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Chapter 15

FROM A-4 TO EXPLORER I: A MEMOIR*

Kurt H. Debus†

WHITE SANDS PERIOD

This discussion of rocket technology will cover the period from 1945 to 1958 when rocketry came of age under the impetus of military requirements, or rivalry between great powers, which was diverted into a unique theater of activity. Out of this effort came the machines by which men left their planet to explore outer space.

These enterprises required enormous commitments of resources in science, technology, industry, and government. For the purpose of this paper I will arbitrarily constrain the content to four programs, each built upon the other, and in the building introduced refinements, sophistication and steadily increasing capabilities.

We will begin with the A-4 system which became the V-2 weapon after modification that achieved operational status in 1944. We will discuss the employment of this vehicle in upper atmospheric research following its importation to the United States. Next we will consider the development of Redstone and Jupiter ballistic missile systems, and conclude with the application of Redstone as the carrier for the first U.S. Earth satellite.

Some of these activities have been described in the literature; consequently, I will deal with selected portions and refer to the A-4 as a baseline from which to trace the subsequent developments in technology.

A personal word may serve to put my remarks in context. I was one of the group of 130 scientists, engineers, technicians and administrators who elected to accompany Dr. Wernher von Braun to America as the war in Europe reached its inevitable conclusion. Dr. von Braun had been technical director of the Peenemuende Research Station on the Baltic coast where we were engaged in rocket projects. Each of us signed short-term contracts with the U.S. Army with the understanding that at some time and in some way we would continue the work begun in Germany in 1932 when the Ministry of National Defense first sponsored research in this little-known field. In my case, as was also true of a small number of

* Presented at the Seventh History of Astronautics Symposium of the International Academy of Astronautics, Baku, 1973. Note: A condensed version of this paper was presented by Dr. Robert Gray, Manager, Shuttle Office, Kennedy Space Center, in the absence of Dr. Debus at the Baku symposium.

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the group, there was a short detour before reaching the United States. We proceeded to Cuxhaven to assemble and launch several V-2s under British auspices. We rejoined our colleagues at Fort Bliss, Texas, which is located on the outskirts of El Paso, about 80 kilometers (100 miles) from White Sands Proving Ground to the north in New Mexico (Figure 1).

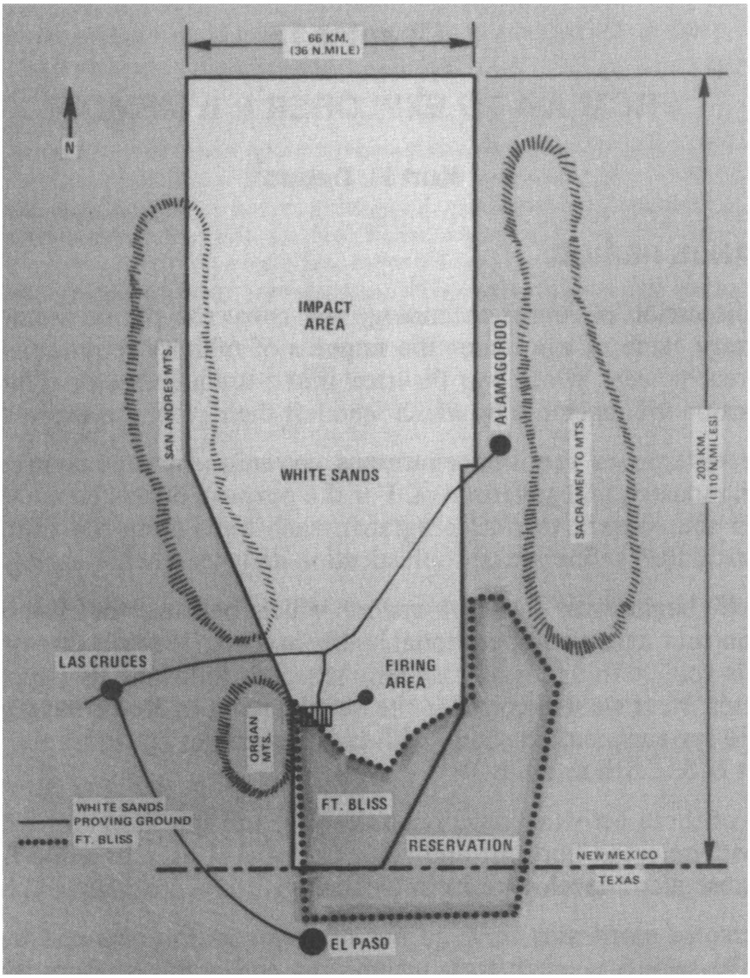

Figure 1 Ft. Bliss-White Sands area.

By coincidence, related to the unusual geography of the area, the American rocket pioneer, Dr. Robert H. Goddard, test-fired some of his liquid-propelled rockets 15 years earlier on the Mescalero Ranch, east of White Sands. We knew very little about Goddard and his work. In 1950, because of patent claims against the Army and Navy, several of us received special clearances and were permitted to examine the Goddard drawings and technical reports. We were astonished to learn that he anticipated some of the fundamental solutions we arrived at in Peenemuende, including the gimbaling of engines, employing jet vanes and other basic principles.

Looking back at our reception in a new country, it was one of the few occasions in history when one of the victors in a long, bitterly fought and costly war welcomed a small group of professionals from the enemy nation and gave them the opportunity to conduct research and development and to share in the fruits of their work as citizens of a democracy.

There were problems, as might have been anticipated, because of the novelty of our occupations and the extraordinary circumstances of our immigration. For example, the U.S. Civil Service Commission, which regulates employment in the Federal Government, was caught totally unprepared. There were no neatly printed descriptions for positions filled by men engaged in rocket propulsion, guidance, tracking, telemetry, aeroballistics and all the other highly specialized disciplines represented in our group. No such skills had been previously identified in the Government. One of our top flight engineers, Hans Hueter, found himself officially labeled "gun turret designer," although he had nothing to do with guns or turrets. Some years later he supervised the development of mobile equipment required to support the Redstone ballistic missile system in the field army.

We needed facilities and we built them. Instrumentation experts and test equipment designers labored with hammer and saw to construct barracks that never succeeded in keeping out the fine sand blown by desert winds. They cut and welded steel, mixed and poured concrete for a static test stand. When a trainload of supplies arrived, they stripped to the waist to unload, catalog and store the multiple items. For instance, one requisition asked for shovels and the Army shipped 1,002 of them (Figure 2).

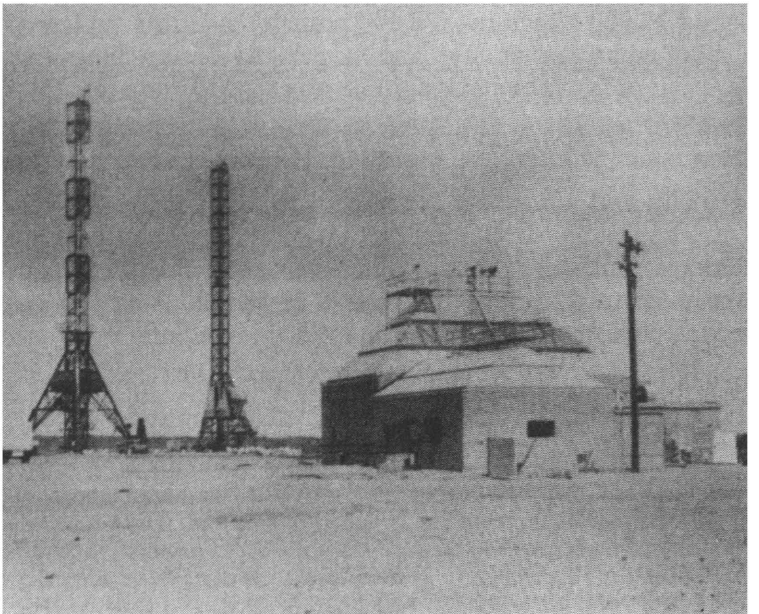

Figure 2 V-2 blockhouse at White Sands Proving Ground. Launching towers for rockets at left.

