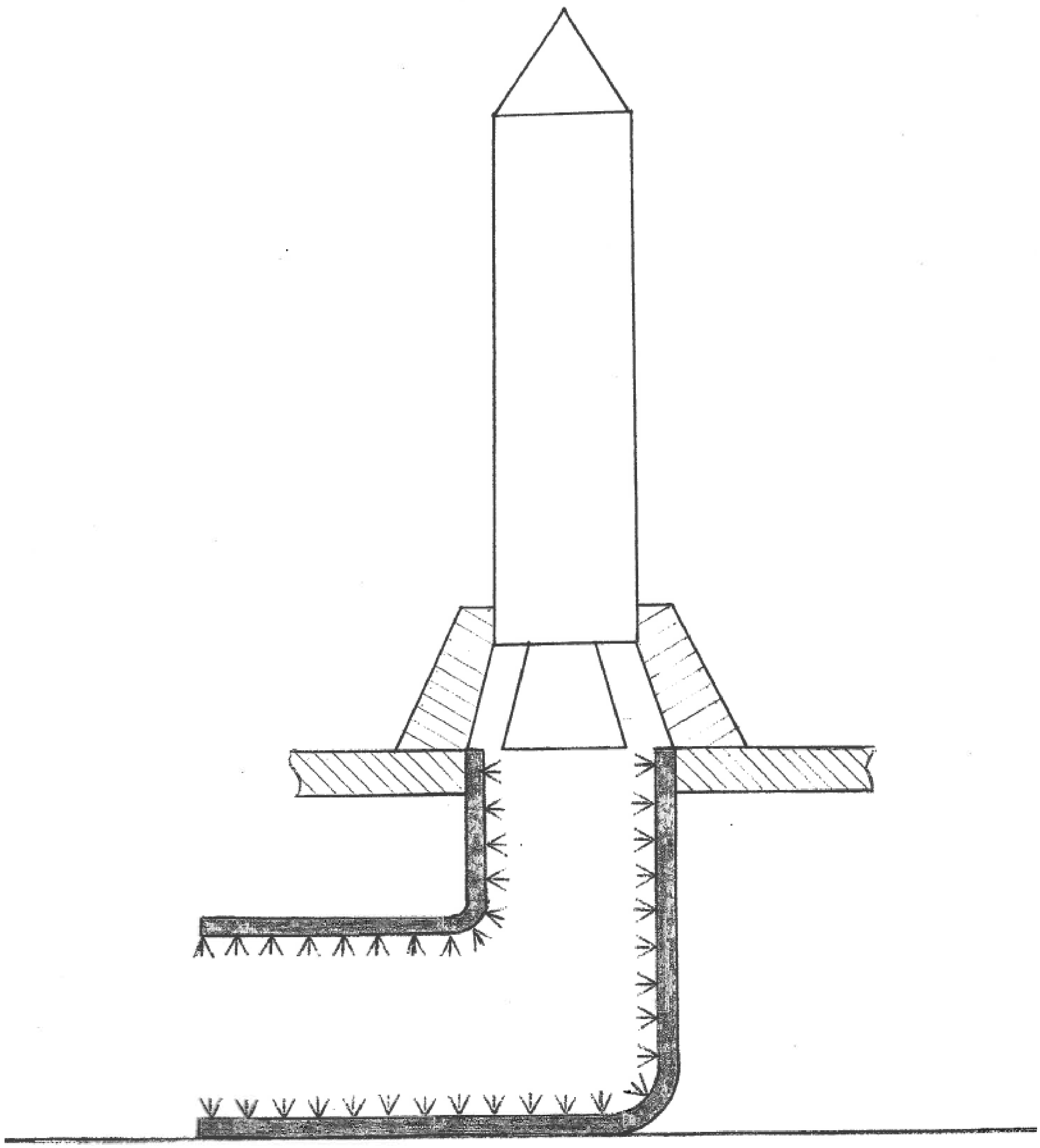


Figure 7: Atlas Missile Launch

The Atlas ICBM

As previously discussed, in October 1945 at the onset of the Cold War, the U.S. Army Air Force requested industry proposals for a missile system to deliver a warhead as far as 6000 nautical miles. Six years later, after the outbreak of the Korean War, the Consolidated Vultee Company (Convair) of San Diego, California was awarded a contract to investigate the development of a ballistic missile system later named by Convair as "Project Atlas". In January 1955, the Air Force, under intense international pressure because of Russia having exploded both atomic and hydrogen bombs, ordered the Atlas into production even though it was only in the early stages of development.

