MARSHALL SPACE FLIGHT CENTER,
REDSTONE ROCKET TEST STAND
(Redstone Missile Test Stand)
(The Interim Test Stand)
(Marshall Space Flight Center,
Building No. 4665)
Redstone Arsenal
Dodd Road
Huntsville Vicinity
Madison County
Alabama

HAER No. AL-129-A

HAER
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45-HUVI.V
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HISTORIC AMERICAN ENGINEERING RECORD
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HISTORIC AMERICAN ENGINEERING RECORD

MARSHALL SPACE FLIGHT CENTER, TEST STAND
(Redstone Missile Test Stand)
(The Interim Test Stand)
(Marshall Space Flight Center, Building No. 4665)

HAER No. AL-129-A

Location: On Rte. 565 between Huntsville & Decatur. Madison Quadrangle, UTM 16.530560.3832160.

Date of Construction: 1952

Builder/Fabricator: N.A.S.A.

Present Owner: U.S. Army

Present Use: Rocket Development

Significance: The Redstone Interim Test Stand, in use from 1953 to 1961, was developed by Dr. Wernher von Braun and associates to test the Redstone rocket propulsion system. Constructed for $25,000 out of materials salvaged from the Redstone Arsenal, the Interim Test Stand accommodated 362 static tests, including 200 that led directly to improvements in the Redstone rocket for the Mercury manned flight program. Adapted over the years to new rocket developments, the Interim Test Stand never experienced the progressive growth in size and cost that typified test stands in general, remaining a modest but effective testament to the engineering ingenuity of the rocket pioneers.

Project Information: The REDSTONE Recording Project is part of the Historic American Engineering Record (H.A.E.R.), a long range program devoted to the documentation of the engineering and industrial heritage of the United States. The H.A.E.R. program is administered by the National Park Service. This recording project was cosponsored by the Facilities Office of Marshall Space Flight Center, with the assistance of Mr. Pete Allen. Special gratitude is given to the retired engineers, builders and operators of the Redstone Test Stand who have assisted the recording team in accurately interpreting the site and its operations.

Field work, measured drawings, photographs and this historical report were prepared under the general direction of Eric N. Delony, Chief of H.A.E.R. The project was managed by Richard O'Connor, H.A.E.R. Historian and Craig Strong H.A.E.R. Architect. The field team consisted of Field Supervisor Thomas M. Behrens, H.A.E.R. Architect; Historian, Danny J. Bonenberger, West Virginia University; Architecture Technicians, Amy E. Vona, University of Virginia; Michael E. Pugh California Polytechnic University in Pormona, and Erin L. Walsh Miami University (Ohio).

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We would like to thank all of the retired engineers and technicians who worked at the interim test stand between 1952 and 1962. Without the generosity and expertise of these men, our report and drawings would have lacked many important details. In particular we would like to thank Charlie Gillespie, James Pearson, Frank Rutledge, Bill Grafton, Jack Conner, John Kastinakis, John Shirey, and Paul Artis for helping us to interpret old photographs, for proofreading our drawings and prose, and for tirelessly answering our many questions about rocket testing at the interim facilities.

We also acknowledge and thank the German rocket pioneers that worked on the Redstone Guided Missile System development program. Engineers Konrad Dannenberg, Bernhard Tessman, Karl Heimberg, Ernst Stuhlinger, and Fritz Weber explained not only the design and development of the Redstone, but also some of the finer details of liquid propellant rocket testing in Germany.

The many fine people of the U.S. Space and Rocket Center generously aided our cause. Gratitude is extended to Joe Moquin, James Hagler, Konrad and Jackie Dannenberg, Mitchell Sharpe, Steven Horton, Doris Hunter, Steve Moquin, Fred Ordway, Tommie Blackwell, and Darlene Perry for providing unlimited access to their vast collection of resources.

The document librarians at the Redstone Scientific Information Center (RSIC) were quite helpful in making this large archive of sensitive NASA and U.S. Army technical documents accessible to a historian with limited time and clearance. Thanks to Shirley Hughes, Gwynn Wallace, Barbara Sullivan, Mrs. Jackson, and the rest of the staff at the RSIC. Thanks also to Julia and Marie at Rocketdyne's Canoga Park Archive for going out of their way to send information to the team.

Special thanks to the HAER support staff in Washington: historian Rich O'Connor, architect Craig Strong, and research assistant/editor Sue Benz. And finally, thanks to field supervisor Thomas M. Behrens, and architects Michael E. Pugh, Amy E. Vona, and Erin L. Walsh for their enthusiasm and dedication to the project.

Dan Bonenberger
Project Historian
March 1996

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our Leader just smiled. He said, "You're not to blame.
And those Zooks will be sorry that they started this game.

..."Our slingshots have failed.
That was old fashioned stuff.
Slingshots, dear boy,
are not modern enough.

"All we need is some newfangled kind of a gun.
My Boys in the Back Room have already begun
to think up a walloping whizz-zinger one!"

Dr. Seuss, *The Butter Battle Book*, 1984.

INTRODUCTION

The arms race is nearly as old as the human race. Since prehistoric times, humanity has sought weapons with ever-increasing range and destructive power. As man slowly learned the secrets of nature, he applied them to craft better weapons using sticks, stones, and other common materials of daily life. From the slingshots, spears, bows, and arrows of early man, to the guns and cannons made possible by the discovery of explosive powder, the reach and destructive force of man's weapons increased steadily throughout the ages. As the Industrial Revolution advanced into the twentieth century, the range and power of man's weapons grew to new heights (and depths) as demonstrated by the machine gun, the tank, the submarine, and the airplane.

World War II brought two monstrous new weapons: the American atomic bomb and the German V-2, a liquid-fueled, long-range rocket. Following the war, the United States military set scores of scientists and engineers to work making the atomic bomb more destructive, but smaller and lighter; the liquid-fueled rocket engine more powerful and reliable. Within five years, both projects had advanced considerably. The atomic bomb was reduced to 6900 pounds, and the a prototype rocket engine based on the V-2 produced 75,000 pounds of thrust, nearly 50% greater than that of the V-2.

When the Korean war escalated in 1951, many people feared that the United States and Soviet Union would soon collide on the battle field. With renewed vigor, the United States Army pursued plans to develop a missile to carry an atomic warhead. Early in 1951 the team of German and American engineers at the Redstone Arsenal in Hunstville, Alabama began designing the XSSM-G-14 missile based on the weight of the smallest atomic payload (6900 pounds), and the thrust of the North American Aviation engine (75,000 pounds). Combining the range of the V-2 with the destructive power of the atomic bomb, the XSSM-G-14 was bound to be the greatest weapon on Earth.

But, as prehistoric man quickly realized, no matter how big a weapon is, or how far it can reach, a weapon is useless if it does not reach a target with consistency. With an atomic bomb as the payload, the Army was committed to developing a missile with unprecedented accuracy and reliability. The Army spent millions of research and development dollars perfecting the propulsion and guidance systems of the REDSTONE Guided Missile. An exhaustive testing program at the Redstone Arsenal throughout the 1950s made the REDSTONE the most dependable missile in the Army arsenal.

Cold War American military strategists in the 1950s speculated that the Soviet Union might be planning an invasion of the West. As a deterrent to Communist aggression, the United States deployed the REDSTONE missile to N.A.T.O. troops in West Germany in 1958. The Iron Curtain held strong, but the Cold War expanded in another direction. Chasing the Russians in the race to outer space, the United States called upon the most trustworthy of its powerful missiles. On May 6th, 1961 a REDSTONE rocket carried America's first astronaut, Alan Sheppard, into outer space, and three weeks later, America enthusiastically accepted President John F. Kennedy's challenge "before this decade is out, of landing a man on the Moon, and returning him safely to the Earth."[1]

In the historiography of rocketry and space travel, most emphasis has been placed on the space race and the Apollo moon mission. People are naturally fascinated by the drama and underlying tension of a rocket launching from the pad at Cape Canaveral, its precious human cargo thrust toward the stars. The story of our brilliant scientists and the daring astronauts that manned the Mercury, Gemini, and Apollo missions has been told in countless volumes. Despite all of this attention to the U.S. space program, several aspects have been largely ignored.

Neglected are the men that built and tested the rockets. Forgotten is the development, fabrication, and testing process. Ignored is the hardware that was engineered to measure the internal workings of each rocket during testing. By focussing on the ends instead of the means, historians and other writers have left a remarkable gap in the history of spaceflight. This gap is in the critical area of rocket development and testing.

Since the earliest days of liquid-propellant rocketry, testing has been performed in three steps: engine testing, static rocket testing, and test launches. First, prototype engines are tested on an "engine test stand", engineers refine the most promising designs during a period of extensive testing. After the engine has been proven, it is assembled along with the fuel

[1]John F. Kennedy, speech, May 1961.

tanks and guidance system into a complete rocket in preparation for the second stage of testing. In this step, the rocket is secured to a "static test stand" that is anchored to the ground. With the rocket restrained, engineers run the engine at full power and examine the behavior of the propulsion system. They check for imperfections and refine the system by improving weak components. Finally, after passing the static test, the rocket is prepared for the most exciting phase of testing, the test launch. In this final phase, the missile is fired into the sky. The flight test demonstrates the harmony (or disharmony) of all of the rocket components and systems, especially the guidance system. From the early days of amateur rocket development to the SATURN boosters of the APOLLO moon mission, engineers advanced liquid-propellant rockets during these three phases of tests.

Dr. Wernher von Braun headed the development of the Saturn V rocket as director of NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama.[2] Von Braun had been building and testing rockets since he joined the German Society for Space Travel as a teenager in 1930. Three decades later, his team at MSFC designed and built the moon rocket based on the principles advanced over thirty years of liquid-propellant rocket evolution. The evolution and testing of the rockets that led to the design of the SATURN rockets is much too extensive to address in one book (See Appendix 1 and 2). This paper addresses a small but significant step in the path to the moon: static testing of the REDSTONE missile 1953-1960 at the Interim Test Stand on the grounds of the Redstone Arsenal (See HAER No. AL-129-A-42).

Certainly, as the home of propulsion system testing for the REDSTONE missile, affectionately known as "Old Reliable," the Interim Test Stand is an engineering landmark with unquestioned national and global significance. Even an abbreviated list of REDSTONE "firsts" is impressive: first missile ever used to detonate an atomic warhead; carrier of first atomic warhead deployed to NATO troops; the booster for the first American satellite; the rocket that carried the first American astronaut into space. Further, SATURN V propulsion engineers designed the moon rocket based on technology that they had developed for REDSTONE.

The significance of the Interim Test Stand goes far beyond its role in refining the REDSTONE, for the Interim Test Stand is an aberration in the long history of rocket propulsion test stands; rocket test stands that evolved with the career of Wernher von Braun. From the simple test stand erected by the German Society for Space Travel in 1930, to the 400 foot SATURN V

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[2]In 1960 a section of land in the Redstone Arsenal became NASA's Marshall Space Flight Center. The MSFC plot (leased on long term from the Army) consisted of the land and facilities where the Army had developed the REDSTONE missile.

test stand constructed in 1963-64, testing facilities grew progressively in size and cost. The Interim Test Stand is an exception.

In 1951, engineers at Redstone Arsenal designed the propulsion and guidance systems of the XSSM-G-14 Missile to carry a 500 pound warhead 500 miles. But, because of the Korean War and the mounting tension of the Cold War, the specifications were changed and the development pace accelerated. The missile was now to carry the smallest of America's atomic bombs, a 6900 pound warhead, for a range of 175 miles. The following year, fabrication of the first REDSTONE began, and the Army faced a dilemma: further development depended on a propulsion test stand, but an inflexible law stated that no research and development funds could be spent constructing facilities. It did not matter that the facilities were vital to research and development. It did not matter that the project had A-1 priority and was considered paramount to the national security of the United States.[3]

Rather than wait for funding to go through the two-year Congressional appropriation process, then wait another year or two for construction of permanent facilities, REDSTONE engineers designed a $25,000 interim ignition test stand, the maximum amount allowed for constructing facilities without Congressional approval. When the first REDSTONE was completed in spring of 1953, the Interim Test Stand was ready. Nearly all of the money had been spent on a large concrete foundation to counter the missile's powerful thrust. On this base, welders constructed a small stand using pipe and metal salvaged from around the arsenal (See HAER No. AL-129-A-36).[4]

While they waited for Congressional appropriation and construction of permanent facilities, design engineers used the information gained during static testing at the Interim Stand to steadily improve the REDSTONE engine and propulsion system. In 1957 a permanent test facility called the Static Test Tower was finally completed and equipped, but the Army decided to continue operations at the Interim Test Stand rather than make a disruptive move to the new Static Test Tower. By 1961, engineers

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[3]OGMC Aerodynamics and Structures Branch, " Monthly Report" Numbers 9 through 13 (July-November, 1951).

[4]Oral History Interviews by the author, Bernhard Tessman and Karl Heimberg, August 1995.

and technicians had performed three hundred sixty-two static tests at the stand, including about 200 tests that improved the REDSTONE for the MERCURY manned flight program.[5]

From 1953 through 1960, Interim Stand engineers and technicians tested the REDSTONE propulsion system through a long and tedious process. This paper explores the testing process and activity at the Interim Stand during three distinct periods: First, the early developmental period at the Ordnance Guided Missile Center (OGMC) from 1953 to 1955; Second, the Army Ballistic Missile Agency (ABMA) period from 1956 to 1958, when management was transferred from OGMC to ABMA; and third, the MERCURY period that began in 1959 and lasted through 1960.

This paper was designed to explain the industrial process of rocket propulsion testing and the significance of the Interim Test Stand facility. To understand the complex testing procedure at the Interim Stand, one must understand how the REDSTONE propulsion system worked. This paper begins with a study of the earliest liquid rocket engine tests in the late 1920s. The brief survey of German rocketry is an aid to readers with little technical background to understand how liquid-propellant rockets work at a basic level. By exploring the simplest rockets of the REDSTONE lineage, the function of the intricate REDSTONE propulsion system becomes easier to understand. This also gives perspective to the way that rocket testing evolved over the decades and explains the significance of the Interim Test Stand beyond its association with the famous REDSTONE missile. To truly grasp the importance of the Interim Test Stand one must understand how it fits in the evolution of rocket test facilities.

The first chapter of this paper is an overview of German rocket and test stand development, from amateur days (1928-1932) to the Army development (1932-45). The second chapter is devoted to the transfer of German rocket scientists and engineers and their technology to America. After an overview of slow developments in the five years following the war, the paper turns to the design (1951-52) and development (1953-1958) of the Army's REDSTONE missile, and adaptation of the rocket (1959-60) for America's first step in the manned exploration of outer space.

Two terms in rocketry are vital to the study of propulsion system testing. "Control" and "instrumentation" practices changed dramatically since the 1920s with the advance of rocket technology. These words are used in a variety of ways in the jargon of rocketry. "Control" is used to describe the control of

[5]NASA, "MSFC Master Plan," Unpublished Reports, 1960-Present., "REDSTONE Log Book," Numbers 1,2,4, and 5, Unpublished engineer's log books, 1954-1960.

the rocket in flight and the control of components in the propulsion system. Today, "instrumentation" applies to the many electronic components in the rocket and in the facilities where the performance of the rocket is evaluated. To avoid confusion, this study of propulsion testing limits usage to only one definition for each word. Almost without exception, "control" refers to the means of controlling the flow of propellants within the rocket, and "instrumentation" refers to the devices used to examine the internal characteristics (temperatures, pressures, flow rates, etc.) of the rocket propulsion system.