Even while building, and planning, and undertaking specific research tasks assigned by the Army, we looked ahead to more ambitious projects. Dr. von Braun, Karl Heimburg, Walter Riedel (who later returned to Germany) and I recall our first look at California. We had pooled our limited funds to buy a car, probably the last and worst produced before the war. Since none of us were authorized to drive, it was arranged that an Army sergeant would be both escort and chauffeur. The official reason for the trip was to survey points on the West Coast for future launch sites. We set out, overcoming some mechanical problems enroute, and reached Indio, a small town in California, where an alert deputy sheriff overheard German conversation and promptly took us into custody. The sheriff joined us, heard our explanations, brought out some bottles and a most pleasant interlude followed. The Fort Bliss authorities talked to the sheriff about 2 A.M., whereupon he escorted us to the local hotel, arranged lodgings and bade us farewell. From that trip emerged maps for Point Mugu, Point Sal, Point Hueneme, Point Buchon and Point Reyes on the California coast as well as Cape Mears and Cape Blanco in Oregon. We enjoyed the scenery and considered the Pacific Ocean an excellent long-range test area. Vandenberg Air Force Base, which is headquarters of the Western Test Range, was later developed as a major military launch base, in the Mugu-Hueneme area. But we were told -- this was 1946 -- it was the Atlantic Ocean, not the Pacific, which was considered Mare Nostrum and hence we should look east and not west for future launch operations.

Let me briefly review the A-4 as a point of departure. It was successfully launched from Peenemuende for the first time October 3, 1942. The vehicle measured 14 meters (46 feet) in length, with a diameter of 1.65 meters (5 feet, 5 inches), weighed 12,900 kilograms (28,440 pounds) at liftoff, and carried a mixture of methyl alcohol and water as fuel, and oxygen. At Brennschluss (burnoutz) it attained acceleration of 5gs. The peak altitude was 80-90 kilometers (50-56 miles).

By current standards, it was not a very imposing rocket. But at the time of its development, A-4 represented a major technological accomplishment. It achieved supersonic velocity and withstood heating up to 1,250 degrees Fahrenheit in the descent phase. The years of trial and error which made the A-4 possible involved a large-scale research and development undertaking in which thousands of scientists and engineers fought unknown forces. Scores of clerks labored to compute trajectories and reduce data from a single test in that pre-computer era.

Some of the essential investigations are mentioned to emphasize that we knew very little about the environment in which the vehicle must function, scarcely more than had been accumulated from balloon ascensions and low-level aircraft flights:

- o Wind tunnel tests had to be carried on. It took years to devise tunnels of supersonic capacity, plus measuring methods, at speed ranges from 6 to 4,500 meters (19.5 to 14,760 feet) per second. Only by such methods could research determine the stability of rocket designs, distribution of air flow, operation of rudders, and drag measurements with and without exhaust gas streams.
- o Test-bed studies were conducted on the combustion chamber of the engine as well as the complete propulsion system which, in turn, required development of test equipment and measuring methods.

- Measuring methods had to be developed by which to plot the complete flight path.
- Studies were conducted to evaluate methods of steering the rocket at all ranges of air velocities encountered in the trajectory. A model technique had to be devised which would reproduce the attitudes of models in flight.
- Investigations were carried out to measure the influence of exhaust gas streams upon radio communications between the rocket in flight and ground stations.

The best that German industry and science could offer was pressed into finding solutions to these and other developmental problems. The A-4 was visualized as a research tool to explore the upper atmosphere and thus to derive the essential data upon which more powerful machines would be designed to explore space.

Late in the war, when the tide turned against Hitler, he demanded the so-called vengeance weapons from which came the V-2, which was the A-4 in modified form. Since A-4 had a range capability of approximately 322 kilometers (200 miles), the V-2 could fly the same distance. Since A-4 carried an instrument compartment of about 1,000 kilos (2,204 pounds), that became the maximum weight available for the high-explosive warhead. Not until then was the requirement stated for a nose cone adapted to the weapon system. Further, the military wanted to move the weapon about, so the Peenemuende group developed the transport vehicles and the launch handling equipment. You may recall that some 4,000 V-2s were produced in factories elsewhere in Germany. As a weapon, it had a rather erratic performance record. To mention one related deficiency, Germany had no proximity fuze.

To return to White Sands, commencing in 1946 and extending over the next four years, our assignments from the Army required assembly, checkout and launch of V-2s in an upper atmospheric research program, and developmental work on ramjet vehicles which were to be capable of military applications over longer ranges (Figure 3). Along the way, we learned the methods by which the military contracted with industry and research institutions; conversely, industry became acquainted with us. We formed a project organization initially which had five major sections: project and design; steering; chemistry and thermodynamical; test; and production. The test section included a White Sands test group, measuring laboratories (the term suggests much larger facilities than actually existed), and test stand measuring services. About 35 of the group remained at White Sands, while the larger number worked in shops and laboratories at Fort Bliss.

There the design group was concerned with studies of fuselage, combustion chamber, pumps, cooling, valves and measuring, while the scientific group dealt with flight mechanics, aerodynamics, materials testing, mathematics and statics. The steering section, where I served as deputy, was responsible for remote and self-control devices, simulators, radio monitoring, guide beams, integrator and cutoff devices, telemetering, gyros, stabilizers and testing. Other units worked in propellants and fuels, thermodynamics, design and construction of launch installations. There was a production group which was concerned with inspection, manufacturing engineering, tool and jig design, pneumatic and mechanical testing.

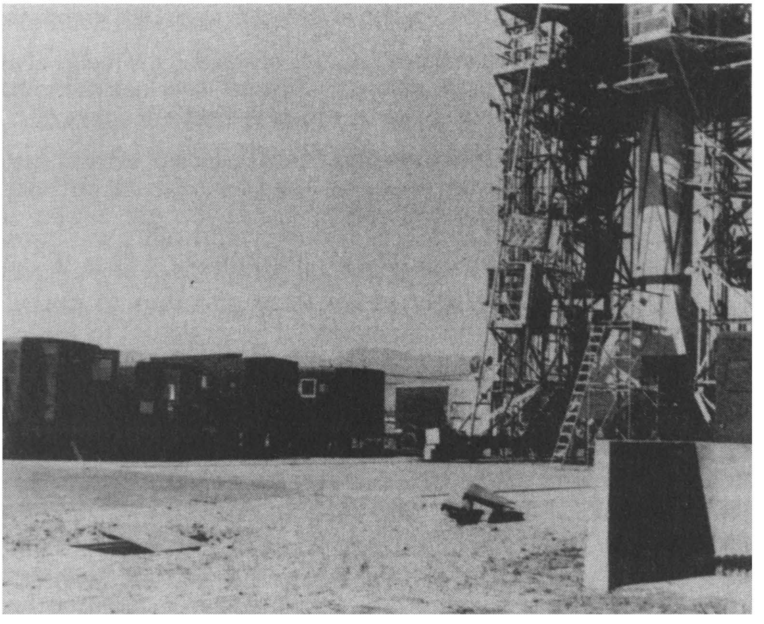

Figure 3 V-2 in the service structure on the White Sands Proving Ground launch pad which was located six miles east of the industrial area. Trailers housed checkout and control equipment. The service structure moved away from the vehicle on rails before launch.

We made the most of techniques gleaned from the Peenemuende experience. As an illustration, a rocket motion simulation facility was developed by which to reactivate the A-4 motion simulator brought from Germany, and to provide a larger and more flexible simulator applied to future guidance and control studies. This device was employed in the dynamical analysis of the Hermes 2 concept, which will be described later.

The Army formed of a V-2 Upper Atmosphere Research Panel on January 16, 1947, which coordinated the work of experimenters from several institutions that developed the instrumentation and distributed data derived from carrying these experiments aboard the V-2s. Measurements were taken of solar and cosmic radiation, atmospheric density, pressures and temperatures, the ionosphere, and micrometeorite distribution. Some payloads carried biological specimens including monkeys. The Army, its contractors and other Government or university research groups, welcomed the V-2 boosters for this program. Among the experimenters were the Naval Research Laboratory, the Jet Propulsion Laboratory which had been engaged in Army rocket projects for some time, Massachusetts Institute of Technology, Princeton University, General Electric Company, and the Ballistic Research Laboratories (Figure 4).