The design that evolved was an ultra-thin skin airframe missile with integral propellant tanks that required 5 psi of internal pressure at all times to prevent it from collapsing under its own weight. (See Figure 8.) Wernher von Braun, the famous German rocket scientist, worried that the design would not survive the extremely high stresses at launch when all engines are operating under full thrust. The design included three RP1/LOX engines, all of which were ignited at launch as in-flight engine ignition systems were not yet perfected. The two outside engines called "boosters" burned for a few minutes and then were jettisoned. The center engine called the "sustainer" continued to burn for a few more minutes and remained attached to the missile. All three engines were "gimballed" or pivoted at the base and were controlled by signals sent from the guidance system to steer the missile during powered flight. After that, two small engines called "verniers", one on each side of the missile, did the steering. The design incorporated a "nose cone" that separated from the missile and continued toward the target on a ballistic (arced) trajectory. The Atlas is sometimes referred to as being a one and one-half stage missile because of not having two separate sets of fuel tanks to go along with the two separate booster and sustainer engine stages.

The initial launch test versions were identified as "Atlas A" and were 75 feet, 10 inches long and ten feet in diameter. They were equipped with just the two booster engines and had a range of 600 nautical miles which was all that was needed to validate major design objectives such as the launch system and the thin-skinned airframe. There were a total of eight Atlas A launches made down the Air Force Eastern Range which extends from Cape Canaveral to the tip of Africa. See Figure 9.

The following chart lists the results of the eight flights:

S/N	Date	Pad	Results
04A	06/11/57	14	Booster fuel system failure
06A	09/25/57	14	Booster fuel system failure
12A	12/17/57	14	600 mile success
10A	01/10/58	12	600 mile success
13A	02/07/58	14	Flight control failure
11A	02/20/58	12	Flight control failure
15A	04/05/58	14	(Records conflict)
16A	06/03/58	12	600 mile success

The launch system, missile thin-skin structural integrity, and other systems were considered validated by the tests; however, only three or four of the eight Atlas A missile launches were considered successful depending on which historical record is used. Regardless of which record is used, the performance of the Atlas A missiles left much to be desired since the system was released for production over two years before flight testing started during a time in the Cold War when it was urgently needed.

The Atlas B test missiles were built more to the final design configuration with all three engines installed. The flights were made longer to test major events such as booster engine shutdown and separation, sustainer engine shutdown, vernier engine shutdown, and nose cone separation. The first Atlas B was launched from Cape Canaveral in July 1958. At approximately three quarters of a minute after launch, the engines lost power and the missile exploded. A total of ten Atlas B missiles were launched from Cape Canaveral, the last being six months later. Three of the ten launches ended in failure which was a record only slightly better that the Atlas A launches. Fortunately, an Atlas B missile was successful in December 1958 putting into earth orbit a famous message from President Eisenhower calling for world peace. The launch also put the U.S. ahead of Russia in the amount of weight put into Earth orbit. The Russian Sputnik launched in October 1957 was the first object put into Earth orbit by man. What worried U.S. officials was, not only the Sputnik, but the fact that the missile that put it into space was powerful enough to launch an H-bomb on the U.S. At the urging of the military, President Eisenhower accelerated America's missile programs. Within six months after Sputnik, the nation's space budget went from 0.5 to 10.5 billion dollars a year.

The Atlas C was more closely configured to the production version with each booster engine producing 165,000 pounds of thrust; the sustainer engine producing 57,000 pounds of thrust; and each vernier engine producing 1000 pounds of thrust. The missile was 6 feet, 8 inches longer than the Atlas B. Four of the six launches were successful with the last one held in August 1969 travelling the 6000 nautical miles distance down the Eastern Range.