2 THE GERMAN ROOTS OF ROCKETRY AND STATIC TESTING

2.1 Hermann Oberth: The Principles of Rocket Propulsion and Spaceflight

At the age of thirteen, Wernher von Braun read *Die Rakete zu den Planetenraeumen* (*The Rocket into Planetary Space*), a book that inspired him to spend his life designing rockets for space travel. The book, published two years earlier in 1923, was written by a Rumanian German, Hermann Oberth. Oberth's calculations were derived from the laws of physics and the higher mathematics of integral calculus, so he used rhetoric and illustrations liberally in hopes of illuminating the physical principles of motion that would allow rockets to fly into outer space. To escape the Earth's gravity, he proposed the development of a new type of rocket, one fueled by liquid propellants rather than the solid fuels of traditional rockets.[6]

Oberth based his calculations on the three Laws of Motion published in Sir Isaac Newton's *Principia* of 1687.[7] According to these laws, the force directed by a rocket toward the Earth must be greater than the force of gravity acting on the mass of the rocket. Likewise, the thrust of the rocket must be maintained for a long duration to escape the Earth's gravity. Oberth

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[6]Hermann Oberth, *Die Rakete zu den Planetenraumen* (Muenchen and Berlin,1923). Later reproductions by Uni-Verlag Feucht (Nuernberg, 1960/1964/1984). The book correctly forecasted many of the problems that America encountered in the Mercury, Gemini and Apollo programs.

[7]Also known as the "Mathematical Principles of Natural Philosophy". Simply stated: 1, A body at rest tends to stay at rest, and a body in motion tends to stay in motion unless acted upon by an outside force. 2, An object accelerates when acted upon by an outside force. The rate of acceleration is proportional to the force and inversely proportional to the mass of the object; $a=F/m$. 3, For every action there is an equal and opposite reaction.

calculated that solid propellants, used in rockets since the fourth century, were not powerful or efficient enough to escape the Earth's gravitational pull. Liquid propellants had never been utilized before in rocketry, but Oberth used them in his calculations for designing a new type of rocket. He knew that liquid fuels were man's only chance of escaping the Earth's gravity and traveling into planetary space.

2.2 Promoting rocketry: Valier, Ley and the VfR

Oberth's book, while not widely accepted, managed to stir the imagination of dreamers throughout Europe and beyond. While science fiction writers like Jules Verne and Edgar Rice Burroughs had written about space travel for decades, their stories were not based on the laws of science. Because his fantastic subject had no scholarly predecessor, Oberth was associated with science fiction and ridiculed by mainstream scientists. In the 1920s, after 40 years of German scientific, technological, and industrial progress forged on empiricism, who would be foolish enough to take seriously a book on space flight? Most of Germany's scientists were not ready to speculate on something as foolish as the proposition that space ships could leave the Earth and fly among the moon and planets.

Some men dared to dream and were captured by Oberth's theory. Some saw the logic in his arguments and granted the author leave for the speculative nature of his subject. Certainly he could not address all of the technical problems that would have to be solved, for there was not yet even one liquid-propelled rocket. The remarkable number of obstacles that Oberth managed to foresee, explain, and address in his book won the respect of many who were not afraid to ponder the fantastic.

Berlin engineer Max Valier was one such dreamer, but he was also a pragmatic salesman and eloquent propagandist. Even before the publication of Oberth's *Die Rakete zu den Planetenraumen*, Valier had been traveling around Germany lecturing on rocketry and spaceflight in hopes of attracting financial support for his work in solid-fuel rocket engine development. To reach this end, he always explained the dramatic and practical applications of rocket engines. Rocket-powered cars and rocket-assisted take-off for heavy aircraft were more easily envisioned than a rocketship traveling between the planets.

Valier read Oberth's monumental work in 1923, and was inspired to write a more vernacular explanation of space travel.[8] In turn, science writer Willy Ley deemed Valier a

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[8]Max Valier, *Der Vostossin den Weltraum* (1924). This work shows that even Valier had trouble understanding Oberth's equations.

brilliant engineer and skilled orator but felt that his book was still too technical to become popular. In 1926, Ley published *Die Fahrt im Weltall* (*The Journey into Space*) selling 6000 copies of the short non-technical book by 1931. Then, in the spring of 1927, Ley and Valier joined forces to promote their common dream.

Together with another engineer, Johannes Winkler, Ley and Valier started a space flight society to promote and unite those that were working on the common goal of rocket development. They founded the Verein fuer Raumschiffahrt (VfR), or Society for Space Ship Travel, on 5 July, 1927 in a Breslau Tavern, published the journal, *Die Rakete*, and launched an aggressive membership drive. Within a few months, Professor Oberth had joined, and by the end of its second year the society had attracted 870 members.[9]

Despite their new association, the German rocket pioneers continued to work individually. In 1927, Valier convinced automobile magnate Fritz von Opel that a rocket powered auto was within reach. Though he saw the potential advantages of liquid fuels for racing (they were not only safer and more efficient than solids, but also allowed for variable thrust, essential for handling the automobile around turns), he knew that very little work had been completed on liquid rockets. To attract funds and continue his research, he needed the demonstrable reliability that only relatively well-established solid rocket fuels could provide.

The following year, Oberth too found a source to fund his own rocketry project. World renowned film director Fritz Lang had read many science fiction books about space travel that were popular in the 1920s, and his wife had written a screen play based on the work of Oberth and Ley. In 1928 Lang asked Oberth to be the technical advisor on a film to be called *Die Frau im Mond* (The Woman on the Moon). Oberth agreed and, prompted by Ley, convinced Lang and the Ufa film company to finance the construction of a liquid-fueled rocket to be fired as a publicity stunt at the premier of the film (See HAER No. AL-129-A-17).

With only twelve weeks to produce a working rocket and no practical experience working with metals or fuel, Professor Oberth hired engineer Rudolf Nebel and a Russian aviation student named Scherschevsky. The project was doomed to fail: the goals were too lofty, the personnel too inexperienced, and the time too short. Nebel had exaggerated his credentials, and the Russian was, in Oberth's words, "the second laziest man" he had ever met.[10] Nebel proposed making a small (1/2 gallon of propellant)

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[9]Frank H. Winter, *Prelude to the Space Age: The Rocket Societies:1924-1940* (City of Washington,1983), p36.

[10]Which raises the question, why did Oberth not recruit help from within the VfR?

rocket, but Ufa (Lang's film company) held outrageous expectations for the project. They wanted a rocket that was at least 45 feet tall (approximately the same size as the V-2). In a compromise, Oberth and his assistants boldly attempted to construct a seven foot rocket with propellant capacity of two gallons. The film premiered on 15 October 1929 to a large crowd and proved to be a grand success for Ufa, but Oberth's small team of misfits was not in attendance. Oberth and Nebel had quietly skipped town, after failing to produce a functioning liquid rocket. [11]

While Oberth was working on the film and rocket (1928-9), Valier and Winkler, the early leaders of the VfR, drifted apart in pursuit of their own personal goals. Valier had successfully developed solid rocket engines for publicity demonstrations, applying rockets to a variety of vehicles: an automobile, a rail car, and later a sled, depending on the fancy of his sponsor (See HAER No. AL-129-A-18).[12] Late in 1929 he finally found a source to fund the development of a liquid rocket engine for a motor car. Paul Heylandt, a liquid nitrogen and liquid oxygen manufacturer, provided funding and facilities at his Industrial Gas Utilization Co. in South Berlin. Concurrently, Johannes Winkler resigned as president of the VfR and as the editor of *Die Rakete* to pursue his own interest in designing liquid rocket engines. Oberth was persuaded to assume the presidency of the VfR, but the journal was abandoned.[13]

The abandonment of the VfR journal is a benchmark that reveals a substantial change in direction (priorities) for the

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[11]Ley, *Missiles, Rockets, and Space Travel* (1961), 126-7; Winter, *Prelude*, 38-9. Marsha Freeman has written a great deal on Oberth and his contributions to space science in *How We Got to the Moon: the Story of the German Space Pioneers* (1993), chapters 1-3.

[12]Fritz Beck, *Raketenflug*, Silent film (1944). subtitles trans. 1961. USSRC, p4-5. The film is also available at the National Archives in Washington, D.C. In conjunction with auto magnate, Opel, Valier equipped a 4HP Opel chassis with solid rockets. The "Opel-Rak I" sped down the track at 60 mph in the first public demonstration on April 1928 at Opel's Race Track in Ruesselsheim. Valier split with Opel in May and teamed up with the company of J.F. Eisfeld, Silberhuette/Anhalt. The Eisfeld-Valier R I was a rail car. In its first public trial the car reached 115 miles per hour before derailing, after which, the car reportedly attained a speed of approximately 190 mph.

[13]From the standpoint of a historian of liquid rocket technology it is truly tragic that the VfR's journal was abandoned in 1929, for beginning in 1930, progress in this technology increased exponentially.

VfR and its leaders. The journal had served the goals of its founders as a means to connect those scattered dreamers across Europe that were making solid propellant rockets or planning the design of the first generation of liquid-propellant rockets. Within this public forum, the principles of liquid rocketry and spaceflight were debated. Along the way, some skeptical engineers and scientists began to accept the possibility of spaceflight. Though it would be an exaggeration to suggest that the spaceflight movement became widespread due to *Die Rakete*, the movement certainly gained respectability among some of the public and more importantly with some wealthy patrons. The rocket and space flight enthusiasts who founded the society, bound together through the contents and spirit of *Die Rakete*, had argued about the challenges of liquid rocketry and space flight, spread their enthusiasm to new circles, and were ready to confront their *raison d' etre*: the development of liquid-propellant rockets.

2.3 Early Rocket Development: Heylandt and the VfR

The German rocket pioneers depended on donations from VfR members, wealthy citizens, and private industry to develop liquid-propellant rockets. By 1930 the American Great Depression reached Germany, and the economy of the Weimar Republic, already strangled by reparations from World War One, sank even further. During tough times there was little money for instrumentation, so engines were designed and advanced slowly on a trial and error basis, building on the experience and mistakes of each run. The valves that released propellants into the engine were controlled manually. Lessons learned during the fledgling days of liquid-propellant rocketry paved the way for slow and steady progress.

Oberth and Nebel gained valuable experience in their *Frau im Mond* fiasco, not to mention a number of tools, equipment, and an iron stand that was built for launching the rocket. In conjunction with the change in the VfR's leadership and focus in 1929, the Society moved its headquarters to Berlin, attracting three Berliners to its ranks: Rolf Engel, Klaus Riedel, and eighteen year old Wernher von Braun. Von Braun had been working as an apprentice at the Borsig Engineering Works and attending a Technische Hochschule (Technical University) outside of Berlin.[14]

The group spent the Winter and Spring of 1930 reworking the unfinished *Frau im Mond* rocket, the Kegelduese, in preparation for a certification test that Nebel had arranged with the Chemische-Techniche Reichsanstalt (National Institute for

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[14]Frederick I. Ordway, and Mitchell Sharpe, *The Rocket Team*, 14., Winter, *Prelude*, 39-40.

Theoretical and Applied Chemistry[15]). The rocket team hoped that the CTR would help fund its rocket development dreams, or at least that a certification by the respected Reichsanstalt would open up paths to new private and industrial contributions. Their attempt at gaining respect for their liquid-fueled rocket engine was preempted by a more dramatic event at Heylandt.

In 1929, Valier had turned his full attention to liquid propellants. Throughout the year he tested the design of a new liquid-propellant rocket engine with the aid of Arthur Rudolph and Walter Riedel, two Heylandt engineers. The testing procedure was primitive and dangerous, and methods of instrumentation and control were simplistic. The rocket engine was attached upside down to a modified kitchen scale. (See HAER No. AL-129-A-19) During the run, Valier paced around the engine looking for red spots on the walls of the chamber that indicated the chamber was too hot. His assistants controlled the volume and pressure of fuel and oxygen into the engine by manually turning valves according to hand signals received from Valier. As Valier looked for dangerous hot spots, he added weights to the scale, providing a rough measurement of the thrust. His engineers noted the pressure gauges on the propellant tanks at moments of optimum engine performance. Thus a small amount of helpful data was gained from these earliest methods of instrumentation.[16]

The Valier team demonstrated progress on 25 January 1930 at the Heylandt plant, by successfully running a liquid oxygen/gasoline rocket chamber for approximately 5 minutes.[17] By spring, Valier and his team of Heylandt engineers had finished outfitting a car, the Valier-Heylandt Rak 7, with their first liquid propulsion system. On 19 April, Valier successfully ran his new rocket car on the plant grounds.[18] Valier had moved one small step closer toward his dream of space flight.

Four weeks later, tragedy struck the VfR community. At the Heylandt plant, Max Valier and his two Heylandt engineers, Rudolph and Riedel, were running a static test of a liquid fueled

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[15]Germany had a number of national science and technology institutes. The first was the Physicalische-Technische Reichsanstalt (PTR) which was founded under the impetus of Werner von Seimens as a National Bureau of Standards to aid the infant electric power industry. In 1930 Nebel was hoping that the CTR would similarly aid the infant liquid rocket industry. He would be disappointed.

[16](Arthur Rudolph) Oral History Interview,(August 4, 1989), 7-9.

[17]Beck, *Raketenflug* trans., 8.

[18]Beck, *Raketenflug*, trans., 8.

rocket engine in preparation for the run of their next dragster.[19] The engine exploded in the test stand and a piece of aluminum shrapnel struck Valier in the chest. Riedel caught the staggering Valier and ran for help. Rudolph, stunned, ran to the aid of his fallen colleague, but within moments Valier was dead. Liquid rocketry had claimed its first life, the life of the most outspoken and tireless promoter of the obscure new discipline.

Despite their grief, von Braun, Nebel, Klaus Riedel, and the rest of the team continued their work readying the steel and copper Kegelduese for the slated trial. Despite persistent downpours of rain, the rocket engine tested beautifully. The CTR official certified that the Kegelduese "had performed without mishap on 23 July 1930, for 90 seconds, consuming 6 kg (13.2 lbs.) of liquid oxygen and 1 kg (2.2 lbs.) of gasoline, and delivering a constant thrust of about 7 kilograms (15.4 lbs.)"[20]

Although the test was technically a success, the engine was horribly inefficient, barely producing enough thrust to overcome the weight of the propellants. Considering the substantial weight of the engine, fuel tanks and other components of the rocket, the engineers were a long way from reaching outer space. Oberth wanted to work on refining the Kegelduese, but Rudolph Nebel and Klaus Riedel believed that the team needed to regress. They believed that the next step should be the development of a minimum rocket (See HAER No. AL-129-A-20).