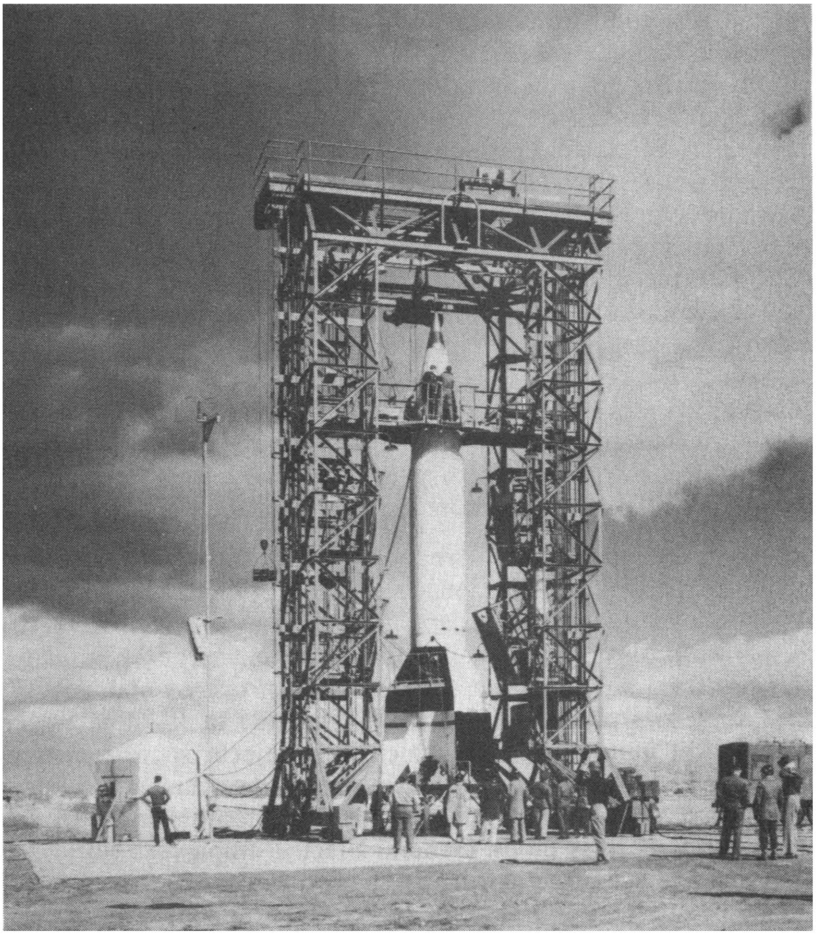

Figure 4 V-2 Rocket high-altitude research vehicle in service structure. Pad Utility Building at left. White Sands Proving Ground.

Between April 1946 and December 1949, some 50 rockets were launched with varying degrees of success, having been assembled from sections, components and parts transported from Germany in 300 freight cars. Most of the material came from an underground Mittelwerke plant near Nordhausen. Over 12.7 metric tons (14 tons) of drawings, test reports, wind tunnel studies, and scientific papers were retrieved from a tunnel in the Harz Mountains with the help of Karl Fleisher, Walter Riedel and Dr. Eberhard Rees, who later succeeded Dr. von Braun as director of NASA's Marshall Space Flight Center. Only two complete vehicles with originally matched components were found in the huge collection rounded up by U.S. troops.

Since the troops knew little about the prizes they found, it was understandable that many imposing-looking, large containers were shipped along with the rest. When opened at White Sands, many of the boxes contained glass wool. The story behind the wool again points up the state of the art. We had experienced repeated breakup of the V-2 configuration at the point of reentry. Different theories were offered to explain the blowups, such as flutter that might tear out rivets, but no one theory could be convincingly demonstrated. As one solution, it was decided to insulate the fuel and cryogenic tanks from the skin. While we investigated various remedies, about 10 missiles were launched vertically in a special series so that the phenomenon could be visually observed. There was no program, simply a vertical launch and reliance upon the Earth's rotation to move observers away from impact. All of those launches occurred at twilight, to obtain maximum lighting on the vehicle itself with the observers in shadow. And since it was next to impossible to remain calm and collected while standing still, apparently directly under the ascending rocket, field glasses were provided which were offset to an angle of 90 degrees. At 60, 80 and 100 kilometers (37, 50 and 62 miles) the observers reported the vehicle began descent tail first; then as it was pulled over it became unstable, very violent behavior occurred and the missile broke apart. The glass wool was selected to protect the tanks from heat which penetrated the outer shell and which might explode the fuel. We then had far more than we needed at White Sands.

Nearly 50 of the top sections were too heavy for the research flights and lacked access doors through which instruments could be installed. The Naval Gun Factory produced a special compartment adapted to the purpose. In the total collection there were, in varying states of repair, 115 control chambers, 127 main frame sections, 100 thrust frames, 90 tail sections, 180 pairs of oxygen and alcohol tanks, 200 turbine-and-pump assemblies, 200 hydrogen peroxide tanks, heat exchangers, valves, and 215 rocket motors, some of which were rejects, some earlier types, some were unfinished. There were time switches, servos, inverters, and 50 gyros. Missing components, those which needed refurbishment, or modification were fabricated by industry or in the Fort Bliss shops. General Electric employees worked closely with our group under Army contract during this period (Figure 5).

A reinforced concrete blockhouse, which resembled a box topped off by a pyramid-shaped section, was located near the launch stand. There was a movable service structure in the shape of an inverted "U" with a work platform at the instrument compartment level. The structure moved on rails to clear the stand prior to launch.

At this point, some observations concerning launch need to be stated. It is the final, definitive act which culminates the fabrication and assembly of sub-systems, components and systems which comprise the total vehicle. During its time interval, commencing when the stages are turned over to the launch crew, the launch environment is demanding, harsh, and unyielding. Since we have only expendable boosters available, which is still the case at this point in time, once the rocket has been set in motion there is no possibility of recall. It must function as designed through all kinds and phases of stresses once and once only, or it fails. What that statement implies underlines many of the complications and delays which occurred in the decade between start of military sponsorship and the flight of the A-5 vehicle in December, 1939. This will be remembered as the smaller and less powerful project which preceded and made possible the A-4.

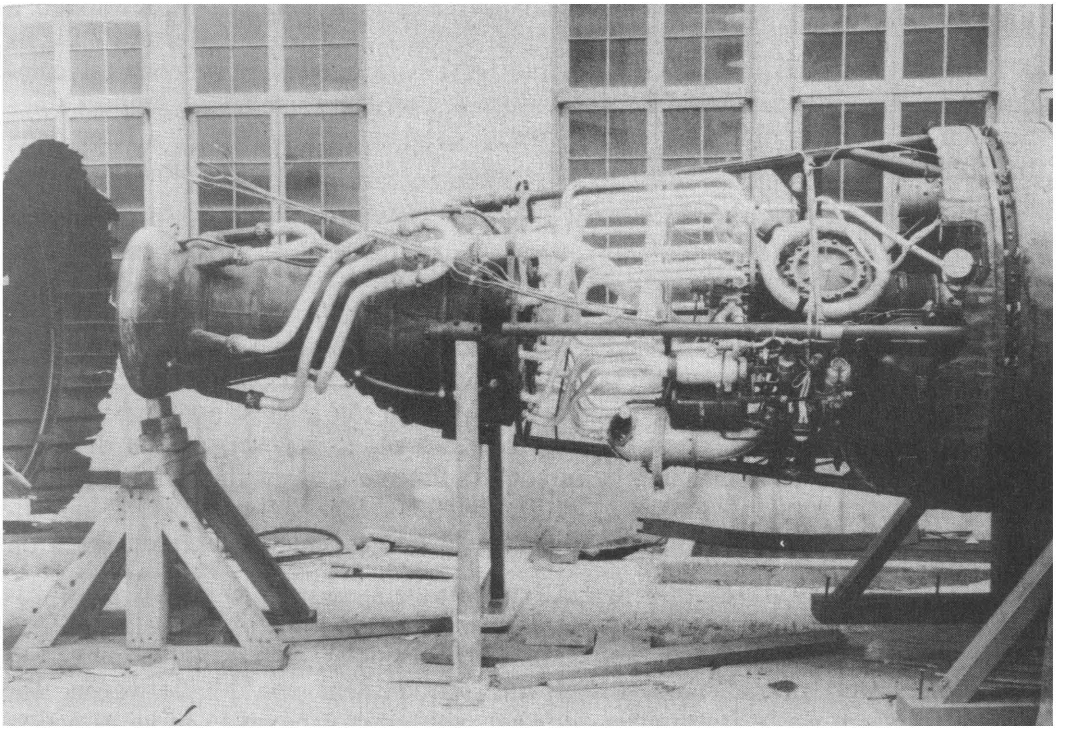

Figure 5 V-2 engine in Proving Ground hangar. Larger and more powerful liquid-propellant engines, which incorporated the basic features of the moor, were employed for U.S. tactical and strategic ballistic missiles. While the V-2 employed a gas motor, the former Peenemuende team introduced an electric motor during the White Sands Proving Ground launches.