The Atlas D was a prototype of the operational Atlas. As previously mentioned, the Air Force had released the Atlas for production even before vehicle testing was started because of the competition with Russia for leadership in missile development and deployment. The Atlas D was similar to the Atlas C except that each booster engine thrust was increased to 183,500 pounds. The first three test launches, attempted between April and June 1959, all ended in failure; nevertheless, after two straight successes the missile was declared operational in September 1959. It was deployed in hardened bases in California, Nebraska, and Wyoming. Seven of the next ten launches were successful. It went on to become a reliable space exploration vehicle with names such as Atlas Able, Atlas Agena, Atlas Centaur, and Mercury Atlas which put the first U.S. astronauts into Earth orbit. The Atlas Able was used to launch a probe to the moon. The Atlas Agena was used in the Ranger program obtaining the first close-up images of the Moon and for the Mariner program which was the first spacecraft to fly by another planet. The LH2/LOX Centaur was put on top of the Atlas for dozens of launches such as the Surveyor Lunar Landing spacecraft and most of the Mars Mariner programs. (See Figure 10.)

The Atlas E was an upgraded version of the Atlas D. It had more powerful engines and an all-inertial guidance system. Previous Atlas missiles had guidance systems that relied on radio commands from the ground to aid in navigation. All-inertial guidance systems of that time used signals from gyroscopes that remain in a fixed position relative to the position of the missile to steer the missile on its correct path. In July 1961 an Atlas E missile was successfully launched from Cape Canaveral for a distance of 9054 miles. It was deployed horizontally in hardened underground shelters in Washington, Kansas, and Wyoming.

The Atlas F was the final and most advanced of all the military Atlas ICBMs. It was modified to be stored vertically underground fully loaded with RP1 fuel. At launch, LOX was loaded, the missile raised, and then fired. This could be done in ten minutes, five minutes faster than the previous Atlas E. It was deployed in Kansas, New York, Nebraska, Oklahoma, Texas, and New Mexico.

The last of the one and one-half stage models was Atlas II which was used for non-warhead missions only. It had 63 successful flights with the last one held in August 2004. It is considered one of the most reliable launch vehicles in the world. With the Centaur upper stage and four strap-on boosters, it can put very heavy payloads into geosynchronous (fixed in the sky) and other Earth orbits.

The latest version of the Atlas is the Atlas V. It is an Atlas in name only. It no longer has thin skin and one and one-half staging. It incorporates a rigid frame for ease of transporting and handling. Ironically, originally designed to be used against the Soviet Union, the Atlas now uses Russian built engines for the first stage. It was put into service in 1999 and is used to put military payloads and commercial satellites into orbit.