Throughout the Summer of 1930, Nebel, Riedel and Kurt Heinisch worked on the farm of Riedel's grandparents in Bernstadt, Saxony, constructing their first minimum rocket, Mirak I.[21] The rocket was made of a cast aluminum head and a long aluminum alcohol tank. The combustion chamber was cooled by placing it inside the oxygen tank. In his memoirs, *Die Narren von Tegel*, Nebel described testing at the Bernstadt farm:

> First the propellant pressure must climb to ten atmospheres, then the fuel valve must be open. The gas was driven with the help of the carbon dioxide cartridge (used to pressurize seltzer bottles) and then ignited. Finally, oxygen was

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[19]The Heylandt team had been making remarkable progress. At least six different runs of the liquid powered car had been successful. Beck, *Raketenflug*, trans, XX. The exact fuel used by Valier is unclear, some accounts say Kerosine, some gasoline, some diesel oil. Rudolph later joined the team at Raketenflugplatz, while Reidel later became a design chief at Peenemuende.

[20]Winter, *Prelude*, 39 This quote is not footnoted by Winter, perhaps Ley, *Rockets*, 132-4.

[21]Minimum Rakete.

> added. With this sequence (operation) was obtained. Our protective room was a great straw pile behind which we went when it was time. Through a large mirror the rocket could be observed from this place. With a so-called barograph the thrust of the Mirak was recorded, and we could read off the values for the pressure and time. In the first experiment in the field there was a thrust of only 400 grams (14 ozs). Later we raised it to 2 kgs (4.4 lbs) and after that to 3.5 kgs (7 lbs). With this thrust, the rockets would have flown if we let them go (loosened them from their restraints used in the static tests). But we wanted first to have some practice in burn tests. [22]

On the 7th of September, 1930 they prepared for a public launching of their Mirak at the farm in Bernstadt (See HAER No. AL-129-A-21). To their knowledge, this was to be the first liquid-propellant rocket launched in the world. Unfortunately, the rocket exploded on the stand shortly after ignition. The dejected scientists headed to Berlin in search of a more permanent facility where they could design, construct, test, and launch the next generation of Mirak rockets.

2.4 The Raketenflugplatz, Berlin.

By the end of September, Nebel et al. had founded the Raketenflugplatz (literally: Rocket flying place), on the Northeast side of Berlin at an abandoned ammunition depot owned by the city. The depot was small and the facilities were meager, but Nebel managed to lease the property from the city at almost no cost to the team. Though Nebel wasn't much of an engineer, he was adept at acquiring construction materials, hardware, fuel and other supplies from public and private sources at little or no charge.

Throughout the winter the small group worked on designing and constructing the Mirak II and the Mirak III. When weather permitted, they worked on improving the facilities. At the end

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[22] Winter, *Prelude*, 40. quoting from Nebel's *Die Narren von Tegel*. It must be noted that Nebel memoirs are known to contain inaccuracies and exaggerations.

of February, the group learned that their former VfR president, Johannes Winkler, had achieved the world's first liquid-propellant rocket flight at Dessau on 21 February.[23]

In March, 1931, they finished converting the *Frau im Mond* rocket launcher into a static test stand for the next generation of Mirak rockets, which were nearing completion.[24] They erected the stand next to a small two-story building, rom which they controlled and observed the engine and rocket tests. The simple facilities seemed grand compared to those at the Riedel farm. A mound of earth (rather than a pile of hay) protected the men in the event of an explosion. A pulley system now controlled propellant and nitrogen valves, running between the stand and the small control house (See HAER No. AL-129-A-22).[25] At their humble testing facility, the VfR group gained confidence and experience with each firing.

The Mirak I was improved by including an oxygen pressure escape valve to correct an obvious design flaw and renamed Mirak II. Despite this improvement, the Mirak II was destroyed in an explosion on the test stand in April of 1931. In April and early May, a new rocket configuration was successfully fired on the test stand. Designed by Klaus Riedel, the Mirak III had a water-cooled engine in the fore, but instead of a long, solitary shaft like the earlier Miraks, this rocket was trailed by two long aluminum tanks (one gasoline and one nitrogen) with space between for the hot exhaust trail. The motor of the Mirak III was called the "egg motor" by some because they thought it resembled the egg of a prehistoric bird that had been unearthed the previous year in Madagascar. It was technically called the 160/32 motor because it consumed 160 grams (5.6 oz) of fuel per second and provided thrust of 32 kg (70 lbs). With a fully

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[23]Though this was praised as the first liquid fueled rocket flight in the World, at least two others, the American Robert Goddard and the German Friedrich Sander, had flown such rockets in secret in the late 1920s. Winter, *Prelude*. 37.

[24]Winter, *Prelude*. 42. Winter does not identify this as the Frau im Mond rocket launcher. However, there is no doubt about this fact.

[25]Nitrogen was used to force fuel into the combustion chamber, but oxygen entered the engine under its own power. Oxygen occurs naturally in a gaseous state. When artificially generated liquid oxygen (LOX) attempts to attain its natural state, it produces high pressure gaseous oxygen. This pressure is used in rocketry to force the oxidizer (LOX) into the engine.

fueled weight of only about 20 lbs, the Mirak III was theoretically capable of achieving an altitude of three miles.[26]

On the 10th of May, the Mirak III was on the stand undergoing a static test when it broke free of the stand. Without a parachute, the rocket ascended 60 feet before crashing to the ground. Following its first successful flight, the rocket was repaired and dramatically renamed the Repulsor I, after the space rocket in an 1897 science fiction novel. The Repulsor II was launched nine days later and, after flying 150-200 feet, the pyrotechnic parachute release functioned perfectly. Repulsor III flew the following month to astoundingly new heights. Of the four successful flights logged that June, the most impressive claimed a 640m ascent (2100 feet), ten times higher than any previous test launch. Still, parachute problems plagued the team.[27]

Though they were excited about their successful flights, rockets were incredibly expensive and funds were scarce. Every time a rocket was shot into the air, regardless of the success or failure of the flight, a huge investment vanished in flames. To increase the chance that each test flight would provide valuable information, the Germans remained committed to static testing. If something in the engine failed, the rocket team could examine the rocket, find out what the problem had been, and learn from their mistake. Otherwise an expensive engine, fuel tanks, and other instruments would likely be destroyed with little evidence of what had gone wrong.

Static testing of the Repulsor IV rocket designs began in August of 1931. For increased flight stability, the new rocket utilized the one stick design of the earlier Miraks (See HAER No. AL-129-A-23). The engine and rocket functioned so soundly that the team focussed development efforts for the next year almost exclusively on this design. The Repulsor IV rocket flew from the Raketenflugplatz to greater and greater heights during the following year, reaching a top altitude of 1.6 kilometers.[28]

Ley's private notes provide an overview of the work preformed during the first year of rocket flying at the Raketenflugplatz. By May 1932 there had been more than 270 static tests and eighty-seven rocket flights, twenty-three demonstrations for clubs and societies, and nine for publicity.[29] Among the visitors to the RFP were Edward Pendray, a founder of the American Interplanetary Society and Dimitri Marianoff, the

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[26]Winter, *Prelude*. 120.

[27]Winter, *Prelude*, Appendix.

[28]Winter, *Prelude*. 43, 120.

[29]Winter, *Prelude*, 43.

son-in-law of Albert Einstein. In a 1944 biography of Einstein, Marianoff explained his impression of the men at Raketenflugplatz.

> The rocket airdrome consisted of a few starkly simple barracks and many workshops. The impression you took away with you was the frenzied devotion of Nebel's men to their work. Most of them were (like) officers living under military discipline. Later I learned that he and his staff lived like hermits. Not one of these men was married, none of them smoked or drank. They belonged exclusively to a world dominated by one single wholehearted idea.[30]

Despite the rocket team's enthusiasm and devotion to its cause, bad luck and a worsening economy stifled progress at the RFP. An accident at the Raketenflugplatz occurred in October, when a one-stick Repulsor strayed off course, the parachute failed, and the rocket crashed into a building owned by the police. The following month, severe restrictions were placed on the group, limiting the size of their rockets and confining flights to workdays between 7am and 3pm, and then only if the wind was calm. By 1932, the flow of money had slowed to a trickle. Following the economic collapse of central Europe, membership in the VfR dropped below 300, and even the wealthiest patrons withdrew support.

In desperation, Nebel approached the Army for funding. Though he promised no money, Walter Dornberger, head of Army rocket development, agreed to host a demonstration at Kummersdorf, where the Army had begun research on solid and liquid-propellant rockets. Nebel took his brightest young designers, Klaus Riedel and Wernher von Braun, to shoot off one of their large, water-cooled one-stick repulsors. The impressive rocket was 12 feet tall, weighed 45 pounds when loaded with fuel, and claimed a thrust of 130 pounds. In a disastrous demonstration, the rocket rose vertically only about 100 feet before swerving horizontally into the nearby forest.[31]

The Army group was highly disappointed. New to rocketry, they hoped to learn valuable information from the experience of the Raketenflugplatz men. But the VfR lacked money to purchase expensive instrumentation and recording devices, so they had

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[30]Winter, *Prelude*, 42. quoting Dimitri Marinoff with Palma Wayne, *Einstein, an Intimate Study of a Great Man*. Garden City, New York: Doubleday, Doran and Co., Inc., 115.

[31]Dornberger, *V-2*, 31-2.

confronted problems on a trial and error basie. At their test stand in North Berlin, the VfR group had virtually no instrumentation. A dynamometer crudely measured thrust, and pressure gauges were located on the propellant and nitrogen tanks, but they did little to advance rocket development on scientific grounds. In his 1952 book *V-2*, Dornberger explained the ambitious desire of Army Ordnance:

> We wanted to advance the practice of rocket building through scientific thoroughnees. We wanted thrust-time curves of the performance of rocket motors. We wanted to know what fuel consumption per second we had to allow for, what fuel mixture would be best, how to deal with the temperatures occurring in the process, what types of injection, combustion-chamber shape, and exhaust nozzle would yield the best performance.[32]

2.5 Army Ordnance Liquid-Propellant Rocket Development at Kummersdorf.

Between 1932 and 1938, at the Kummersdorf Proving Ground, engineers of the Army Ordnance improved rocket engines and propulsion systems through static teeting with an emphasie on instrumentation. By monitoring thrust, and the temperature, flow, and pressure of propellants fed into the rocket, the Ordnance team quickly advanced the technology of rocketry. Before rushing into a development program, the Army had wieely explored the state of the art by merely observing the progress of amateur and private rocketeere, like the men of the VfR and Heylandt.

They next contracted Paul Heylandt's company in December of 1931 to conduct experiments for determining the ideal expansion nozzle shape, for they knew that the nozzle (where exhaust escapes the rocket) could theoretically add significant thrust.[33] The results were surprising: information from transducers placed on a variety of nozzles showed that the widest nozzle tested

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[32]Dornberger, *V-2*, 21.

[33]In fact the nozzle of the Space Shuttle main engines add about 80% to the thruet generated in the combustion chambers. This is known as the C (or K) factor in the theoretical calculation of rocket thrust: T=P*A*C. Thrust = Pressure in the combustion chamber multiplied by the Area of the combustion chamber throat multiplied by the C factor.

(15%) was the most efficient. Prior to this test, most believed that the narrowest nozzle would be most efficient. The Army's small investment in empirically improving rocket engines had proven wise.

With this success, Army Ordnance planned to take liquid-propellant rocketry to a new level by directing generous funds to a mixture of in-house and contracted development. In June of 1932, plans for Kummersdorf's first liquid-propellant rocket engine test stand included provisions for generous amounts of instrumentation. That autumn, the Army negotiated a contract with Heylandt to construct a small steel 20kg thrust Lox/Alcohol engine for testing different propellant mixtures.[34] In October, Dornberger offered von Braun a contract to join the Army's ambitious rocket development program. With the new test stand under construction, and the ongoing relationship with Heylandt, it was evident that the Army was prepared to spend the money necessary to methodically and empirically solve the riddles of rocket design. Von Braun readily accepted the proposition and began work by the first of November. The same month, Walter Riedel, one of the Heylandt engineers that had worked with Valier on his liquid rocket car, also joined the Army's rocket team.

By mid-December the test stand was completed (See HAER No. AL-129-A-24 and HAER No. AL-129-A-25). By today's standards the test stand was small, but it was far advanced from the tiny stand at Raketenflugplatz. Three walls, twelve feet high and eighteen feet long, protected the heavy, cast iron stand from the weather. The fourth wall consisted of two metal doors, and the roof was retractable.[35] Dornberger's explanation of the test stand in his book *V-2* included a detailed account of the instrumentation and control methods typical at Kummersdorf.

> At the corners of the back wall there were openings at eye level, fitted with mirrors to enable the testing staff to observe the rocket motor. In the middle of the same wall were two iron hand-wheels, their shafts leading through the wall to (the) valves (of the propellant system). The place was full of switches, little valve handwheels, reducing valves, three-way cocks, electrical instruments, clocks, and rows of meters and other gadgets connected with the fuel tanks and to critical points of the combustion chamber that needed watching... Thin piano wires from the tanks led over rollers through the concrete wall

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[34] Dornberger, *V-2*, 28., Neufeld, 18,19,78, and photo following 82.

[35] Dornberger, *V-2*, 23-4.

> to instruments that would trace the graphs of fuel consumption during firing...
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> In the control room the engineer, Walter Riedel, stood on a narrow wooden grating, grasping two big steering wheels. When pressure was right in the spherical containers (holding liquid oxygen and alcohol, respectively) a turn of the wheels would open the two main valves and let the propellants into the combustion chamber. Riedel's eyes were on the meters. Beside him the mechanic Gruenow was regulating the flow of nitrogen from the pressure flasks into the tanks by handwheels controlling the reducing valves. He kept his eyes fixed on the quivering needles of the gauges showing tank pressures.[36]

This test stand was home to the development of the Ordnance team's first two rockets, the A-1 (Aggregate 1) and the A-2. The nosecone of the A-1 was a ninety pound gyroscope that spun like an artillery shell during flight. The engineers hoped that this rotation would keep the missile stabilized, but the rocket was simply too top heavy, so the A-1 was abandoned. A new design, the A-2, featured a gyroscope at the center of the rocket. The engineers at Kummersdorf spent two long years developing the 650 pound (300 kg thrust) engine and the propulsion system for the A-2 (See HAER No. AL-129-A-26 and HAER No. AL-129-A-27). The exhaustive testing at the static test stand paid dividends in December of 1934, when two A-2s were launched from Borkum Island in the North Sea. Both flights were successful, reaching a top height of 1.4 miles.[37]

While some engineers worked at perfecting the A-2 during 1934, others turned their attention to developing more powerful rocket engines. The next generation of engines, one with 2200 pounds of thrust and another with 3500 pounds, were too powerful for the original Kummersdorf test stand, so the Army built two larger stands. One was for engine testing. The other was built for future static tests of the A-3 rocket, which was to be twenty-five feet long (See HAER No. AL-129-A-28).

In 1935, during the early development of the A-3, the Army realized that it would soon need to find a new home for rocketry. The Kummersdorf test range was only twenty miles from the heart

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[36]Dornberger, *V-2*, 24-25.

[37]Dornberger, *V-2*, 36., Huzel, *From Peenemuende to Cape Canaveral*, 235.

of Berlin. There was little room for expansion, and the conspicuous sound of engine tests was beginning to draw attention to the Army's secret development project. In April of 1936, Army Colonel Becker and Air Force General Kesselring agreed to begin construction of a new center for Army and Air Force rocketry at an isolated peninsula on the Baltic coast, a place called Peenemuende.