We were blindly trying, without exact measuring data by which to identify stress corrosion, the sudden forces impacting the vehicle during pressurization and liftoff, which never again occur, sheer forces, wind gusts, and heating. The absence of empirical data greatly complicated the task until refinements and innovations in data acquisition systems enabled designers to define the parameters, understand the conditions, and devise mechanisms to overcome them.

Returning to that A-5 flight as an example, it was possible for 77 seconds to record nine parameters such as the position of the stable platform in three planes, rudder positions, pressure in the combustion chamber, takeoff and cutoff. Since the missile was designed for recovery, only on-board recording was required. The A-4, on the other hand, brought new problems since we could not plan on recovery and the measurements would have to be transmitted through a radio frequency link. A telemetry system was put together for the purpose but accuracy, linearity, and reliability were far from satisfactory. The instruments could measure only slow-changing events since the frequency response was one-half to one-fifth Hertz. An improved system with a capacity of 12 channels was in the making when the A-4 program terminated.

During the 1947-1950 period, the Naval Research Laboratory developed a telemetry system with 18 channels that was utilized in the V-2 and Hermes 2 flights at White Sands. This was a pulse position AM type employing mechanical commutation. Again we depended upon recovery of the instruments after impact since the data were accumulated by needle-tracing mechanical devices. At a later date, the Cook recorder became available which stored the measurements on film.

The end purpose for which a rocket system is developed exerts profound influence upon launch concepts. In the research environment, such as Peenemuende, or White Sands, the planner may design and build ground support facilities, site launch pads, locate propellant and oxidizer pressure vessels, propellant transmission lines, and other required installations to best advantage considering terrain, and range safety to protect personnel and other installations, and take such other steps as may be desirable to obtain maximum return with the highest assurance of success. On the other hand, when requirements are super-imposed on the development schedule which dictate tight allowance in time or cost, or the facilitation of a missile system to render it mobile to make it available for safe handling and launching by troops instead of experienced engineers and technicians, launch takes on quite different proportions.

Just such special arrangements were imposed in the transformation of the A-4 to the V-2 which was deployed with a train of 30 vehicles, or a combination of rail cars, trucks and prime movers. For this requirement the Meillerwagen was developed which was a transporter-launcher with erector beam to serve as access means and connecting carrier. It also carried the launch table.

The static test stand built at White Sands occupied the side of a cliff. The rocket was placed on top of a heavily reinforced concrete shaft bored into the rock face and open at the bottom to divert flames away from the cliff. The inner corner was rounded off to deflect the blast horizontally. Massive steel braces which incorporated thrust-measuring devices secured the rocket during hot firings, the first of which occurred March 15, 1946 (Figure 6 and 6a).

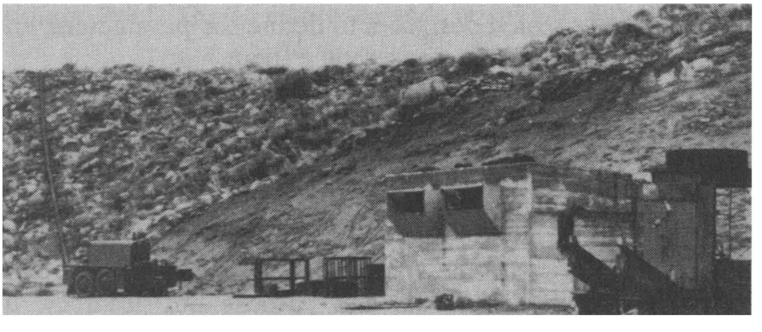

Figure 6 V-2 Rocket static test site control bunker at White Sands Proving Ground.

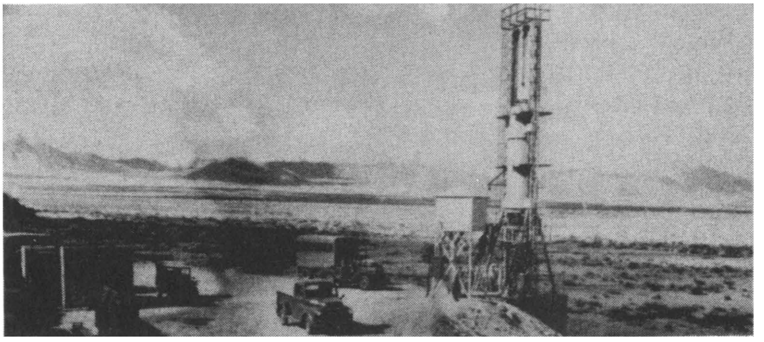

Figure 6a V-2 rocket tankage and engine in static test stand. Control bunker at left. White Sands Proving Ground.

Considering the aging of components and the modifications to the vehicles to accommodate the research program, the White Sands program came off quite well. The standard empty weight of the V-2 including the 998 kilograms (2,200 pounds) warhead was 3,990 kilograms (8,800 pounds). The vehicles launched in 1946 averaged 68 kilograms (150 pounds) overweight, while those launched the next year averaged 181 kilograms (400 pounds) heavier. By 1948 the extra weight had grown to 239 kilograms (527 pounds) and in 1949 to 454 kilograms (1,000 pounds). Meanwhile, the rocket had been lengthened 1.5 meters (five feet) to increase the capacity of the instrumented compartment from .45 to 2.27 cubic meters (16 to 80 cubic feet). From 13 to 17 vehicles were launched annually. Near the end of the series one shot was fired to altitude and the configuration reached 206 kilometers (128 miles) above the Earth.

New programs came to White Sands while the V-2 series was carried on. The U.S. Navy brought in the Viking and Aerobee vehicles, the former intended for military applications aboard ship, while Aerobee was a high-altitude research carrier. In 1949 several events occurred which changed the pace, direction and scale of our efforts, resulting in the eventual phasing out of White Sands activity since the supply of V-2s was almost exhausted, but accelerating the work being carried on at Fort Bliss.

One such event concerned Project Bumper which was executed by the General Electric Company under its Hermes research and development contract. Eight V-2 boosters had been assigned to Bumper. This configuration consisted of the V-2 as a first stage carrying an Army-developed liquid fueled rocket, the WAC-Corporal, as a second stage. Of course, staging was by no means a novel idea. Hermann Oberth expressed it mathematically long before. It provides a highly useful technique by which to drop off excess weight in reaching out to longer ranges or much higher altitudes. Its full development and exploitation came in the later vehicles designed to carry manned and unmanned spacecraft. On February 24, 1949, a V-2 carried the Corporal into the upper atmosphere, then was separated while the Corporal's engine ignited and boosted the upper stage to a peak of 402 kilometers (250 miles) altitude (Figure 7).