Figure 8: Schematic Atlas Missile - Integral Propellant Tanks

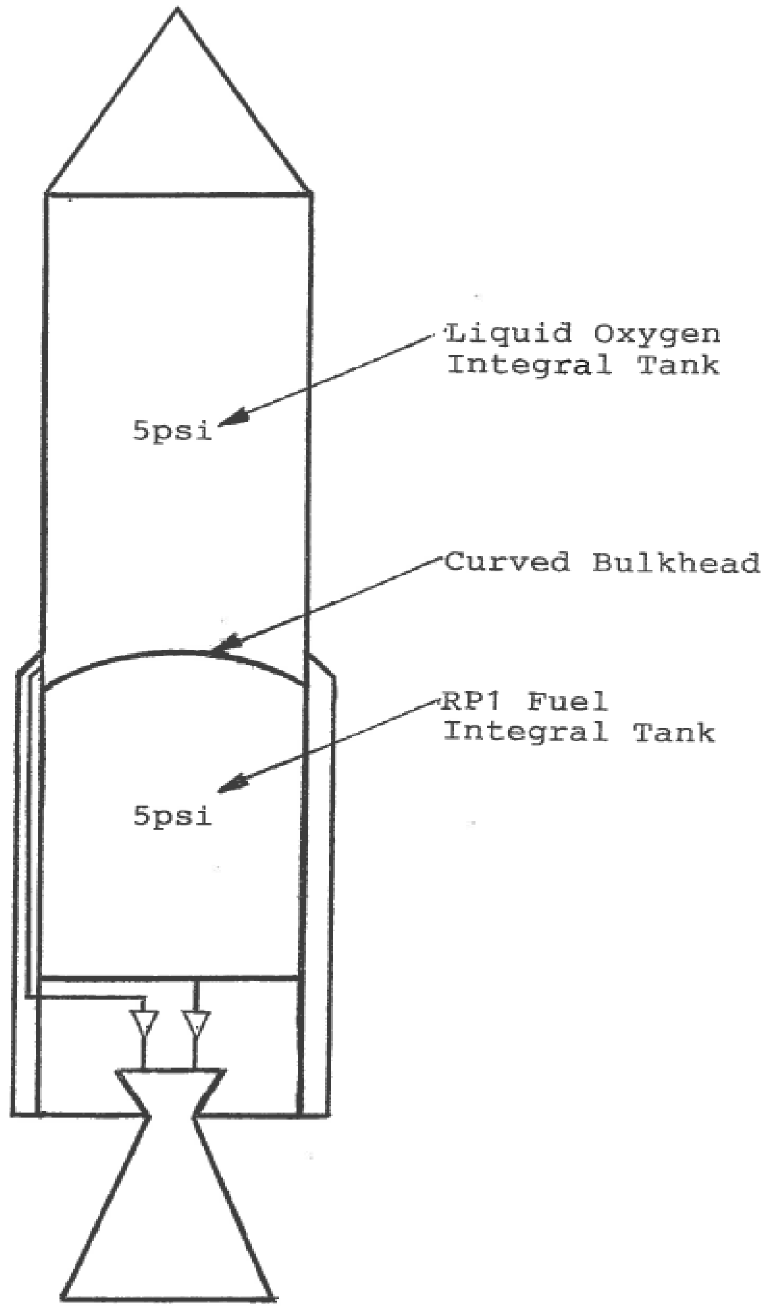