During construction of Peenemuende facilities from 1937 to 1939, A-3 development continued at Kummersdorf. Like the A-1 and A-2, the A-3 used liquid oxygen as an oxidizer and a mixture of 75% alcohol and 25% water as fuel. In the same manner as its predecessor, the propellants of the A-3 were forced to the engine by high pressure gaseous nitrogen. Though it had many similarities to the earlier Kummersdorf rockets, the A-3 was much larger than the A-2. This caused many problems for the Army's rocket team, for the twenty-five foot rocket proved much harder to control than its smaller cousin.

Expecting this phenomenon, the engineers designed a new control system for the A-3. Instead of one large gyroscope, the new rocket had three small ones. The three gyroscopes corresponded to pitch, roll, and yaw; the three directions that a rocket can divert from its flight path.[38] When the A-3 strayed in one of these directions, the corresponding gyroscope would move slightly, sending a signal to rudders in the exhaust jet. Theoretically, the movement of the rudders would divert the exhaust and send the A-3 back on course. Since most flights were dismal failures, the rocket team reworked the A-3 to incorporate improved guidance technology that was being developed for the A-4; the rocket that later became famous by the name V-2. The A-3 with A-4 guidance technology was named A-5.[39]

2.6 Peenemuende and A-4 (V-2) Rocket Development

In the Fall of 1939, England and France declared war on the Third Reich in response to Germany's Blitzkrieg attack on Poland. Field Marshal von Brauchtisch, the commander in chief of the German Army, assigned Peenemuende 'highest priority', but Adolph Hitler was not so enthusiastic. Emboldened by the lightning-fast conquest of Poland, he slashed Peenemuende funding, stating that he would need no rockets for the war against France and England. His skepticism was rational. Though rocketry was a potentially devastating weapon, it was still in a fledgling state. When World War II began, the German propulsion engineers at Peenemuende had barely begun testing prototype rocket engines for

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[38]Pitch is a tilting forward or back, Yaw is tilting left or right, Roll is twisting about the longitudinal axis of the rocket.

[39]Huzel, 236.

the A-4. Guidance engineers at Kummersdorf were still trying to refine steering technology for the A-5. It would take sustained effort over many years before the A-4 was to ready to mass produce as a weapon of war (See HAER No. AL-129-A-29).

Despite strains on the German economy during the war, the Army rocket project at Peenemuende was a massive, well-funded undertaking. From designing to test launching, Several hundred technicians and engineers developed all aspects of the A-4 at this site on the Baltic coast. They designed, manufactured, and calibrated components for the A-4 rocket. They assembled the engine, tested, and refined it at their extensive testing complex. The engineers at Peenemuende developed the A-4 propulsion system at their colossal Pruefstand I (See HAER No. AL-129-A-30 and HAER No. AL-129-A-31). Even more immense was the Pruefstand VII complex at Peenemuende where engineers and technicians assembled, inspected, and static fired the completed rockets. During static firings at Pruefstand VII, engineers monitored not only the propulsion system, but also the guidance system of the A-4. There were twelve pruefstands in the test complex, allowing rocket scientists to experiment with alternative fuels, components, and engines; to cold calibrate A-4 engine components; to static fire combustion chambers, engines, and completed rockets; and to test launch their rockets.

Control and instrumentation changed dramatically at Peenemuende. During early development of the A-4 engine at Pruefstand I, propellants were controlled by the traditional method of manually turning valve hand wheels (See HAER No. AL-129-A-32 and HAER No. AL-129-A-33). Gradually, analog electronics were introduced to control propellant flow. By the time full rocket testing began at Pruefstand VII, propellant control was operated at a remote location using analog electronics exclusively. The design engineers attempted to remove human error from the control process. This simplification of the launch sequence was essential to making the A-4 an efficient weapon.

At Peenemuende, the Army also extended its commitment to instrumentation. To the gauges, mercury tubes, and simple recorders employed at Kummersdorf, the engineers added high speed recorders to more accurately measure the change over time of temperatures, pressures, and flow rates during test runs. In each recorder, an ink pen responded to changes in the propellant system by moving slightly. Paper moved steadily past the pen, providing a record of one variable in the system during a test. The measurement staff at Pruefstand VII also introduced oscilloscopes to monitor and study the behavior of higher frequency changes like vibration and critical pressures. Many values of less significance were still recorded by photographing gages and mercury tubes at intervals of several seconds.[40]

In 1943, following several failed launch attempts, the fourth prototype A-4 flew dramatically from the Peenemuende launch site. Following this first successful flight, the scientists were ecstatic. The turbopump worked perfectly, forcing propellants from their tanks at a rate far greater than the pressurized nitrogen system used on all previous rocket designs. With additional testing, the A-4 fuel-injection and guidance systems would be ready for production. But, before the rocket engineers could fix these problems, their attention was diverted by events far from Germany.

By the Summer of 1943, the Allies advanced toward Germany from all directions. In the South, General Patton took North Africa. In the Atlantic, the Allies sank over half of the German U-Boats. From the East, Stalin's forces advanced across the Ukraine.[41] With Armies retreating, Hitler returned his attention to the Peenemuende team. In desperation, the Fuhrer threw Germany's remaining strength and resources into the mass production of the A-4, which he renamed the V-2: Vengeance Rocket II.

Aggregate (full rocket) static testing had been an important step in the development of the V-2, but the hurried fabrication pace precluded this step for the mass produced V-2 rocket. Some engines were static fired, but for the overwhelming majority of V-2s, testing was reduced to cold-calibration of components (Pruefstand V) and firing individual combustion chambers (Pruefstand VIII). V-2 components were shipped to the Mittlewerk where prisoners assembled the rockets. The Army launched the completed V-2s as quickly as they could be produced.

Because of Hitler's order for retaliation against England, the V-2 had been rushed into production before it was ready. The ambitious A-4 development project had ended prematurely, so design engineers were forced to push a production model based on unrefined propulsion and guidance components. The rocket was heavy, clumsy and unreliable.

Though the V-2 had scant effect on the war, it had profound impact on the future of the World. The V-2 became the prototype for Cold War American and Soviet missiles and space launch vehicles.

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[40]Interview with Joe Gonzallas, measurements and instrumentation expert at White Sands, N.M., Redstone Arsenal, and Cape Kennedy during testing of the V-2, Redstone, Jupiter, and Saturn rockets., September, 1995.

[41]Davidson, ed., *Nation of Nations*, 1040.

3 UNITED STATES ARMY ROCKETRY: THE REDSTONE

3.1 Studying the V-2, 1945-1950

The Allied victory rested on cooperation between nations that had committed to win at any cost. Soldiers fought tirelessly to turn back the expansion of the German Empire. Citizens of the Allied countries made tremendous sacrifices at home to aid troops at the front. Domestic industries slowed to a halt: large electrical, automotive, and aerospace corporations, founded to manufacture modern conveniences, changed direction to manufacture war materials, tanks, ships, airplanes, and other weapons. Cooperation between military and industry was not new. In previous wars, large manufacturers like Henry Ford had converted production to aid the military. However, unlike other wars, when World War II drew to a close, military and industry did not divorce. Rather, the military-industrial complex expanded to develop and refine the new weapons created during the war.

After learning of the German V-1 and V-2 weapons developed at Peenemuende, the Army Ordnance Department presented a contract (DA-30-115-ORD-1768) to the General Electric Company in November, 1944 to research and develop long-range ballistic missiles for use against ground targets and high altitude aircrafts.[42] But, because liquid rocket technology was still a new and unrefined field, the Army planned to spend about five years experimenting with rocketry before rushing into the mass production of any "promising new weapons".[43]

As the war in Europe drew to a close, the Americans, British, and Soviets sought technological reparations from the wasted German nation. In separate missions, the Big Three confiscated German war technology and recruited German engineers and scientists. A group of American Army scientists and engineers, known as the Alsos Mission, followed closely behind the frontline troops that conquered western Germany. They swept across the land, searching for scientists, engineers, and hardware from the atomic bomb, V-1, and V-2 programs. Though

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[42]Bullard, *History*, 8, the contract was made on 20 November, 1944.

[43]Devorkin, *Science*, 61. quoting from the transcript of a "Joint Army-Navy Meeting on Army Ordnance Research and Development, the Pentagon, 26 June 1946." Because of this cautious attitude, most of the General Electric Hermes designs never left the drawing board.

they found no evidence of the feared German atomic bomb project, the German rocket team was easy to find.[44]

In fact, the rocket team actually sought and located the Americans. They had organized themselves at a retreat in the mountains and sent von Braun's English-speaking younger brother to approach the Americans. Bernhard Tessman, the main test stand and facilities design engineer at Peenemuende, and Deiter Huzel, another Peenemuender, had buried tons of V-2 documents in a mine for use as a bargaining chip with the Americans. In association with Project Paperclip, Colonel H.N. Toftoy of the U.S. Army Ordnance Corps (later Commander of ARGMA at the Redstone Arsenal) extended contracts to selected rocket specialists from Peenemuende in the spring and summer of 1945. By the end of the year, 118 members of the German rocket team, hundreds of V-2 components, and tons of Peenemuende documentation were shipped to the United States.

General Electric had been studying the V-2 for about a year in conjunction with Project Hermes, so they were the obvious choice to head the V-2 launch program in the southern New Mexico desert at the Army's White Sands Proving Ground. Their mission under this new contract (DA-30-115-ORD-23) was described as follows:

> In general this work will consist of the firing of a number of German rockets... Also included is the necessary work in connection with the actual firing such as transporting, handling, unpacking, classifying (identifying), reconditioning, and testing of components of German rockets as well as assembling and testing subassemblies and complete rockets, manufacture of new parts, modification of existing parts, conducting special tests, constructing temporary test equipment not available at the Proving Ground, procuring and handling of propellants and supervision of the launching of rockets.

In this task, General Electric was aided by the expertise of about 100 members of the German rocket team stationed about 60 miles to the South at Fort Bliss, Texas (See HAER No. AL-129-A-34).

The Germans, excited about coming to America to continue their work developing large rockets, quickly became disillusioned. Upon signing the contracts with Colonel Toftoy, they envisioned continuing the unfinished development of the A-4 (V-2) that had begun in Peenemuende, then redesigning and

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[44]For a controversial account of the Alsos Mission, see Linda Hunt, *Secret Agenda*.

developing the A-9 space rocket. Unforeseen by the German rocket pioneers, the American defense budget was slashed continuously in the post-war 1940s, and the Army adopted a conservative time-frame for developing the first generation of American liquid-fueled rockets.

Consequently, the German rocket pioneers were charged with less challenging tasks. They served as consultants to American engineers and scientists involved in guided missile and space science research. Instead of refining the V-2, they assisted Americans in the monotonous task of assembling, inspecting and launching the old V-2s. Though the work seemed redundant to the German team, the testing and launching of V-2s provided valuable experience for Americans new to the field of liquid propellant-rocketry.[45]

At White Sands, General Electric aggregate (full missile) static tested the first completed V-2 in March, 1946. After this firing, the rest of the V-2s were launched without this preliminary test. There were several related reasons for this. The Peenemuende engineers had not designed the components of the V-2 for long term storage, and in the desert of New Mexico, over a year after fabrication, V-2 components had begun to deteriorate. Since many of the V-2s launched at White Sands carried scientific experiments designed by top American scientists from industry and academia, America simply could not afford to subject the invaluable V-2s to the punishment of a static test. This was not without precedent, for at the end of WWII, V-2s had been launched without static testing. With the allies advancing, there had been no time for aggregate testing, so after engine component tests, the rockets were quickly assembled and launched.

Eventually, the Germans were assigned to more enticing tasks. Some conducted studies and proposed their own new guided missile designs for the Hermes project; others went to work for North American Aviation, a California-based company that was designing a new rocket engine based on the V-2.[46] As the decade closed, the fortunes of the German team rose even higher.

3.2 Huntsville, Alabama: A New Home for Army Rocketry

After years of cautious research on missiles, the Army boldly prepared to meet its future military needs. In 1948, Col. H.N. Toftoy, chief of the Rocket Branch in the Office, Chief of Ordnance, complained that the Ordnance Department could not meet

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[45]Oral History Interviews by the author: Konrad Dannenberg, June, 1995, Bernhard Tessman and Karl Heimberg, August, 1995.

[46]Frederick Ordway III, The Rocket Team: Chapter 18,"V-2s in the Desert," 344-362.

its responsibilities to research and develop guided missiles and rockets. Research and development facilities were scattered and inadequate, funding was poor, and there was a shortage of skilled personnel. The Ordnance Department agreed with Toftoy's suggestion that these problems could be solved by establishing a single arsenal devoted to rocket development. [47]

After a survey of possible locations, the Ordnance Department proposed the Redstone Arsenal in Huntsville, Alabama as the Ordnance Guided Missile facilities. The Secretary of the Army approved the proposition on 28 October, 1949. Although powerful Alabama Senator Alan Sparkman certainly influenced the decision, the location was adequate in its own right. The town was remote, but only seventy miles from Birmingham, the industrial capital of the South. The Redstone Arsenal was huge, and its extensive facilities, built during the Second World War to manufacture chemical weapons, lie vacant since 1946. Complimenting a rail link to Birmingham, the Tennessee River formed the southern border of the arsenal, providing access for barge travel. The industry, transportation, labor, and facilities of the area justified the choice of Redstone Arsenal as the new home for Army missile development.

On April 15, 1950, the Ordnance Guided Missile Center (OGMC) was formally established at the Redstone Arsenal. That summer and fall, members of the German rocket team and their families traveled from Fort Bliss, Texas to Huntsville, a small town in Northern Alabama where the foothills of Appalachia give way to the great plan. Through the years, the OGMC was used much like Kummersdorf and later Peenemuende, where the German Army had centralized its entire rocket development program. But, unlike the German *Alles unter einem Dach* (all under one roof) philosophy, America was committed to the contractor system. Whereas the Peenemuende team had designed and constructed the components of the engine, propulsion and guidance systems, and assembled, tested and launched the rockets all at the same location, activity at the OGMC was not all-inclusive. The German and American engineers at the OGMC designed and tested the propulsion and guidance systems, but most components were manufactured by independent contractors. Though prototype missiles were constructed at the Redstone Arsenal, the Chrysler Corporation mass produced them near Detroit, Michigan. The Guided Missile Center inspected and tested the propulsion and guidance systems, but missiles were test launched at the Army's White Sands Proving Ground and at the Atlantic Test Range (now called Cape Kennedy).[48]

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[47]Bullard, 17-18.

[48]AL-9, 33-4., Bullard, 18-23.