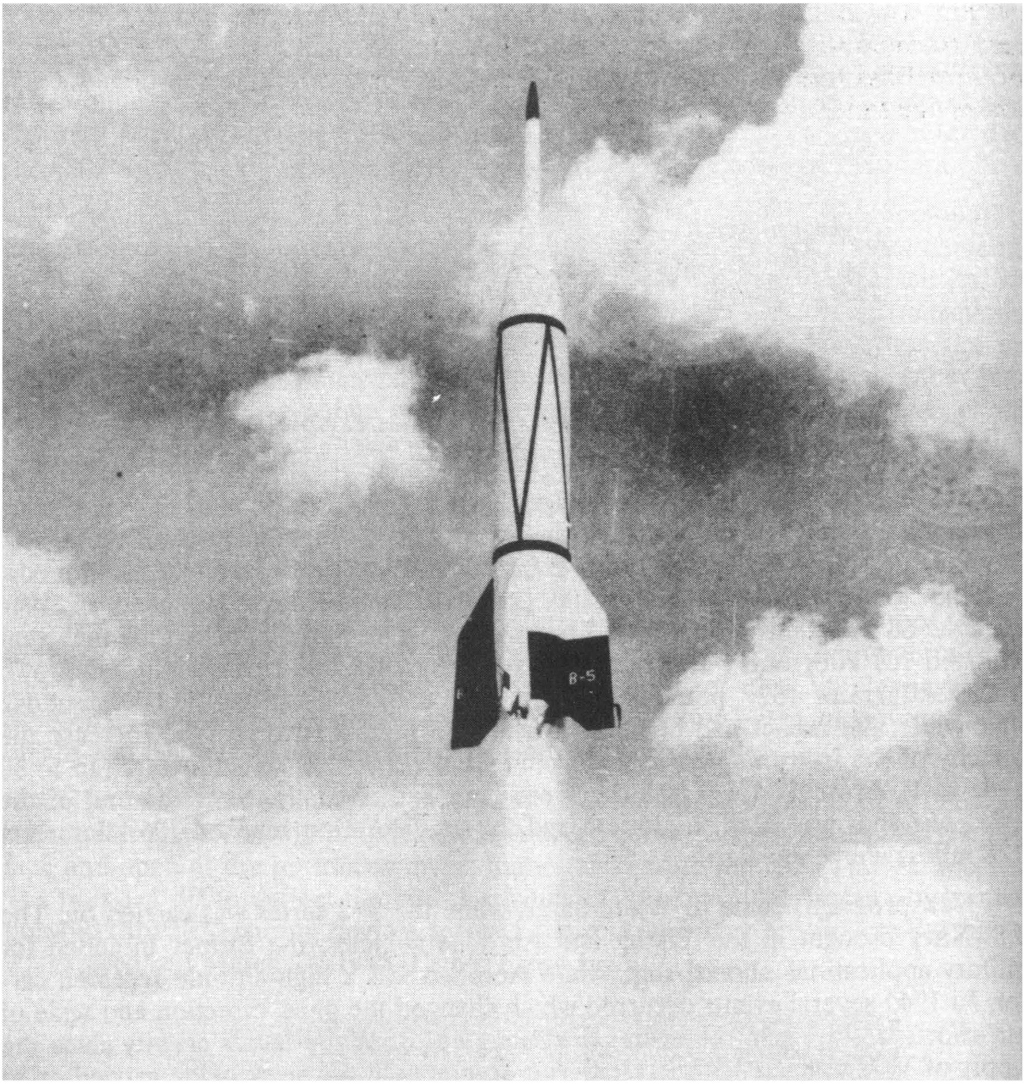

Figure 7 Bumper 5. High-altitude research vehicle to measure ion density. V-2 Rocket and solid rocket Wac-Corporal second stage. Launched February 24, 1949 at White Sands Proving Ground. Reached altitude of 63 miles.

That accomplishment lent new urgency to the search for a test range capable of accommodating vehicles that would travel much farther than the confines of White Sands. Eventually it led to Cape Canaveral on the Florida coast as will be mentioned shortly. At this time, too, the Army decided to consolidate its rocket development projects in a 16,200-hectare (40,000-acre) reservation in northern Alabama. Dr. von Braun and others drove there to examine the facilities of an Army arsenal and returned to White Sands to "sell" us on the advantages of a move. They showed a film of Huntsville, which is the neighboring city, and the arsenal buildings. Wernher's talents as salesman were used effectively on other occasions. This time he made much of the fact that Huntsville offered "nice breezes" in sharp contract with the desert-like surroundings at White Sands. We had, by that time, been reunited with our families and had lived in somewhat cramped conditions in the Fort Bliss reservation, so there was genuine appeal to the opportunity to find homes and settle down (Figure 8).

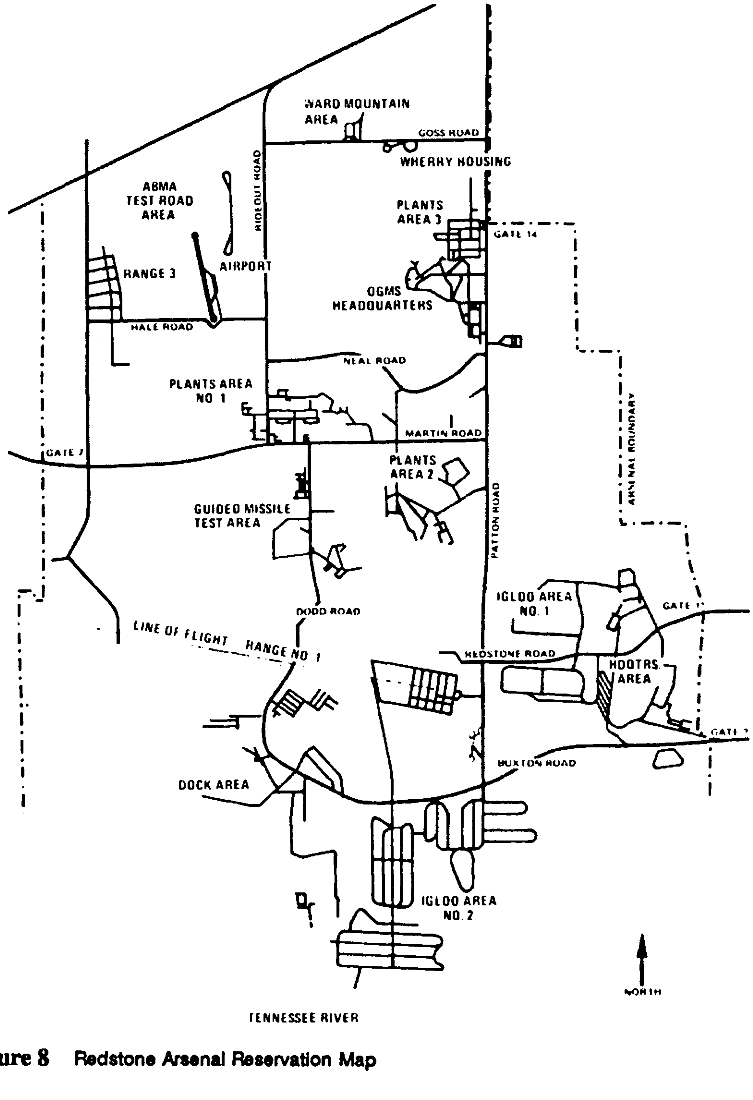

Figure 8 Redstone Arsenal Reservation Map

We had reorganized the so-called project division. Dr. von Braun became chairman of a development board as well as project director. I was his technical assistant and secretary to the board. We retained a test firing group, a static test unit at White Sands. There were 29 sub-groups in charge of assigned technical functions.

While a few V-2s remained, that program was history and the opportunity offered by the Army to undertake the development of a new ballistic missile system brightened the future. We would become part of a larger team made up principally of American-born engineers and technicians, many of them graduates of Southern universities. We would move the technology forward in new surroundings and we would make a contribution to the defense of our new country.

THE REDSTONE PERIOD

There was an obvious parallel in the circumstances in which we conducted research and development projects from 1946 to 1960, first at White Sands Proving Ground and Fort Bliss, later at Huntsville, Alabama, and Cape Canaveral, Florida. As in Germany, the projects were financed by the Army whose primary interest concerned the exploitation of rocket technology for weaponry. There was, I might add, a much happier ending.

In the Spring of 1946 when we began launching V-2s at White Sands with scientific instrumentation, the Army requested the group to investigate the feasibility of vehicles capable of longer ranges. This activity was carried on at Fort Bliss and became identified as the Hermes II project. The General Electric Company pursued several Hermes tasks under Army contract and was instructed to fabricate the Hermes II missile being designed by the German engineers and scientists. General Electric also supervised the assembly of the V-2s and their firings.

Hermes II was not conceived as a weapon system. Rather it would serve as prototype from which later models might grow that would carry heavier payloads over greater ranges. The entire Hermes program was severely handicapped by the lack of engineering data on performance at high Mach numbers in such areas as aerodynamics, temperatures, configurations, weights, and ranges. It was assumed that no ballistic vehicle could survive reentry at ranges beyond 1,127 kilometers (700 miles) because no known material could withstand the extreme temperatures, hence the concept of marrying a modified V-2 with a ramjet evolved. The V-2 would serve as a booster stage from which the ram, called Organ, would be launched at 20,100 meters (66,000 feet) in altitude (Figure 9).