Figure 9: Air Force Eastern Range - ICBM Flight Path

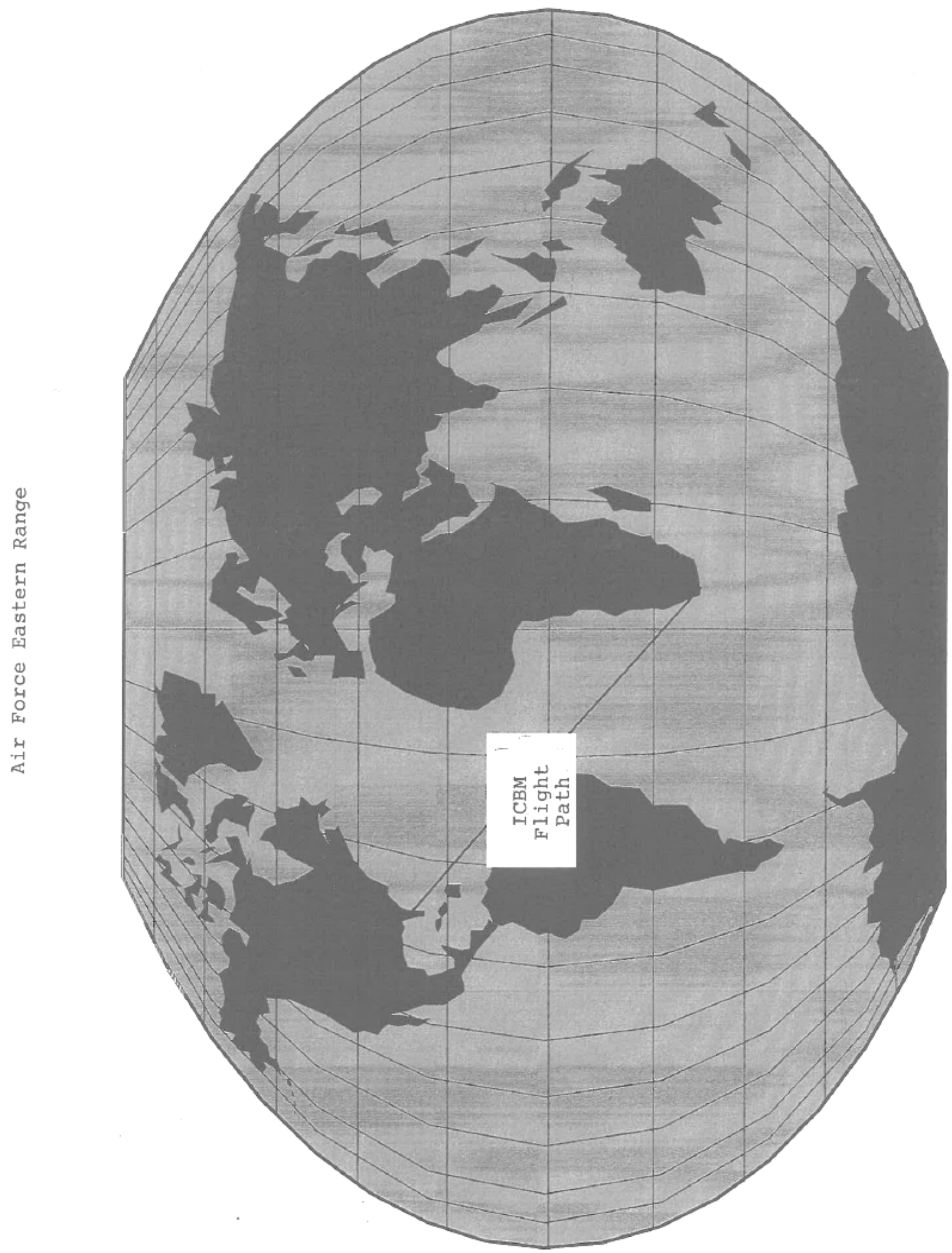
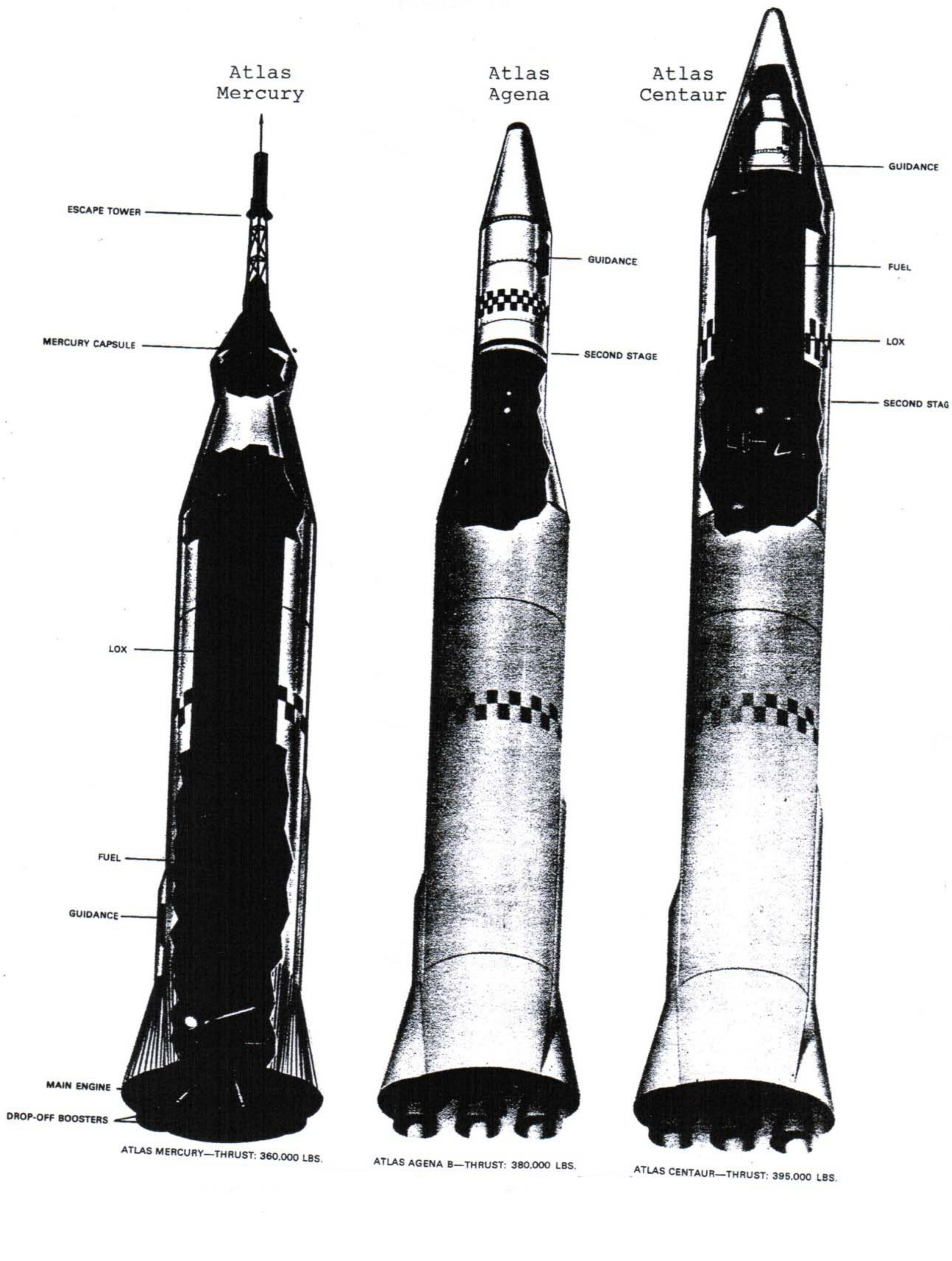