In 1950, after five years studying rocket designs, assessing the needs of U.S. forces, and planning Cold War strategy, the Army took two steps toward developing its first large missile. The Office, Chief of Ordnance directed the Guided Missile Center in July to design and develop several prototype missiles that would carry a 3000 lb warhead, 500 miles. Two months later, the Ordnance department transferred the Hermes C1 missile contract from General Electric to the OGMC. In doing so, the responsibility for engineering, designing, constructing, and testing the missile, was transferred from private industry to the military.[49]

Despite the high priority placed on the project, the Chief of Ordnance ordered that activity and funding during fiscal year 1951 be limited to that prescribed in the July preliminary study. By the end of 1950 the missile center team, headed by Wernher von Braun, completed its preliminary study of rocket designs. Of several designs submitted, the North American Aviation engine (based on the V-2 engine) was refined the furthest and judged most satisfactory. The best guidance system was the OGMC's own inertial guidance system, again because it was based on principles developed ten years earlier in Peenemuende, rather than on new, but unrefined technology.[50] One could deduce that these propulsion and guidance systems were chosen only because von Braun was partial, but this is only half true. Von Braun was partial because he knew that the systems were tried and proven. New designs for propelling and guiding rockets held great potential, but years would pass before they could be made dependable enough for production.

3.3 Inside the REDSTONE Missile

A number of innovations made the REDSTONE fly further and more accurately than its predecessor, the V-2. The engine and missile body of the REDSTONE were much lighter those of the V-2. When Hitler had desperately ordered the V-2 rushed into mass production late in World War II, Peenemuende engineers had not yet perfected the single plate injector (through which propellants are injected into the combustion chamber of the motor). In the post-war calm, North American Aviation replaced the bulky V-2 eighteen-pot injector with a single plate injector, making the NA-75-110 (REDSTONE) engine much smaller and lighter. The addition of explosive bolts between the warhead and the propulsion unit allowed the warhead to travel optimum distance without carrying along the heavy booster. Since the booster unit was discarded at high altitude, the integrity of the body during

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[49]Bullard, 19-25.

[50]Bullard, 29-31.

descent was of no concern. Only the warhead unit needed to be built of steel to withstand descent through the atmosphere, so a light aluminum fuselage replaced the heavy body and internal tanks of the V-2.[51] In addition to advances in the propulsion system and structural design of the missile, engineers also refined the system that guided the missile through the air.

Despite many improvements over the V-2, the REDSTONE was essentially an enlarged and perfected version of its predecessor. The REDSTONE and V-2 guidance systems were based on the same principles. Three gyroscopes located in the top of the rocket related to the three directions that a rocket can move. In accordance with Newton's first law of motion, gyroscopes maintain their position unless acted on by a outside force. The yaw gyroscope sensed the missile turning to the left or right of the prescribed trajectory. The pitch gyroscope reacted to the rocket tilting forward or back, for an increased or decreased flight angle causes a missile to exceed or fall short of its target. A roll gyro was included to measure and correct the motion of the missile turning about its longitudinal axis. An on-board analog computer processed information from the gyroscopes and relayed signals to four rudders located at the aft of the tail unit in the exhaust of the engine. These rudders moved to correct the flight path of the missile.

The REDSTONE propulsion system also ran on the same principle as its predecessor, the V-2. To propel the REDSTONE quickly into the upper atmosphere, over 5000 gallons of propellants had to be pumped from the liquid oxygen (LOX) and alcohol tanks and burned in less than two minutes. To provide the necessary flow rate, the REDSTONE included a small steam driven turbopump, much like the one developed at Peenemuende. Steam was produced by forcing a large quantity of hydrogen peroxide into a small steam generator (or "Pot") where the H2O2 mixed with potassium permanganate pellets, producing high-pressure, high-temperature steam.

Steam drove the turbopump (a turbine attached to twin pumps) that pulled LOX and alcohol from their tanks at about 170 and 200 lb/sec, respectively. Alcohol was pumped through the double walls of the combustion chamber for cooling purposes before reaching the injector plate. The LOX and alcohol ignited in the combustion chamber as they mixed in a spray from the injector plate. The tremendous heat and pressure generated in the combustion chamber exited the engine through the throat of the exhaust nozzle, producing the rocket's powerful thrust.

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[51]These facts are common knowledge. For more on the V-2 see unpublished manual: *The Missile A-4 Series B: Description of Missile as of Jan. 2, 1945*. trans. Schenectady, New York: General Electric. On REDSTONE see unpublished book: *This is REDSTONE*. Chrysler Corporation Missile Division

The propulsion system controlled itself automatically after liftoff, like an automobile with cruise control. A small analog computer regulated the speed of the turbopump and thus the flow of propellants into the engine. When the turbine speed dropped below a set rate, a signal caused an increase in the pressure of the hydrogen peroxide tank. This forced hydrogen peroxide into the pot at a greater rate, producing higher pressure steam that accelerated the spin of the turbopump. As propellants pumped into the engine at a greater flow rate, the thrust of the missile rose to acceptable levels. When the turbine started to turn too quickly, the brain of the engine decreased the pressure in the peroxide tank.

Though the REDSTONE propulsion system ran basically on the same principles as an automobile, ignition in the two vehicles was executed in a markedly different manner. To start an automobile, you merely enter the vehicle, turn the key and drive off; the starting system is completely self-contained. The REDSTONE was started from a remote bunker about 100 yards away. Aside from the obvious safety concern, there was a more pressing reason for remote ignition. Rockets must be kept as light as possible; every extra ounce of weight aboard the vehicle detracts from its velocity and range. That is why all components in a rocket are constructed with the lightest materials available. Nothing is included in the missile unless it is absolutely essential during flight.

Thus, the fuel and electricity used to start the engine, the pneumatic system used to regulate pressure within the rocket, and all other pre-launch systems and components were located outside of the rooket when possible. A control engineer in a remote bunker initiated the launch sequence by merely pushing a button on the control panel. Electric signals raced along cables to the solenoid valves that restrained the igniter fuel. As the valves actuated, a small amount of alcohol and liquid oxygen were fed to the engine. Another signal sparked a pyrotechnic igniter located just below the injector in the combustion chamber. A thin wire in the chamber heated as the temperature rose. When the wire burned through, signals caused the main LOX, alcohol and hydrogen peroxide valves to open. Within seconds, the turbine was at full speed and the missile in flight.

3.4 Design and construction of the first REDSTONE and the Interim Ignition Test Stand

When the Fort Bliss group moved to Redstone Arsenal, it continued development of the Ramjet rocket that had consumed most of its efforts in the desert of the American Southwest. In early 1951, priority rapidly switched from the Ramjet to the HERMES C-1 project, the 500 mile missile. In February, Colonel Toftoy instructed the Guided Missile Center to change its payload requirement from 1500-3000 pounds to 6900 pounds, enabling the

HERMES C-1 missile to carry the smallest of the atomic warheads developed by the Atomic Energy Commission.[52] By March, a plan for developing the HERMES C-1 had emerged. The missile was now technically called the XSSM-G-14, but it was more commonly referred to as the MAJOR missile. The project was given priority 1-A. To fulfill the accelerated goals for producing a series of developmental missiles, the Army split responsibility between the Arsenal and private industry. The Arsenal was to use existing components when designing the missile. If none were available, design engineers were to write up specifications, and hire private contractors to build components. In special cases, prototype components could be built at the arsenal and later turned over to private production. Of the proposed 75 missiles of the developmental series, the first twenty-four were to be assembled at the arsenal, the remainder to be fabricated by a defense contractor. [53]

Throughout 1951, engineers at the arsenal designed and developed the propulsion system, guidance system, and structure of the missile.[54] The Aerodynamics and Structures Branch (A+S) of the OGMC designed the propulsion system around the XLR43-NA-1 engine that was being modified by North American Aviation for the needs of the Army. Engineers of the A+S also designed the fuselage, tail and warhead sections, choosing the materials and space distribution for cables and instruments throughout the missile. Another team continued work perfecting the design of the guidance system. [55]

In the Fall of 1951, after fulfilling its obligation to develop the XLR43-NA-1 rocket engine the U.S. Air Force project MX-770 (the NAVAHO missile), North American Aviation began development testing of the powerplant modified for the special requirements of the Redstone Arsenal's XSSM-G-14 (MAJOR) missile. The modified NAVAHO engine was named NAA-75-110.[56] The MAJOR Project demanded that the engine's burn time be extended from 60

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[52]Bullard, 34.

[53]Bullard, 39-40.

[54]Bullard, 39-40.

[55]OGMC, Aerodynamics and Structures Branch, "Monthly Report #9 (MR-9)", 20 July 1951, also MR-10, MR-11, MR-12 and MR-13; August-November 1951.

[56]The name NAA-75-110 referred to the manufacturer, North American Aviation; the thrust, 75,000 pounds; and the engine burn time, 110 seconds.

to 110 seconds and that the ignition sequence be fully automatic after actuation of the start button.[57]

During the Spring of 1952, engineers at the NAA Aerophysics Laboratory in Santa Suzanna, California static tested prototype 75-110 engines ("A" series) and began introducing components of the production ("B") series as they became available. In June, NAA engineers static fired the first complete production engine, B001.[58] Within six weeks, a production engine had passed the qualification test required by the OGMC. Between July 21st and 26th, a "B" series engine endured four full duration (110 second) runs without a breakdown. The engine was packaged and readied for shipment to the OGMC for inspection and missile assembly.[59]

After years of designing components and systems for the new rocket, the staff at the Redstone Arsenal was prepared for its next task: fabrication of the first XSSM-A-14 missile, now renamed REDSTONE. In September 1952, the Ordnance Department reorganized its Huntsville facility in accordance with its future tasks. The OGMC was renamed the Ordnance Missile Laboratories with eight subdivisions: Aerodynamics and Flight Mechanics, Structures and Mechanics Laboratory, Fabrication and Assembly, Launching and Handling, Guidance and Control, Computations Laboratory, Test Laboratory, and the Missile Firing Laboratory. These eight laboratories were to handle all aspects of REDSTONE development, from design to launch.[60]

When assembly of the first REDSTONE began in the autumn of 1952, the Army was faced with a dilemma. Refining the missile depended on a propulsion test stand, but an inflexible law stated that no funds for research and development could be spent constructing facilities - no matter how essential the facility was to developing the missile. The Ordnance Test Laboratory (Test Lab) could not afford to wait for money to go through the bureaucracy of Washington. The first prototype missile would be ready by spring, long before any money arrived. Rather than wait, von Braun directed his designers to design an interim test

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[57]Rocketdyne, a division of NAA, Inc., "Quarterly Report of Progress on Contract DA-04-495-ORD-53 for period ending 19 OCT 51," Canoga Park, CA., 1-7,16.

[58]Rocketdyne," Quarterly Progress of Progress on Contract DA-04-495-ORD-53 Rocket Power Plant NA Model 75-110 for Period Ending 19 July 1952," Downey, CA., 8-13.

[59]North American Aviation," Qualification Test Results of Prototype NAA 74-110 Rocket Engine," Downey, Ca., 1-5.

[60]HAER-AL-9, 34-5., Ordnance Missile Laboratories,"Progress Report No. 12: XSSM-A-14 (REDSTONE) Missile, 1 April-30 June 1954," OC-DOA, Redstone Arsenal, Huntsville, Alabama, 3-100.

stand to meet the minimum needs of the Test Lab while they waited for funding and construction of permanent facilities. The limit was set at $25,000, the maximum amount allowed for constructing buildings without Congressional approval.

When the Fabrication and Assembly Lab finished building the first REDSTONE propulsion unit (the entire missile with the exception of the guidance system and warhead) in the spring of 1953, the Interim Test Stand was ready. Welders of the mechanical support shop had constructed the stand using metal salvaged from around the arsenal. The small structure was anchored to a large, reinforced-concrete foundation that had absorbed nearly all of the $25,000. There was no money available for constructing bunkers to house the control and recording instruments, so two railroad tank cars that had been used to transport chemicals at the arsenal during the war were cleaned out, modified to house equipment, and buried under a mound of earth about 100 yards from the test stand. The Test Lab transferred recording instruments from the abandoned RAMJET project and installed them in the railroad tanks along with equipment that had been designed to control the REDSTONE propulsion system (See Drawing 6 of 7).[61]

Meager funding mandated improvisation in the early days of REDSTONE development. Bernhard Tessman, test facility designer at Peenemuende and Redstone Arsenal, explained that there were no elaborate blue prints made for the interim stand. Designs were simply sketched on scrap paper. Later, Mr. Tessman and Clyde Vandersee, head of the mechanical support shop (the shop that constructed the stand), drove around the arsenal looking for material to fit their structural needs. Mr. Tessman and Karl Heimberg, director of the Test Lab for the majority of REDSTONE development, also explained that the original flame deflector was constructed from sheets of carbon-graphite attached to a base of temperature-resistant concrete. The carbon-graphite material had been developed in Germany for use in the guidance rudders to withstand the extreme heat of the exhaust jet. Various electrioal engineers and technicians of the test lab can trace the origin of the cables that linked the control and recording instruments to the test stand and missile. During World War II, these cables served to control barrel movement on the Army's heavy artillery guns. Early members of the test lab had to cut corners and make creative use of the materials that were available to them.[62]

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[61]Oral History Interviews conducted by the author with Bill Grafton and Jack Connor, August, 1995.

[62]Oral History Interviews by the author with Bernard Tessman and Karl Heimberg in July of 1995, and others, June-August, 1995.

Interim Test Facilities were built of salvaged material as a temporary measure for testing the REDSTONE propulsion system while the Test Lab waited for funding and construction of a permanent facility. Despite these humble beginnings, the Interim Stand endured nearly a decade of continuous use. The stand grew with the missile, serving the expanding needs of the Test Lab during the three phases of REDSTONE development: REDSTONE, JUPITER-C,and MERCURY-REDSTONE. The technicians of the Test Lab and Support Shop modified the Interim Stand and associated facilities to meet the requirements of special tests and the day-to-day needs of the crew (See Drawing 7 of 7).

3.5 The Interim Stand and Early REDSTONE Development, 1953-55

During the earliest period of development, roughly 1953-1955, engineers and technicians tested the prototype REDSTONE missile propulsion system at the interim test stand. Design engineers used data from these short duration tests to refine the components and systems of the early REDSTONE. The second distinctive period began in 1956, when the Army reorganized its missile development program. After February 1, when the Army Ballistic Missile Agency (ABMA) took over responsibility for the REDSTONE Guided Missile System, engineers continued testing the missile, but work expanded to meet the demands of the tactical REDSTONE. Also during the ABMA period, engineers modified the Interim Stand and the REDSTONE to aid in the development of the JUPITER missile, the Army's next step in liquid rocket development. In the third period, 1958-1960, engineers used the Interim Stand to "manrate" the MERCURY-REDSTONE propulsion unit. Modified components were tested and refined at the Interim Stand, and before fabrication, they sustained qualification tests. Finally, all of the MERCURY-REDSTONE flight vehicles sustained a full duration run at the Interim Stand before launching at Cape Canaveral.[63]

Propulsion testing at the Interim Stand was an important link in a long chain of events between constructing and launching the REDSTONE rocket. During the first two years of prototype REDSTONE development, the personnel of the Ordnance Missile Laboratories spent about seven months building, testing and launching each missile. After rigorous testing, REDSTONE contractors shipped their missile components to the OML at Redstone Arsenal. For about six weeks, the Fabrication and Assembly Lab constructed each missile for static firing. Next,

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[63]Oral History Interviews conducted by the author: James Pearson, Head of Mechanical Division, 1957-60; June-August, 1995, Charles Gillespie, Mechanical Division Foreman, 1956-60; June-August, 1995, see also, Appendix 1 and test reports in the Bibliography.

the lab delivered the missile to the Test Lab's Interim Test Stand, where it was inspected for about a week. Then, overall tests and several static runs of about 15 second duration lasted for about a month. The missile was dried for a few days in a vacuum chamber, then returned to the fabrication building.