The modified V-2 would burn 54 seconds and attain a maximum velocity of 5,794 kilometers (3,600 miles) per hour. Gyroscopes, servos, jet and air vanes in the ramjet would control the vehicle. Pressurized pistons would separate the ram when the velocity increment carried the vehicle to maximum altitude, then its motor would ignite and burn 400 seconds achieving a velocity of 969 m/sec. (3,180 ft/sec). The motor was a two-dimensional jet with rectangular cells, burning hydrocarbon plus additive and developing 13,113 newtons (2,948 pounds) thrust.

Missile O, first of a proposed series, was launched May 29, 1947 to test the effectiveness of the ramjet diffuser mounted in the nose of V-2 which was programmed for a relatively short flight at low altitude. After four seconds of normal flight, no program occurred. Cutoff was belatedly commanded at 46 seconds. The vehicle attained 79.3 kilometers (49.3 miles) altitude and impacted 76 kilometers (4 miles) away near Juarez, Mexico. Telemeter records of Organ were only partially satisfactory. Two differential pressure readings showed an oscillation of the rocket with a frequency of about one-half per second after 40 seconds burning time.

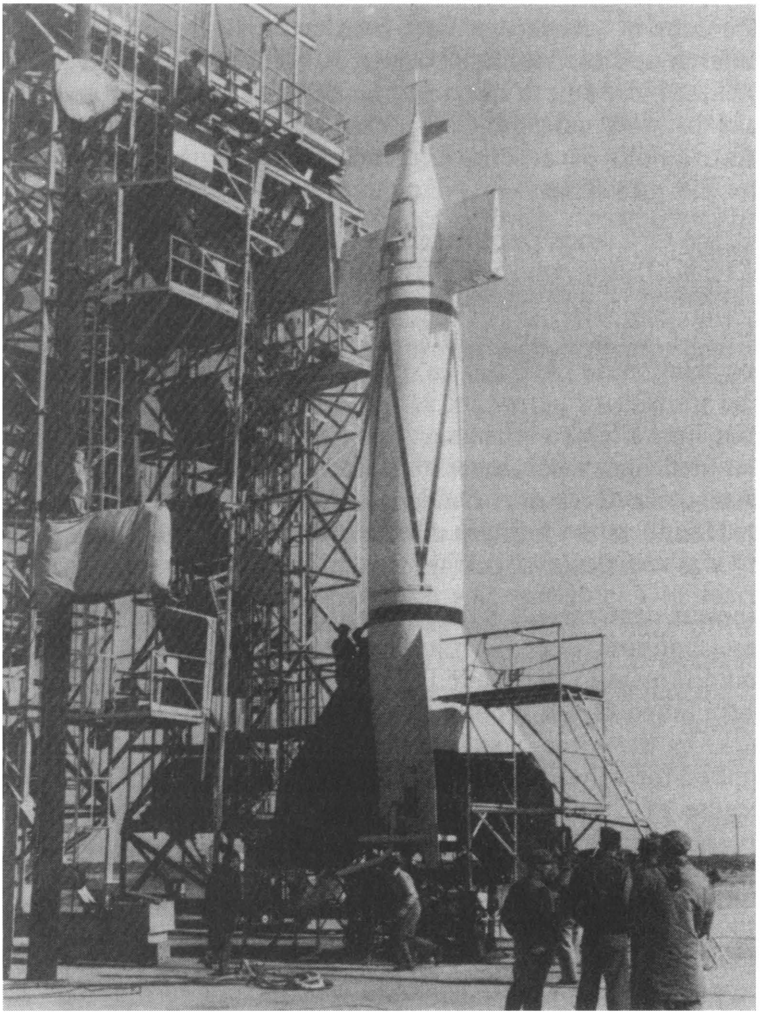

Figure 9 Hermes II-B. Test of aerodynamic stability of the inert second stage. Each stub wing in second stage contained a 12-channel recorder. White Sands Proving Ground.

This episode resulted in an order to stop all launches until an effective safety system could be devised. Three methods were employed thereafter: radar tracking, continuous impact prediction by an electronics system, and the use of sky screens for visual observation. Safety limits were posted on the screens, against which the observers could determine if the vehicle was deviating up or down, or to the right or left.

The Hermes I project continued active for some time and included injection and combustion testing performed at South Lake, California at 2,987 meters (9,800 feet) altitude, wind tunnel testing at Aberdeen Proving Ground, Maryland (which had one of the two available wind tunnels), airflow tests at Fort Bliss and static tests conducted at White Sands. The project was later terminated in favor of the ballistic missile which began to emerge in the mid-1950s.

Since the pace of activities at Fort Bliss cramped the limited facilities such as chemical, material and electronic laboratories, some unidentified miscreants under cover of darkness picked up a quarter mile of fence one night and moved it sufficiently to take in more acreage. Component test facilities and a small production shop were also employed at Bliss to produce missing components for later V-2 firings and for Hermes II items.

By 1948, the Ordnance Department recognized that large facilities were essential. Colonel H. N. Toftoy, who had played a key role in bringing the German group to the United States, urged his Department to consolidate Army rocket development projects at a suitable installation. Ordnance selected Redstone Arsenal, and the adjoining Huntsville Arsenal, a deactivated chemical plant, at Huntsville, Alabama. The transfer of personnel and their families, equipment, and even some buildings from Fort Bliss to Alabama began April 15, 1950, and was completed in October. Our colleagues of General Electric moved with us. Concurrently, the Army established the Ordnance Guided Missile Center at Redstone Arsenal with Major James Hamill as the military director and Dr. Wernher von Braun as technical director. I was von Braun's special assistant.

The five-year contracts we signed with the Army expired in 1949 and we were offered several options. we could return to Germany--about a dozen elected to do so--or we could remain in the United States either to work for Ordnance or accept jobs elsewhere. Some of the group went to the Air Force, others to the aerospace industry which, by that time, was showing increasing interest in rocketry. All who remained applied for American citizenship which created something of a diplomatic problem because of the unusual way in which we had entered the country. The problem was solved by having us taken across the border into Mexico from which we reentered Texas via trolley car for a four-cent fare.

The Guided Missile Center was organized along functional lines which recognized the specializations inherent in our work. There were branches concerned with propulsion, fuels, structures, aerodynamics, guidance, launching and handling, and one which became my chief interest, the launching of experimental missiles. Later, these sub-divisions grew into laboratories.

The first major task assigned to the Center by Army was to investigate the feasibility of a tactical missile system with a range of 805 kilometers (500 miles), which could carry a payload of 1361 kilograms (3,000 pounds) at velocities of Mach 2 or higher, and with target accuracy of 914 meters (1,000 yards). The study would determine whether liquid or solid fuels should be used, the type of guidance system, and whether the vehicle should be a ramjet, or a ballistic missile. When the United States became involved in the Korean War, June 25, 1950, the urgency attached to the study became acute. The results were presented to the Army in January 1951 with a recommendation that a single ballistic missile should be chosen for ranges of

740 to 833 kilometers (400 to 450 nautical miles); beyond that, a two-stage ballistic missile was preferred.

The army approved the single-stage version, emphasized the importance of accelerating development and instructed the Center to use available hardware whenever possible. We selected a propulsion system developed by North American Aviation as booster for the Navaho project of the U.S. Air Force. Basically, this was a redesigned and improved version of the V-2 engine which could be further modified and put into quantity production by late summer of 1951. The bipropellant liquid- fueled engine had a fixed thrust of 347,000 newtons (78,000 pounds) for a maximum period of 121 seconds. It was regeneratively cooled by circulating the ethyl alcohol around the combustion chamber. Energy was provided by 75 percent combination of alcohol and liquid oxygen which were transferred to the chamber by high-pressure pumps driven by a steam turbine. In turn, the turbine was propelled by decomposed hydrogen peroxide which formed high-pressure, high-temperature steam.