Figure 10 – Atlas Mercury/Agena/Centaur



The Titan ICBM

The Titan was the second U.S. ICBM and the first to have two distinct stages. The program began four years after Atlas. The Titan was initiated because of the possibility that the radical design approach of the Atlas would not be successful. The Titan I was a more conventional design with a rigid airframe compared to the internally pressurized thin-skin Atlas. The Titan I used the same propellants as the Atlas: RP1 and LOX. The first stage had 300,000 pounds of thrust while the second stage had 80,000 pounds of thrust. There were 70 launches of the Titan I dating from February 1959 to March 1965. Fifty-three were classified as successes and 17 as failures. Like the Atlas, the program was plagued with early failures; however, it finished with a high degree of success. The Air Force accepted delivery of the first Titan eight months before testing started. Two months after testing started construction began on the first hardened site in Colorado. The Titan I was operational from 1962 to 1965 at which time Titan II and Minuteman missiles started their deployment.

The Titan II was designed with a first stage thrust of 430,000 pounds and a second stage thrust of 100,000 pounds; a big improvement over Titan I. Another improvement was the conversion to a hypergolic (self-igniting) fuel and a non-cryogenic oxidizer. This enabled the propellants to be stored in the vehicle at the launch sites and the missile fired within minutes. It also provided for a reliable second stage in-flight ignition. Titan II had an all-inertial guidance system thus not having to rely on ground signals for navigation. In February 1963, a Titan II launched from Cape Canaveral completed a successful 6500 nautical mile flight. With extended range, Titan IIs could now be deployed further south in the U.S. dispersing them more evenly across the states. The Titan II served to defend this country until 1981 when all sites were deactivated in favor of Minuteman. In the mid 1960s, the Titan II was used in the NASA's Gemini two-man space program. All ten of the two-man capsules were successfully launched. In the late 1980s, the Titan II was used to launch a defense meteorological satellite from Vandenberg Air Force Base in California.

Titan III and Titan IV were modified Titan IIs with optional strap-on solid fuel boosters. They were used for launching military satellites into orbit as well as for NASA's Voyager probe to the outer planets; Viking probes to Mars; and the Cassini probe to Saturn.