The final assembly of each missile took about two and a half months. Then, after passing a month of final inspections, the missile was turned over to the Launching and Handling Laboratory. Launching and Handling spent about a week preparing the missile for shipping, and then loaded it onto a special airplane (called the Guppy, because of its odd shape) bound for Florida. After three weeks of preparations and final tests at the Atlantic Test Range, the Launching and Handling Lab fired the missile. Launches provided valuable information to the engineers that developed the REDSTONE guidance system, but most improvements on the propulsion system came from lessons learned at the Interim Test Stand, where engineers could evaluate the internal workings of the propulsion system while it was firmly anchored to the ground.

When the first REDSTONE missile was transferred to the Interim Stand, excitement filled the air. The personnel of the Ordnance Missile Laboratories had been working for two years with nothing tangible to show for their effort. The static run of the first prototype REDSTONE was a big event that everybody wanted to witness. Von Braun, propulsion system development engineers, Test Lab directors, Launching and Handling crew and, of course, the electrical and mechanical engineers and technicians of the Test Lab were all on hand to observe the launching procedure and the much awaited missile firing. As is typical of static tests, the pre-test checkouts and the launch sequence proceeded as if the missile was about to be launched, except that the rocket was restrained.

A crowd of thousands waited in anticipation. Many doubted that the small structure could withstand the force of the large missile that towered above it. Some thought the missile and stand would both go streaking into the sky, but the engineers who designed and constructed the stand were confident it would endure. Finally, inside the control bunker, the Control engineer pushed the ignition button. The missile responded with a deafening roar. A great cloud of smoke, red dirt, and debris rose and engulfed the missile. After about ten seconds, the engine fell silent. Slowly, as the cloud of dirt fell back to earth and the smoke cleared, the missile and stand reappeared - intact! (See HAER No. AL-129-A-37).[64]

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[64]Oral History Interviews conducted by the Author: Leon Ivy, May and June, 1995; Bill Grafton, August, 1995, Charles Gillespie, September, 1995.

During the first few firings, as the pre-test and launch sequences began to take shape, many designers and engineers were on hand to observe and discuss the procedure. The Launching and Handling crew participated in the first static-firings in preparation for the first launches at the Atlantic Test Range (today, Cape Kennedy). But after the first few missiles, the REDSTONE production and development pace began to accelerate. The design engineers were busy analyzing data from previous firings, isolating and refining weak components, and setting up parameters for future tests. With the Launching and Handling crew busy preparing and launching completed REDSTONEs at the Atlantic Test Range, the electrical and mechanical engineers and technicians of the Test Lab were left to run the day to day operations at the Interim Stand.

The REDSTONE missile system was comprised of mechanical and electrical components. When these components worked together in harmony, the results were spectacular. Mechanical and electrical engineers and technicians were hired to test the components and systems of the propulsion system in hopes that one day the system would run flawlessly. As the REDSTONE became more and more reliable over the years, it was modified to aid the JUPITER missile and the MERCURY manned spaceflight programs. At the Interim Test Stand, though the focus of the tests changed over the years, the duties of the electrical and mechanical crews remained essentially the same.

The Mechanical division worked on the physical components and systems of the missile. With the help of a crane operator, the mechanical division aligned and secured the missile in the stand. They performed tests on the pressure and fluid systems of the rocket, checked the function of valves in the missile, and removed and installed components on the engine for special tests as directed by the Test Lab. The head mechanical engineer directed the test procedure, though technically he was on the same organizational level as the heads of the two Electrical divisions at the stand.[65]

The two divisions of electrical engineers and technicians that worked at the Interim Stand were called Control and Instrumentation. After the missile was secure, the Control (also called Networks) group ran an electrical network that linked the missile to the control bunker. Through this network, the Control engineers operated the valves of the propulsion system. The Instrumentation crew installed transducers at various locations within the propulsion system. These transducers were linked to recorders in the remote instrumentation bunker, providing a reading of critical temperatures, pressures, flow rates, and vibrations from moment to moment during each firing; design

[65]Oral History Interviews by the author: Charles Gillespie and James Pearson June-August, 1995.

engineers needed this information to refine and perfect the propulsion system and its components.[66]

Although the Mechanical, Instrumentation, and Control groups had separate responsibilities, the three divisions worked together as a team to test each missile. Preparations typically began three or four days prior to the static firing when the missile arrived at the stand. With the help of a crane operator, the Mechanical division installed, aligned and secured the missile in the stand using four rocket retention bolts and brackets that held the missile just above the tail. Next, while the Control group ran the electrical network that linked the missile to a firing panel in the control tank (or bunker) (See Drawings 2 and 7 of 7), the Mechanical technicians purged all of the tanks in the missile. The Instrumentation crew calibrated and installed transducers. The technicians in the Mechanical division installed the ignitor and valve box, then pressurized the empty alcohol, liquid oxygen, and hydrogen peroxide systems and checked for leaks using soapy water.[67]

After completing the electrical network, the crew ran a series of checks called "functionals" or "components" to make certain that all of the components of the rocket propulsion system functioned properly. During the functional tests, the Control engineer actuated each solenoid valve in the launch sequence individually by flipping a switch in the control tank. A technician on the Test Stand observed the valves to verify actuation. The crew also checked the function of various emergency cutoff switches in the rocket and the emergency fire extinguishing (fire-ex) system located on and around the test stand. After checking and verifying each step in the launch sequence in individual "functional" tests, the crew ran "overall" or "sequence" tests.[68]

The overall test was essentially a dry run of the propulsion system launch sequence. The operation of each valve was displayed on sequence recorders in the control tank. Each valve was linked to a pen on the sequence recorder. As each valve actuated, its pen marked a tick on the sequence recorder chart. By checking the recorder chart, the engineers could tell which valves were actuating too soon, too late, or out of sequence. They adjusted the system and repeated overall tests until the charts revealed that all valves had actuated within narrow guidelines. In the early days of REDSTONE development, these tests were painfully numerous, but as the REDSTONE and its components were refined

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[66]Oral History Interview by the author, Frank Rutledge and Paul Artis, August, 1995.

[67]"Engineer's Log Book #1," 1954-55, 4-17.

[68]"Engineer's Log Book #1," 1954-55, 4-17.

over the years, the number of sequential tests steadily decreased.[69]

Engineers designed the REDSTONE propulsion system to be completely automatic during the launch sequence and in flight. This was done to make field operations as quick and efficient as possible. After prelaunch preparations, the control engineer merely pushed the launch button. With that simple action, the flow of propellants, ignition, and guidance all functioned without human intervention. But, many months of preparations went into making each REDSTONE run automatically. Functional tests fine-tuned individual components, and overall tests adjusted the sequence of the ignition and launch. After several successful dry runs, the missile was prepared for the next step, a restrained launch or "static firing".

The Test Lab fueling support staff arrived with an alcohol tank truck. After tanking about 2000 gallons of alcohol, the alcohol truck drove away and a liquid oxygen truck arrived.[70] Following LOX fueling, the crew tanked the hydrogen peroxide that powered the steam generator. Before each run everyone cleared the test area, and the control and instrumentation tanks were filled with only essential personnel: the head engineers, control technicians, and redline observers.

With everyone in position, the control engineer commanded a technician to push the firing button. The control engineer observed the missile through a periscope, his finger near a cutoff button in case he saw something go wrong. There were many people with access to cutoff switches other than the control engineer. Several crew members were stationed in "pill boxes" at remote locations around the missile to observe the exhaust jet from a number of angles. Each had a cutoff switch at their fingertips. Redline observers watched the behavior of critical transducers within the engine as displayed on recorders in the instrumentation bunker. Before the test they drew red lines across the screen corresponding to the minimum and maximum allowable values (of temperature or pressure). If the needle moved beyond the acceptable parameters, the technician hit the cutoff switch, no questions asked. [71]

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[69]Oral History Interviews by the author with Frank Rutledge, June and July, 1995; Charles Gillespie, August, 1995; and James Pearson, August, 1995.

[70]Liquid Oxygen was not stored at the Arsenal Test Lab until 1956. In the preceding years, liquid oxygen was obtained by rail from Birmingham, resulting in numerous delays.

[71] Redline Instruments: 1. Injector face temperature, 2. LOX tank pressure, 3. Alcohol tank pressure, 4. 750 PSI (Pounds per square inch) regulator pressure. 5. 450 PSI regulator pressure, 6.

Aside from about eight "redline" recorders, about twenty other recorders were located in the instrumentation tank (See Appendix III and Sheet 6 of 7). Each marked the behavior of a temperature, pressure, or flow rate within the propulsion system during the run. Additionally, there were several oscilloscopes in the bunker recording vibrations and pressures at different places in the engine, fuselage, or warhead unit. After a test, the charts from the recorders were examined by Data Reduction, a division of the Test Lab that translated the values on the chart into useful data. The test engineers used this data to calculate essential values like Specific Impulse and Thrust. Design engineers took the data one step further, using the information gained in static testing to isolate and improve weak components in the propulsion system.[72]

Typically, after two successful static tests, the missile was vacuum dried and returned to the fabrication building for final assembly and inspection. Then the Launching and Handling staff packaged the missile and shipped it to Florida. When the missile arrived at the Cape, the launch team began an inspection sequence similar to Interim Stand pre-test preparations. They installed the electrical network and ran functional and overall tests before fueling and launching the missile.[73]

During the early development of REDSTONE (1952-1955), the fabrication and testing process settled into a smooth routine. Over a hundred contractors contributed to the development of REDSTONE, but only three defense contractors built and tested nearly every component in the missile to the specifications of the Ordnance Guided Missile Laboratory: the engine by North American Aviation, the fuselage by Reynolds Metal Company, and electrical instruments by Ford Instrument Company.[74] The OGML Fabrication and Assembly Division assembled these components with others made "in house" by Army engineers in Huntsville, Alabama. Each missile was inspected and static tested at the Interim Test

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Turbine RPM (revolutions per minute), 7. LOX pump bearing temperature, 8. 3000 PSI. These were the most critical readings during the test. "REDSTONE Log Book #1," insert between pp 40 and 42. Interviews conducted by the author, Frank Rutledge, June and July, 1995., James Pearson, August, 1995.

[72]Oral History Interviews conducted by the Author. James Pearson, Frank Rutledge, and Charles Gillespie: June-August, 1995, Paul Artis and Bill Grafton: August, 1995.

[73]"REDSTONE Log Book No. 1," Interview by the Author, Edward Berger, July 1995, and Bill Grafton, August, 1995.

[74]ABMA, "Ordnance Guided Missile and Rocket Programs, Volume IV (REDSTONE), Supplement 1," 69-102.

Stand, then returned to the fabrication building for final assembly. The missiles were loaded on an airplane and flown to Florida where they were launched. [75]

In February of 1956 the Army reorganized its missile development branch. The Army Ballistic Missile Agency (ABMA) took over management of the REDSTONE and JUPITER missile projects, but the same rocket engineers in Huntsville continued developing the two missiles. At the time of the organizational change, about a dozen REDSTONEs had been launched. The time needed to fabricate, inspect, and test each missile was steadily decreasing. The engines, propulsion, and guidance systems were slowly evolving. As missile fabrication and testing became routine, the early development period ended. The birth of the ABMA marked a new era in the evolution of the REDSTONE. [76]

3.6 The Interim Stand and Development Under the Army Ballistic Missile Agency, 1956-1958

Under the direction of the Army Ballistic Missile Agency, a number of significant changes occurred in the REDSTONE missile, the Interim Test Stand, and direction of the test program. During the first three years of use, the Interim Test Stand was modified into a larger structure to better serve the day-to-day needs of the test personnel (See HAER No. AL-129-A-37 and HAER No. AL-129-A-43). While development of the REDSTONE Guided Missile System continued, the design engineers modified several REDSTONEs to aid in the JUPITER development program. These missiles were called JUPITER-C.

In addition to routine missile qualification tests, the crew at the Interim Test Stand static fired the JUPITER-C and ran special tests to increase the reliability and versatility of the tactical REDSTONE missile. In the Spring of 1956, the first Chrysler Corporation REDSTONE was tested at the Interim Stand, and within a year, missile assembly ceased at the Redstone Arsenal. Under a series of contracts dating from 1952, Chrysler Corporation built thirty-eight developmental REDSTONE Missiles and all sixty-three tactical REDSTONEs at a government-owned plant in Detroit.[77]

Several testing innovations greeted REDSTONE #13 (RS13), the first Chrysler Missile tested at the Interim Stand. ABMA engineers and technicians had just finished building a Thrust

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[75] OML, "Progress Report No. 12," 1-105.

[76] "REDSTONE Log Book #1," and "REDSTONE Log Book #2."

[77] Contracts DA-20-018-ORD-13875, 13937, 14074, and 14800. Bullard, "History of REDSTONE," 101-104.

Measuring Device when the missile arrived in March of 1956. The Interim Stand Mechanical Division installed this load cell assembly on the test stand directly over the missile before testing. Data from the load cell compared favorably with the theoretical value calculated using chamber pressure and other measurements (See HAER No. AL-129-A-40).[78]

Important advances also came to the Interim Stand from Rocketdyne, the division of North American Aviation responsible for building and testing the REDSTONE engine (NAA-75-110). Rocketdyne engineers at Santa Suzanna, California and later at White Sands, New Mexico worked closely with the engineers in Huntsville, since they were involved in similar testing. In December, 1955, Test Lab technicians installed a new flame deflector designed by Rocketdyne engineer Carl Kassner. In March of 1956, just before the arrival of the first Chrysler missile, North American Aviation loaned a new Rough Combustion[79] Cutoff Device to the RSA Test Lab.

Rough combustion had plagued North American Aviation rocket engines since the company abandoned the V-2 eighteen-pot injector in favor of a single injector plate for the Air Force NAVAHO Project. Prior to the advent of the automatic cutoff device, test observers had to push an emergency cutoff button if they saw the exhaust flame change to a color that indicated rough combustion. But, before the engine could be cut off manually, engine components usually suffered severe damage from uneven burning in the chamber. The RCC device saved many injectors and thrust chambers from damage while Rocketdyne and Army engineers perfected the new injector system.[80]

The Army and Rocketdyne also worked together preparing the REDSTONE for tactical use. In 1953, Rocketdyne began high and

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[78]T = P*A*C; Thrust is equal to the chamber Pressure multiplied by the Area of the throat (where exhaust leaves the combustion chamber and enters the expansion nozzle), multiplied by a variable, C, that incorporated several factors like thrust generated in the nozzle.

[79]Rough combustion had plagued North American rocket engines since they abandoned the 18 injector V-2 design in favor of a single plate injector for the Air Force's Navaho missile (the engine that preceded the REDSTONE'S NAA-75-110.