Three guidance and control systems were evaluated. One was a phase comparison radar concept of General Electric, another was the AZUSA system of Consolidated Vultee Aircraft Company, while the third was the inertial guidance system which grew out of our work at Peenemuende. We preferred the latter because it could provide target accuracy of 457 meters (500 yards) or less, which was better performance than the military required, and it was available. The heart of the system was a stabilized platform which provided a space-fixed frame of reference and was correctly positioned at the launch site. The entire system could measure any deviation in attitude or displacement from the programmed trajectory. Three computers for lateral guidance, range guidance, and cutoff kept the missile on course and terminated thrust. By adding reentry control, the miss distance relative to target could be reduced to 137 meters (150 yards).

New directions came in February, 1951, when the Army increased the payload requirement to 3,139 kilograms (6,900 pounds) in order to accommodate the most efficient atomic warhead. Since time was of the essence, range would be limited by the available engine. Thus the system would have an operating range of from 80 to 320 kilometers (50 to 200 miles). The army wanted the highest reliability in a mobile system for deployment in the field army. K.T. Keller, then director of guided missiles for the Secretary of Defense, conferred with Guided Missile Center officials and agreed upon a development period of 20 months leading up to the first flight test. The Center and industry would fabricate the research and development vehicles, design and build ground equipment, and construct new facilities required at Redstone Arsenal. After several changes in names, the weapon system was officially designated Redstone on April 8, 1952.

The Center was to provide 12 test missiles by May 1953, with launching and handling equipment, in three lots of four vehicles each. Lot 1 would be ready by January 1953 in order to test the propulsion system, missile structure, booster control system and the roll control between cutoff and warhead separation. Lot 2 would test warhead separation, spatial position control of the warhead, its maneuverability during the descent phase, and measure aerodynamic heating and stresses. Lot 3 would focus on performance reliability, the inertial guidance system, tracking, spatial position control, terminal guidance, improved launch procedures and personnel training. Of equal importance in the military application, the system was internally self-contained and hence immune from external influence. Neither could an enemy by use of radio beams or other devices derive position data by which to locate the launch site.

The Atomic Energy Commission and its contractor, Sandia Corporation, would furnish warheads. Picatinny Arsenal and the Diamond Ordnance Fuze Laboratories supplied adaption kits, the radio proximity fuzes, safety and arming mechanisms. Army engineers developed special vehicles to carry liquid oxygen and hydrogen peroxide and furnished air compressors, fire fighting equipment and theodolites. The Missile Center developed the missile transporter and erector together with other control and measuring equipment and carriers.

Redstone's development program commenced May 1, 1951 and continued seven and one-half years, terminating with the last research and development launch, November 5, 1958. Between those dates, many changes in the hardware took place involving tracking and telemetry systems, fabrication, assembly and propulsion. The engine contractor supplied seven different versions of the power plant and introduced such improvements as a liquid oxygen pump inducer to prevent cavitation, full flow start, gage pressure thrust controller, and absolute pressure thrust controller. Early Redstones employed an autopilot control system. Components of the inertial guidance system were carried as passengers which expedited the development of the complete system tested for the first time on Redstone Nr. 11, September 21, 1955 (Figure 10).

Industry supplied fuselage, guidance components, and many other items. Chrysler Corporation was selected as prime contractor and fabricated Redstone missiles in a Government-owned plant in Michigan. Missiles 1 through 12, and 18 through 29 were built by the Guided Missile Center while Chrysler produced Nrs. 13 through 17, and all of the missiles from Nr. 30 on. Thirty-seven were launched in the research and development phase but only 12 of these were flown exclusively in support of the Redstone program. The others contributed to the follow-on Jupiter missile which will be discussed later. In all, 62 Redstone missiles including the tactical version were produced before the program ended in 1960 as the lighter and more mobile Pershing missile succeeded Redstone.

Our relations with industry were both challenging and, in the end, highly satisfactory. We insisted upon quality and reliability standards that were unprecedented, and specified tolerances and precision that seemed almost impossible. But there was healthy curiosity and excitement about this new field. Chrysler put engineers in the laboratories at Redstone Arsenal to acquire at first hand the techniques of fabrication and assembly. Drawings of dies, tools, jigs and fixtures were turned over to the contractor to assist in setting up his production line.

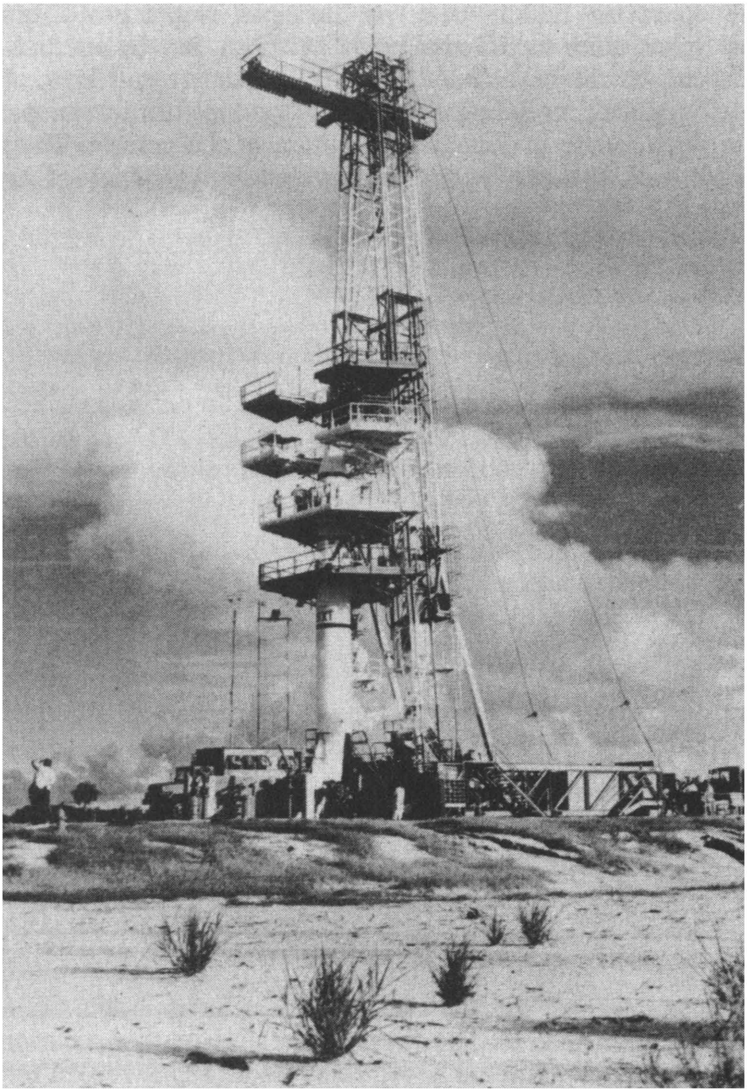

Figure 10 Redstone Missile No. 4, upper portion partly concealed by work platforms, at Pad 4, Cape Canaveral, during the 1953-4 series of tests prior to construction of Launch Complex 5 and 6. This pad was located near the tip of Cape Canaveral.

There was good reason for our seemingly arbitrary concern with reliability. From painful experience during the Peenemuende development, we clearly understood the direct relationship between high reliability and high accuracy in the guided missile. The U.S. Army wanted better than 90 percent reliability in Redstone and specified the maximum circular probable error at the target. In February 1952, I presented Center management a proposal to elevate reliability functions to top level and install the program in every organizational element concerned with the Redstone development. The proposal derived from analyzing guided missile systems and concluded that any part could be classified as "parallel". or "series" in operation. Failure of a "parallel" part would probably not result in failure of the system since its function could be taken over by another part. Failure of a "series" item, on the other hand, would ultimately result in total failure. For example, relay contacts, soldering spots, tubes or most structural parts would, if they failed in flight, cause malfunction or failure of the vehicle. The fact was that overall reliability of the whole system equaled the product of the individual reliabilities of all series components.

1. A guided missile having 100 series components, each component having an average reliability of 99 percent, will probably succeed in only 36.5 percent of firings.
2. If there are 300 series components of the same average reliability, the chances for success are reduced to 5 percent.

While this appraisal stirred up considerable argument, management created a reliability office and the program was installed within the Center and contractor organizations. This initial beginnings of reliability considerations have evolved into today's complex management systems.