The Minuteman ICBM

The Minuteman is a three stage solid propellant ICBM that followed the Atlas and Titan into production and is the only ICBM deployed in the U.S. today. It was made possible because of advancements in solid propellant chemistry and engine designs that were developed since the conception of the Atlas and the Titan missiles. The advancements included more powerful burning propellants; engines with swivel nozzles for steering; and improved engine shutdown methods. The Minuteman is smaller, less complex, and much easier and faster launched from a hardened site than its predecessors, and still able to carry a warhead a long distance.

The Minuteman missile is the brain child of Lieutenant Colonel Edward Hall of the Air Force Ballistic Missile Division. Hall, in 1957, generally working alone except for assistance from the consulting firm of Ramo-Wooldridge, incorporated new design features that were developed by a series of Air Force studies. It offered what hoped to be a missile that would put the U.S. ahead of Russia in the arms race. The Minuteman was first funded in early 1959, approximately three years after Titan. A test run in late 1959 proved that Minuteman could be launched directly from an underground silo without being raised to the surface saving precious minutes over Atlas and Titan. Also, the Minuteman propellants are an integral part of the missile while Atlas and Titan had to be loaded with fuel before launch. In February 1961 at Cape Canaveral, the first Minuteman was launched. All three stages performed flawlessly and the nose cone splashed down in the Atlantic Ocean 4600 nautical miles down range; a feat that Atlas and Titan did not come close to attaining. By the time the flight took place, the Air Force was already planning deployment. The first bases were constructed in Montana, North and South Dakota, Missouri, and Wyoming.

Minuteman II with improved range, heavier payload, and greater accuracy replaced Minuteman I from September 1965 to March 1973. Minuteman III, an awesome weapon, carried a payload called MIRV (multiple independently targeted re-entry vehicle). One missile could deliver hydrogen bombs to multiple separate targets. By July 1975 there were 550 Minuteman IIIs and 450 Minuteman IIs deployed in the U.S.; a force to be reckoned with for nearly 20 years. The fall of the Berlin Wall in November 1989 marked the beginning of the end of the Cold War. As a result of an agreement with Russia, the U.S. was to convert all Minuteman MIRVs to standard single warhead Minuteman IIIs. Five hundred single warhead Minuteman IIIs were to be deployed through 2020.

The MRBM and SRBMs

Because of the longer time needed to develop ICBMs, the U.S. developed the MRBM Thor and Jupiter missiles for fast deployment in Europe to counter the threat of Soviet Union ballistic missile programs. The Thor began development in January 1956 and, within three years, was deployed in the United Kingdom where it remained until 1963, after which time it was withdrawn in favor of the U.S. deployed ICBMs. The Jupiter program was started by the Army in late 1955 and became the first operational MRBM for the U.S. but was never deployed by the U.S. in favor of the Thor. The Jupiter was deployed in Europe by NATO until April 1957. Both were single stage MRBMs with one RP1/LOX engine developing 50,000 pounds of thrust. The Thor is used today as a space launch vehicle called the Delta. The Jupiter was used as a satellite and space probe vehicle called the Juno II.

The SRBM Redstone program was first started in 1953 and was a direct descendant of the German V2 rocket. It was active as a battlefield weapon from June 1958 to June 1964. It was designed as a surface-to-surface missile and was deployed by the U.S. Army in West Germany. The Jupiter A and Jupiter C missiles were actually modified Redstones. America's first satellite and first man in space were launched by a Jupiter C missile. (See Figure 11.)

It can be said that the global expansion dreams of the Soviet Union, as described by Nikita Khruschev when he said, referring to the United States, "We will bury you!", were thwarted by the enormous effort put forth by the U.S. military and industrial complex in developing spacecraft that ensure the safety of the citizens of, not only the United States, but of all of the peace loving nations of the world. Today, spacecraft and the knowledge learned are not only being used to secure the peace, but are used in making great strides in such areas as space travel, space exploration, man moon landings, mars landings, astronomy, communications, weather forecasting, and global positioning systems (GPS).

Figure 11: Redstone Missile