[80]For more on the NAVAHO, see J.W. Powell, "NAVAHO, the 'Know-How' Missile," *Journal of the British Interplanetary Society* 40 (1987), 93-95. Oral Interviews conducted by the author: Edward Berger, Interim Stand control technician, May-September, 1995; Charles Gillespie and James Pearson, mechanical test engineers, July and August, 1995. For an account of rough combustion damage, see "REDSTONE Log Book Number 2," Run #44, RS26.

low temperature tests on the REDSTONE engine in anticipation of Arctic and tropical deployment.[81] During the first two years of operations at the Interim Stand, the crew ran tests to determine the vibration stress on a warhead during firing.[82] The Interim Stand later expanded operations to aid in JUPITER Guided Missile development.

In November of 1955, the Army established the JUPITER IRBM-2 (Intermediate Range Ballistic Missile) Program, integrating the REDSTONE Program with the new JUPITER Program so that the JUPITER Missile System would advance as quickly as possible. Throughout 1956 and 1957, REDSTONE missiles carried JUPITER hardware while fulfilling the development objectives of the REDSTONE Guided Missile System. Several Redstone fuselages were elongated so that the missile could carry prototype JUPITER nosecones out of the atmosphere. These JUPITER-C missiles helped engineers design a warhead that could withstand the intense temperatures of atmospheric reentry.[83]

In 1957 the permanent Static Test Tower and facilities were finally completed using the funds appropriated by Congress for the REDSTONE, but the ABMA decided to continue REDSTONE development at the Interim Stand. After four years of development, the Interim Facilities had proven adequate for testing the REDSTONE and JUPITER-C, and the Army felt that a move to the new facilities would be disruptive to its busy schedule. JUPITER development began at the Static Test Tower while REDSTONE operations continued at the expanded Interim Ignition Test Stand.[84]

In the Autumn of 1956, the REDSTONE Winterization Program moved from Rocketdyne to the ABMA for Phase II. This second phase examined the operational behavior and problems associated with firing the REDSTONE Block I and Block II tactical missile in

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[81]Rocketdyne, "High and Low Temperature Tests of the NAA-75-110 Rocket Engine," 1953.

[82]These tests began in April of 1955 and continued through December of 1955: Missiles RS7, RS12, and RS18; runs 31 through 36. "REDSTONE Log Book Number 1, February, 1954 to April, 1955.", and "REDSTONE Log Book Number 2, April, 1955 to July 1956.", unpublished documents.

[83]ABMA, *Ordnance Guided Missile and Rocket Programs, Vol.IV (REDSTONE), Supplement 1.*, 29.

[84]Interviews conducted by the author. Edward Berger, Interim Stand Technician, August, 1995.

an Arctic environment.[85] Tests on the Block I, NAA-75-110-A-6 (using the sixth in a series of seven engine types built for the REDSTONE by Rocketdyne) began in the Fall of 1957 and concluded in the Spring of 1958. Liquid nitrogen pumped into the alcohol tank evaporated, chilling the alcohol to -25 degrees Fahrenheit. The mechanical crew installed a special insulated tail section that helped sustain the cold temperatures around the engine. Phase II of the Winterization program concluded in the following Winter after 29 firings of the Block II REDSTONE (A-7 engine) at the Interim Stand. The tests revealed that the REDSTONE would function adequately in the Arctic with minor adjustments in the launch procedure.[86]

In late 1957, the REDSTONE received a new mission in preparation for war. After the engineers and skilled technicians at the Interim Stand static-fired two REDSTONE Block I missiles (CC50 and CC51), the missiles were shipped to the Pacific Test Range for Operation Hardtack. In July and August the missiles were launched to determine the effect of atomic explosions in the upper atmosphere. The CC50 and CC51 were the first missiles ever to detonate atomic warheads.[87]

By 1958, the REDSTONE had become a highly effective weapon. After seven years of testing, the engine, propulsion and guidance systems consistently functioned in unison. The first REDSTONE was deployed to the 40th Field Artillery Missile Group in Germany in the Summer of 1958. As the REDSTONE development phase ended in late 1958, fabrication of the tactical production models precluded the need for aggregate testing. All but two of the nineteen Block I and forty-four Block II Tactical Missiles were deployed to the German Cold War front, or test launched at White Sands and Cape Canaveral without testing at the Interim Stand. The ABMA engineers at Redstone Arsenal could have turned their full attention to JUPITER development, but in the Autumn of 1957,

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[85]Apparently Phase I was Winterization tests of the Engine only by Rocketdyne.

[86]ABMA-TFS-239, "Winterization Tests of REDSTONE Booster and A-6 Engine Phase II," March, 1958. ABMA-ORDAB-DTD-22-MA, "Static Tests of A-7 REDSTONE Winterization Booster - Flash Report," May, 1958. ABMA-TFS-407, "Winterization Tests of REDSTONE Booster and A-7 Engine Phase II," January, 1959.

[87]ABMA (James Pearson) ABMA-TFS-215, and ABMA-TFS-223, "Static Tests of REDSTONE Missile CC-50 "Hardtack" Run #88," and "Static Tests of REDSTONE Missile CC-51 "Hardtack" Test #89," January 1958., Bullard, "History of REDSTONE," 149-150,166.

the Soviet Union launched the world's first artificial satellite, providing a new purpose for REDSTONE engineers at the Interim Test Stand.[88]

3.7 The Interim Stand and the MERCURY-REDSTONE, 1959-60

The launch of SPUTNIK I in October of 1957 generated fear and embarrassment in the United States. With a Russian satellite circling overhead, American airspace suddenly seemed vulnerable. Three months later, after testing at the Interim Stand, a JUPITER-C fitted with three solid propellant upper stages launched America's first satellite into space. Despite this great accomplishment, the EXPLORER I satellite was racing around the globe behind SPUTNIK I and II.

The space race had begun, and the "Old Reliable" REDSTONE, with its unmatched launch record, was chosen as America's manned flight vehicle. Still, components had to be improved and many small problems corrected if the REDSTONE was to be entrusted with a man aboard. So, between April of 1959 and July of 1960, the crew at the Interim Test Stand ran over 200 static firings to improve the REDSTONE propulsion system. Prior to the MERCURY mission, firings at the stand had occurred only twice per month.[89]

To accommodate these tests, the stand was enlarged and its foundation strengthened (See HAER No. AL-129-A-44 and HAER No. AL-129-A-49). With renewed enthusiasm, the mechanical, control and instrumentation personnel ran swift and efficient tests to improve the REDSTONE fuel pumps, injector plate, and turbine. Turbopumps that ran for only 120 seconds during flight were subjected to over 2000 seconds of testing. Special injector tests isolated and corrected the problem of rough combustion that had plagued the REDSTONE since its earliest development. Special tests verified the function of a vibration dampening material that was placed between the REDSTONE booster and the MERCURY capsule. The Interim Stand engineers performed qualification tests for all components of the propulsion system before they were assembled into the eight MERCURY-REDSTONE launch vehicles.

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[88]John Bullard, "History of the REDSTONE Missile System," 1963, 162-173.

[89]This average was obtained from the four extant log books, LB1, LB2, LB4, and LB5. 140 firings in 72 months between 1953 and 1959, therefore two firings per month.

Before travelling into space, all eight MERCURY-REDSTONE launch vehicles endured a full duration acceptance test at the Interim Stand.[90]

Conclusion

In May 1961, a tall, slender REDSTONE missile stood towering above the launch table at an airfield on the Atlantic coast of Florida. The missile system had been extensively tested over the previous decade to assure that it flew with precision, for it had been designed and developed to carry America's first atomic warhead.

The launch crew had prepared many tactical REDSTONE missiles for firing in the preceding years, so the pre-launch procedure had developed into a smooth routine: run the network, purge the tanks, install the transducers, leak check the propellant and pressure systems, run functionals and overall tests. Charts from the sequence recorders revealed that all of the valves in the propulsion system had actuated perfectly in the functional and overall tests, so the crew mobilized to finish the final pre-launch details. A truck carrying alcohol arrived, fueled the missile, then drove away. Like clockwork, the liquid oxygen tanker followed suit. Millions of Americans stared at their TV screens in restless anticipation, for this REDSTONE carried not a warhead, but a man. A few minutes later, America's first astronaut took a brief journey into outer space and returned safely to Earth.

It was a proud day for Wernher von Braun, who had watched the dream of space flight grow from an object of ridicule into a national obsession. For thirty years, with generous funding from the German and later the American government, von Braun's rockets had steadily grown larger, more accurate, and more powerful. Likewise, the staff of engineers and technicians designing, testing, and constructing rockets increased in size and skill. His technical staff achieved gains in propulsion and guidance by leaning heavily upon an ambitious testing program.

This paper has focussed on the family of liquid-fueled rocket propellant systems developed under the direction of Wernher von Braun between 1930 and 1960. Even in the earliest days of development, when von Braun was a teenage apprentice with the German amateur rocket team near Berlin, lessons and gains in rocket propulsion technology occurred primarily during static tests. In 1932, when von Braun joined the Army rocketry group at

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[90]Louis Scarbourough, "REDSTONE Log Book #4," and "REDSTONE Log Book #5," 1959-1960., Interview by the Author with James Pearson, Head of ITS Mechanical Division, August, 1995., USAOMC,"Satellite and Space Program: Progress Report for NASA," 7 May 1959, 6-7.

Kummersdorf, new emphasis was placed on using instrumentation to analyze and improve engines and the design of aggregate propulsion systems. Transducers linked to simple recording instruments during static tests provided an account of pressure, temperature, and vibrations at various points within the system. With burgeoning funds, the instruments used to examine the oomponents of rocket propulsion systems continuously challenged the state of the art in recording technology, empowering propulsion engineers to refine engine components, ignition, and propellant control systems. In one decade, thanks in large part to static testing and devotion to instrumentation, the range of von Braun's rockets had increased from less than 10 miles to over 200, and payload capacity had jumped from less than 10 pounds to over 2000.[91]

The development of liquid-propellant rocketry in Germany (1929-1945) helps explain the function and significance of the Interim Test Stand facilities. The historic roots of static testing provide a forum to better understand the importance of the Interim Test Stand beyond its association with the REDSTONE, America's first missile with an atomic warhead and its first space booster. The Interim Stand and the Control and Instrumentation tanks become even more impressive when compared to the test facilities that preceded those of the REDSTONE.

In the transition from 1930s and WWII German socialism to Cold War American capitalism, von Braun saw his budget increase but ran into new obstacles associated with the American economy and political system. In Germany, von Braun had managed all aspects of rocket development. Devoted to secrecy, the German Army advanced its rockets at a central location, employing private contractors strictly as a last resort. In 1950s America, where the private defense contractor was a vital part of rocket development, the von Braun team of scientists and engineers were forced to accept a lesser role, developing the propulsion and guidance systems of the REDSTONE but leaving component fabrication and engine testing to private industry and, in 1957, finally surrendering mass production responsibility to the Chrysler Corporation.

Between 1950 and 1962, the United States invested over $500 million to make the REDSTONE Guided Missile System a vital part of American defense, but in 1952 American bureaucracy threatened to stifle development of the fledgling REDSTONE. Laws for the defense industry (designed to discourage wasteful pork-barrel spending) prohibited spending research and development funds on facility construction. For the REDSTONE, this meant that rocket development money could not be invested in a rocket test stand or instrumentation and control bunkers. With the first REDSTONE nearing completion in late 1952, the team of German and American

[91]von Braun and Ordway, *Space Travel: A History*. 1985, 106.

engineers at Redstone Arsenal were forced to design and construct propulsion testing facilities for less than $25,000, the maximum amount allowed without Congressional approval. Despite the meager facilities devoted to REDSTONE propulsion development, the engineers and technicians at Redstone Arsenal employed the finest electrical and mechanical technology and knowledge to advance liquid-propellant rocketry to new heights.

Thousands of engineers and technicians assisted von Braun in his quest for spaoe travel: American and German rocketeers who built and refined the MERCURY-REDSTONE rocket ship that carried Alan Sheppard into space that day, the German Rocket team, the engineers and technicians at North American Aviation, Rocketdyne, Chrysler, Reynolds, and countless other contractors; the Army and civilian workers at Redstone Arsenal (1950-1960), and at Marshall Space Flight Center (1960-1961). Von Braun and Sheppard have already been exalted for their pioneering work. This paper begins to explore the efforts of the thousands that supported these two great Americans, the men and women that built and tested the engine and propulsion system of the REDSTONE Rocket.

Too often, the thousands of men and women that contributed to refining rocket technology are forgotten. Too often, peripheral concerns like economics, politics, and environmental and social effects of technology are explored without a thorough understanding of the technology in question. However, any attempt to explain technology from an external point of view is doomed to be just as warped and subjective as the internal histories of technology that dominated the first half of the twentieth century. Only by understanding the goals, methods, trials and tribulations of scientists and engineers responsible for technological progress can historians hope to absorb and explain the full meaning of our industrial society.

The REDSTONE played a crucial role in America's Cold War arms and space races. As the first missile to detonate an atomic warhead and the first to carry an American Astronaut into space, the REDSTONE will be remembered throughout history. Even more important, the REDSTONE was the first large liquid-propellant rocket that the German rocket team methodically and deliberately developed to completion. Like the German rockets, the REDSTONE was refined in three stages: Engine testing, aggregate static testing, and test flights. The story of this development, ignored in the past, can provide valuable lessons to the next generation of young engineers as they aspire to intelligently advance the next wave of teohnology.

Appendix I Rockets of the REDSTONE Family

Raketenflugplatz, Germany (1930-1933):
Mirak series
Repulsor series

Kummersdorf, Germany (1932-1939):
A-1
A-2
A-3
A-5

Peenemuende, Germany (1938-1944):
A-4

Huntsville, Alabama (1950-Present):
REDSTONE
JUPITER-C
MERCURY-REDSTONE
JUPITER
SATURN I
SATURN V
Space Shuttle

Appendix II: Test Stands of the Interim Test Stand Family

Raketenflugplatz:
- VfR Test Stand (Mirak and Repulsor series of rockets)

Kummersdorf:
- First Test Stand (A-1, A-2)
- Third Test Stand (A-3, A-5)

Peenemuende:
- Pruefstand I (A-4 engine and full rocket)
- Pruefstand VII (A-4 rocket propulsion and guidance testing)

Redstone Arsenal:
- Interim Test Stand (REDSTONE, JUPITER-C, MERCURY-REDSTONE)
- Static Test Tower (JUPITER, SATURN 1, SATURN 1B)
- SATURN V Test Stand (SATURN V, Space Shuttle Main Engine)

Appendix III: Instrumentation Data from ITS Run #30
Missile RS11, April, 1955.

Oscillograph Data:

Steam Pressure: 350 psi
Chamber Pressure: 300 psi
Lox Inj: 355 psi
Alc Inj: 360 psi
Lox pump inlet: 35 psi
Alc pump inlet: 24 psi
H2O2 Tank: 450 psi
change in P, LOX injector: 55 psi
change in P, Alc injector: 60 psi
steam buildup: .73 seconds

Data from Brown Recorders:

Recorder#:	Measurement:	Reading:
9	Pressure Inlet Steam	362 psi
2	Chamber Pressure	302 psi
	Turbine RPM	4600 rpm
28	Alc Tank Press.	19 psi
	b/f main stage	20.8 psi
5	Lox pump inlet	33 psi
	b/f run	38.8 psi
63	Steam Plant Reg.	454 psi
	set Reg.	450 psi
57	Temp H2O2 line	20.6 degrees C
8	Temp Alc Inj.	372 degrees C
26	Press Lox Tank	35.6 psi
1	Press LOX pump outlet	362 psi
23	Temp LOX pump outboard bearing	-80 degrees C
6	Press LOX injector	366 psi
7	Alc Pump Inlet	22.4 psi
35	Temp before H2O2 Tank	67.5 degrees F
4	Press Ignitor Fuel Inj	384 psi
	prior to M.S.	316 psi
64	Press H2O2 tank	450 psi
12	Temp Turbine Inlet Steam	340 degrees C
25	Temp Inj Face Plate	480 degrees C
58	Press Turbine Inlet steam	360 psi
11	Press alc Pump outlet	414 psi
10	Chamber Pressure	304 psi

Calculations:

M.R.=	1,299 raw
Thrust=	79,000 lbs raw
M.R.(jlstp)=	1.283
Specific Impulse(sl.)=	213.8
F(sl.)=	78,000 lbs

Appendix IV Static Tests at the Interim Test Stand

Run#	Missile#	Date	Notes
1-12	1,2,3		
13,14	4	Feb-Mar 54	
15-17	6	July 54	Camera used to assess quality of flame. Run 17: 12 seconds.
18-22	8	Sep. 54	This 15 sec run first attempted on 8 Sep 54. Postponed due to a leak in the top of the surge chamber. No mainstage for runs 18-20.
23,24	9	Nov. 54	Thrust measurement device, exhaust spray ring.
25,26	10	Jan. 55	A few blocks torn from south side of deflector in run 26. Thrust, Isp calc.
27,28	7	Mar. 55	Powerplant #14. Combustion monitored by audio.
29,30	11	Apr. 55	
31	7	Apr. 55	Trip #2 for missile 7. Velocity pickups on: Sphere, H2O2 tank#2, thrust frame, alc feed lines. No CPS osc. occurred.

32	12	May 55	Velocity pickups in instrumentation compartment (warhead Aft) to determine sonic vibration transmitted to warhead during firing. two "shakers" installed on exhaust nozzle. shaken when empty. then tanked and ran 15 sec MS (main stage)
33	12	May 55	Propellants tanked before shaking (See run 32). then 15 sec MS run.
34	18	Nov-Dec 55	Vibration testing of Warhead unit continues.
35	18	Dec 55	Objective: 8 Sec MS with manual cutoff. New flame deflector? performed satisfactory. Upper ring turned on with about 15 psi in manifold.
36	18	Dec 55	Objective: 30 sec. test to test deflector with jet vanes installed, check tail temp, warhead and aux wrhd vibration analysis. Extra water manifold for deflector and 4 spray nozzles for cooling.

1 Feb 1956: Transfer of Redstone Guided Missile System from the Guided Missile Development Division, Redstone Arsenal to the Army Ballistic Missile Agency (ABMA)

37-38	19	Feb 56	Objective: 3 runs, Run 37: 7 sec. LOX tank Press sw: 31 psi. Sec of Defense present! deflector scorched so drilled more holes in it. Run 38: 15 sec., LOX tank pr.sw.: 35 psi. deflector better with extra holes, velocity pickup on LOX vent valve.

39	13	Mar 56	**First Chrysler missile.** First test that used **new Thrust measuring Rig. Rough combustion cutoff (RCC) device** on loan from North American Aviation (NAA). Representative from NAA visiting. 15 sec run.
40	13	Apr 56	20 sec run.
41	13	Apr 56	30 sec run.
42,43	20	Apr 56	2*20 sec runs. RCC calm indicated a smooth run. Main alc valve leaked about a pint during each run.
44	27	May 56	Increased length: Jup C?, due to trouble aligning the missile, the missile was bolted in place and no thrust measurement taken. first A-4 to fire w/o film cooling holes. Rough combustion due to loose LOX injector ring. auto RCC failed, rough combustion cutoff manually after 3.5 sec. Engine damaged.
45,46	27	June 56	Engine 4034 replaced by 4036. RCC ends run 45 after .3 sec ignition. Run 46: 20 sec as scheduled. Second run of RS-27 canceled due to urgency of RS-27 schedule.
47,48		June 56	20 sec run, cut-off by timer. Test blew drainage ditch bridge away. Low Pcc. therefore Run 48.
49	25	July 56	No Thrust Measurement: no oil in the reservoir. Successful run thus no **need for second run!!**
50	28	Aug 56	Objective: 20 sec test. 100 ft. Crane damaged.

51	CC15	Sep 56	20 sec run with timed cutoff. Success precludes need for 2nd run.
52	CC16	Oct 56	30 sec run to check the stabilized Alc temperature.
53	RS29	c. Nov 57	
54	CC30	Jan 57	20 sec firing, auto cutoff. No need for second firing.
55	RS34	Jan 57	Problems with the LOX flow rate but second run forsaken due to launch schedule.
56	CC37	Apr 57	
57,58	RS24	May 57	Check of LOX vent valve, thrust measurement
59	CC40	May 57	Check of LOX vent valve, thrust measurement.
60	CC26	Jul 57	Jupiter-C. Check mix ratio and tank pressures with tank press sw. setting lowered and .175" diameter LOX heat exchanger orifice.
		Aug 57	Check of high performance injector with modified hardware (the end frame hardware damaged in previous test on the new injector)
62-85			Winterization Phase II Testing on REDSTONE with 75-110-A-6 engine (Block I Prototype).
86	CC48	Nov-Dec 57	Obj.: 20 sec firing to check performance of the R+D prototype booster of the first block of tactical REDSTONE missiles.

87	RS24	Dec 57	Jupiter-C
88	CC50	Jan 58	"Hardtack". 20 sec
89	CC51	Jan 58	"Hardtack"
90	CC53	Feb 58	"Hardtack". 20 sec.
99,100	CC54	Mar 58	First A-7 engine; First R+D prototype of Block II tactical missile.
101-106			Winterization Phase II on REDSTONE with 75-110-A-7 engine (Block II prototype).
107	CC57	Jun 58	Objective: 20 sec test of A-7 engine # 7007 to determine the deflection of the turbopump at the suction line flanges and the chamber in relation to the tail section at the stuffing box. Compare results to run 100. Also measurements of sound pressure level.
108	CC49	Aug 58	20 sec test, auto shutoff, Jupiter-C.
109-137			Continuation of REDSTONE Winterization Phase II, 75-110-A-7 (Block II prototype).
138-9	2002	Mar 59	**First tactical missile with thin-wall center section** (72") to be fired. Test lab designated 22 strain gage and 12 vibration measurements be taken on the center unit and tail section.
140-160	TB	Apr 59	Mercury pump qualification tests. These 21 tests totalled 2000 seconds testing the modified A-7 turbopump system with the REDSTONE test booster.

161-2	TB	Apr 59	Test of Engine 7086 for 100 sec run (with RS test booster center section?).
163-	TB	Apr 59	Test of Engine 5043
	TB	Apr 59	Test of Engine 4043
171		May 59	3 sec run: cutoff by LOX depletion switch
172		May 59	LOX dep. sw. disconnected. 80 sec run.
173	TB	May 59	Thrust varied from 65-76,000 lbs. Chamber# 7086, injector# 181
174	TB	May 59	First run in the **pulsing test series**. A Pulse delivered from N2 tank during this series tested the durability of engine components. Center section RMF 11, engine 5043(A-6?). 5 sec MS.
175-6		May 59	Pulse failed to occur.
177-180		May 59	1500-450 psi pulses. each caused RCC. engine 5043
181-186		May 59	385-570 psi pulses: all stable runs. engine 5043
187-202		May 59	various pulse tests: some stable, some RCC. engine 5043
203		May 59	First in A-7 pulsing test series. 300psi in N2 pulse tank. Turbine overspeed trip cutoff at 1 sec.
204		May 59	RCC cutoff. Various engine components were damaged and replaced.
205-211		Jun 59	Most unstable; RCC

212-217		Jun 59	6 runs on June 5th with pulse. all stable but run 215.
218		Jun 59	Stable combustion but three cracks found at pulse inlet weld. Chamber R024 removed.
219-223		Jun 59	New Thrust chamber (R025) installed. Pulses increase from 350psi (219) to 1500psi (223). All runs stable.
224-238		Jun 59	Various pulses with two diff injectors: Injector 120 (056 type redrilled), then Inj 078 (021 type). Thrust chamber cracked (233) and was welded. Cracked again in run 238.
239-40		Jun 59	Engine 7086 with injector P194 (countersunk). 1st run 20 sec, 2nd run 80 sec.
241		Jul 59	A-7 engine turbine blade qualification test. Turbopump P005. 9 sec. run. Manual cutoff due to low tank press. (10psig)
242-247		Jul 59	Successful long duration firings of 80-120 seconds on pump P005. Steam exhaust orifice varied.
248-260		Jul 59	Long duration firings on pump P005. Mostly 110-120 secs.
249-		13 July	Pump 010 testing
		23-28 July 59	Pump 005-2 ABMA tested with center section RMF39.
298-300	W1005	Aug 59	"Willow"; 300=30 sec run.

(Missiles 1001-1019 are REDSTONE Block 1,Engine NA-75-110 A-6)

	Sept 59	500 cycle and injector impingement angle study. Photocon pressure pickups installed. First mention of motorized TMR valve that has a variable percentage (1-100%) this percentage varies throughout Oct. tests.
301		Chamber P012: scheduled 30 sec test; RCC at 1 sec.
302	Oct 59	Chamber P012: scheduled 5 sec run to investigate the RCC device malfunction on run 301.
303	Oct 59	30 sec run Chamber P012
304	Oct 59	100 sec firing, 84,000 lb thrust, 500 cycle heard after 15th sec. (see Sept 59) Main alc valve leak.
305	Oct 59	27 sec run at 85,000 lb (thrust controller blade valve in full open position due to malfunction prior to test.)
306	Oct 59	50 sec run, 85,000 lb thrust. see prob: 305., 500 cycle present.
307	Oct 59	100 sec run, 500 cycle present.

Injector S/W 183 removed, Injector S/W 140 installed

308	Oct 59	199.59 sec test, 500 cycle oscillation present.
309	Oct 59	120 sec. cutoff by fuel depletion. Due to leak in LOX valve (P007), burning continued for 2 sec after cutoff. Main LOX valve replaced with P001) Intense 500 osc.

310		Oct 59	60 sec, TMRV potentiometer broken due to 500 osc.
311		Oct 59	119 sec, fuel depletion run. 500 osc.
312		Oct 59	110 sec, 500 osc, due to a leak, reg dropped from 580 to 500 during run. Reg replaced.
313		Oct 59	80 sec run. 500 osc.
314		Oct 59	15 sec run; no osc.
315-324		December 59	**Special Injector Study:** Turbopump R001-R, Thrust Chamber P012, Main LOX Valve P-028. Injectors: S/W 152(315-6), 198(317-20),
325	MR-1	Feb 60	See Report DT-TN-6-60
329	MR-2	Mar 60	120 sec static firing to check variable thrust from 70K to 82K lbs. Report DT-TN-11-60
330-334	TB	Apr-May 60	Engine 7112A tested using the Test Booster (TB). Report DT-TN-17-60
335-338	TB	May 60	Capsule on the test booster. Full (110-116 sec) runs. Report MM-M-TEST-1-60
339	MR-3	Jun 60	80 sec test indicated satisfactory performance from 74K to 85K lbs. Report DT-TN-19-60
340	MR-4	Aug 60	99.78 sec. run. Report MTP-M-TEST-61-2
341-343	MR-4	Sept-Oct 60	20 second runs. Report same as above

344	MR-5	Nov 60	100 sec. run. Report MTP-M-TEST-61-1
345	MR-6	Dec 60	100 sec. run. Report MTP-M-TEST-61-4
346	MR-7	Jan 61	100 sec. run. Report MTP-M-TEST-61-6
347-49	MR-1	Feb 61	35, 40 and 50 second runs. Report MTP-M-TEST-61-10
350-51	MR-6	Mar 61	20 and 110 second runs. Report MTP-M-TEST-61-11
352			
353-54	MR-8	Apr 61	20 and 110 second runs. Report MTP-M-TEST-61-13
355-58	TB	May 61	25 to 31 second runs using the test booster.
359			
360	MR-4	Jun 61	100 sec run. Report MTP-M-TEST-61-16
361	MR-6	Jul 61	30 second run. Report MTP-M-TEST-61-17

TERMS

A-1, First rocket designed under German Army Ordnance at Kummersdorf.

A-2, Modified version of A-1.

A-3, Third rocket design built by German Army Ordnance.

A-4, The Peenemuende rocket, later renamed V-2.

A-5, Modified A-3 rocket for refining guidance system, preceded the A-4.

ABMA, Army Ballistic Missile Agency, headquarters: Redstone Arsenal.

ALC., Alcohol, the liquid fuel used in rockets of the REDSTONE family (Amateur German Repulsor series, German A-series, REDSTONE, JUPITER, and SATURN).

ARGMA, Army Rocket and Guided Missile Agency.

CC, Chrysler Corporation, Prime contractor. Manufactured REDSTONE missiles in Warren, Michigan under contract DA-20-018-ORD-12749

CTR, Chemische Techniche Reichsanstalt, the German Institute for Theoretical and Applied Chemistry.

Ford Instrument Co., Division of Sperry Rand Corp.: Guidance and Control subcontractor.

I.I.T.S., Interim Ignition Test Stand, also called Interim Test Stand or Interim Stand.

L+H, Launching and Handling, division of OML.

LOX, Liquid oxygen, the oxidizer of the REDSTONE family of rockets (See ALC.).

MICOM, United States Army Ordnance Missile Command, est 1962.

MSFC, George C. Marshall Space Flight Center, the heart of NASA rocket development - est. within the Redstone Arsenal, 1960.

MSFCL, the Library of the MSFC.

NA, National Archives.

NAA/Rocketdyne, North American Aviation, REDSTONE rocket engine subcontractor.

NASA, National Aeronautics and Space Administration, est. 1960.

NATO, North Atlantic Treaty Organization.

OGMC, Ordnance Guided Missile Center (est. at Redstone Arsenal, 1950).

OML, Ordnance Missile Laboratories (est at Redstone Arsenal, 1952).

Reynolds Metal Co., REDSTONE fuselage subcontractor.

RS, REDSTONE missile.

RSA, Redstone Arsenal.

RSIC, Redstone Scientific Information Center.

RTL, Rocketdyne Technical Library, Canoga Park, California.

S+M Lab, Structures and Mechanics Laboratory.

USAOMC, See MICOM.

USSRC, United Stated Space and Rocket Center, Huntsville, Alabama.

V-1, Vengence Weapon 1, German Luftwaffe unmanned rocket plane.

V-2, Vengence Weapon 2, See A-4.

VfR, Verein fuer Raumschiffahrt, the German Society for Space Ship Travel.

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George Harsh, Interim Stand Electrical Engineer

Carl Heimberg, director of Test Lab 50s and 60s; Peenemuende propulsion test engineer

Leon Ivy, Army laborer. Forth Bliss and RSA

Walter McNabb, Interim Stand Instrumentation Engineer

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Frank Rutledge, Interim Stand Instrumentation Technician

Ramon Samaniego, RSA Facilities Planner

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