During the White Sands period, the pre-launch and launch functions were performed by a team made up of cadres from several different elements of the project. No one organization had the overall responsibility for checkout, assembly, testing and launch operations. Looking ahead to the demands of the Redstone and subsequent programs, I advised Dr. von Braun that in the long run we would require an integrated group responsible for the launch phase. As a consequence, I established the Experimental Missile Firing Laboratory.

Having taken over direction of the Laboratory, I drove to Florida in early 1952 with my deputy, Dr. Hans Gruene, the first two employees of today's Kennedy Space Center, to look over the Joint Long Range Proving Ground which had been established in 1949 with headquarters at Patrick Air Force Base and launch sites at Cape Canaveral, 24 kilometers (15 miles) north on the Atlantic Coast.

Two years earlier, a military-civilian team from White Sands launched the first rocket from the Cape. This was the same Bumper configuration flown at the New Mexico range in February 1949. The two-stage vehicle on that occasion attained an altitude of 402 kilometers (250 miles) which stood as a U.S. record for some years. It consisted of a modified V-2 as booster atop which was mounted a liquid fueled Wac (without any control) Corporal rocket. The flight returned data on separation and ignition of a second stage, its stability of high velocities and altitudes, and the aero-dynamics effects of high Mach numbers (Figure 11).

We found the Cape a sparsely developed promontory. One quonset hut accommodated military and civilian personnel engaged in flight testing ramjet vehicles and an air defense system. The military had selected the Florida site for missile testing by Army, Navy and Air Force because of its favorable climate, the availability of hangars and other structures at the World War II air base, and the opportunity to launch over open ocean across a wide band of azimuths ranging from 45 to 110 degrees with available island chains as fixed base measurement platforms. The United Kingdom permitted the United States to construct and operate tracking stations along the 8,000 kilometers (5,000 mile) stretch of ocean on Grand Bahama Island, Eleuthera, San Salvador, Grand Turk, Antigua and Ascension. Puerto Rico became another tracking site. Cape Canaveral offered a secure base where missiles could be checked out, assembled, fueled and launched without danger to the relatively small communities separated from the Cape by the Banana and Indian Rivers (Figure 12).

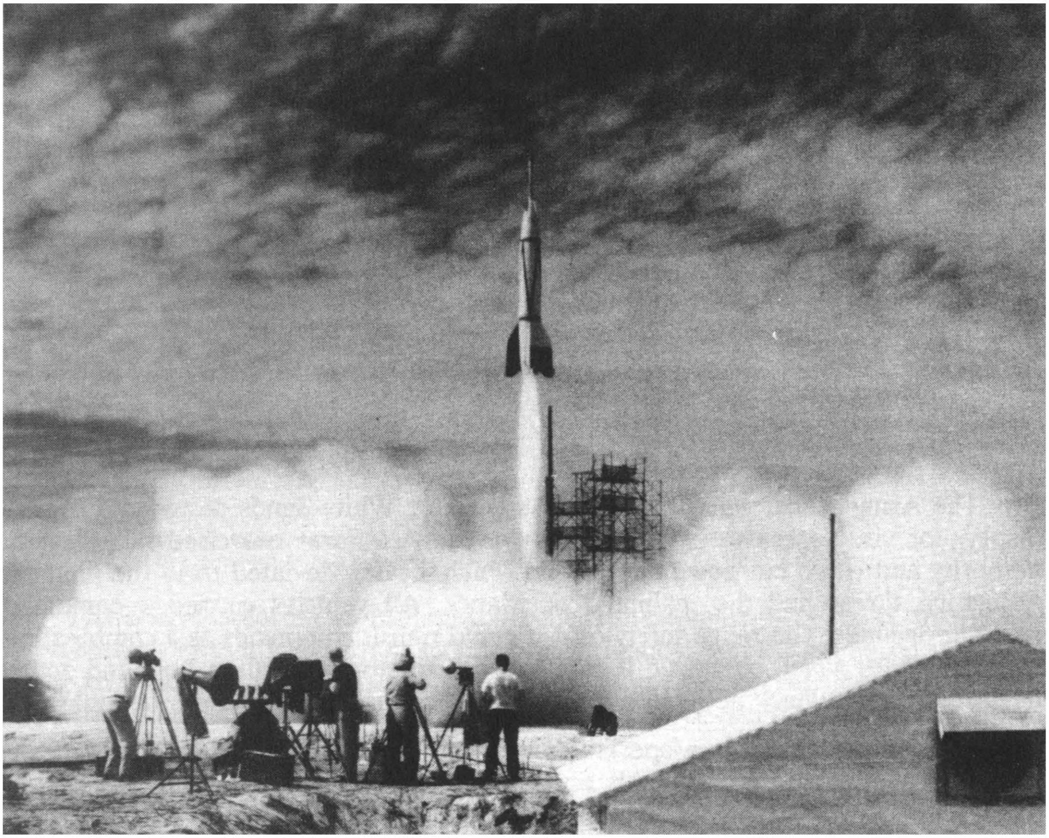

Figure 11 First rocket launched from Cape Canaveral July 24, 1950, was the WAC Bumper configuration. The V-2 became the booster, atop which was the liquid propelled Corporal rocket developed by the Army. A similar vehicle established an altitude record at White Sands of 250 miles.

There were disadvantages, too, including a mosquito problem that required some years to bring under control; poisonous snakes, corrosion, and limited transient accommodations. Tracking and telemetry systems could not satisfy the Redstone requirements. They could not predict impact. To remedy some deficiencies, the Army procured radar which was installed by the Air Force at Grand Bahama Island. Later, we added ballistic cameras for high-precision tracking and calibrating of electronic systems such as the Doppler, Beat-Beat and others. As the Redstone test program got underway, it was determined that Grand Bahama had not been properly located on the map which caused a mis-match between various surveying methods. This error was corrected.

AIR FORCE MISSILE TEST RANGE

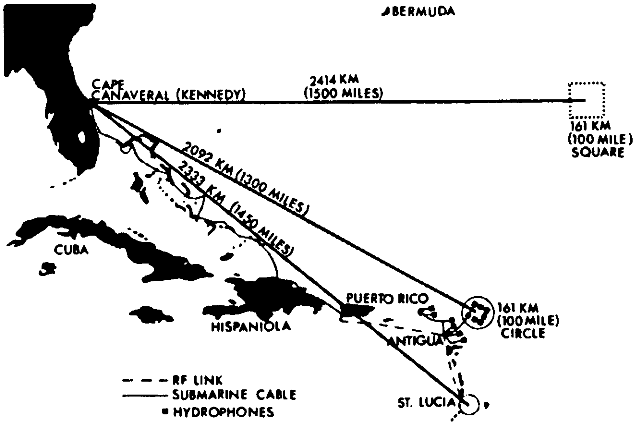

Figure 12

The Army officer who devised sky screens for White Sands designed a similar display for visual observation of Redstone. The Air Force exercised range safety authority and could cut down any missile which, having deviated from the planned trajectory, threatened the mainland or islands. All vehicles carried a command receiver/decoder. The range safety officer could transit commands as a combination of audio tones which energized a cutoff device to stop propellant flow and active destruct circuitry which detonated explosive charges usually placed on the tanks.

The base for Redstone operations was established in June 1953. This meant sharing a quonset hut with the Air Force. A converted oil derrick was modified to become the first service structure. Ground instrumentation was housed in trailers. Later the Air Force built a launch complex consisting of a heavily reinforced blockhouse situated between two launch pads. The pads were connected by rail over which the mobile service structure was moved to support a vehicle on either pad (Figure 13).

Redstone Nr. 1 was shipped from Huntsville to the Cape by air. All of the ground support equipment was transported by train. While the missile was in transit, we desperately tried to locate the Service Structure which was being shipped disassembled by special rail cars across country from the Noble Company in Oakland, California. Dr. von Braun called me frantically every few hours until we finally located the structure. When it arrived, we conducted parallel assembly and erection of both the structure and the Redstone. As a section of the missile was erected on the pad, we assembled the Service Structure frame to the same height and then continued to build up both concurrently. The small initial cadre of Firing Laboratory personnel were augmented by larger numbers from other Guided Missile Center branches and we drove to Cape Canaveral. We continued this operating mode, returning to Huntsville after each firing, driving back to the Cape for the next launch until the Firing Laboratory had built up enough strength to become an independent unit and the firing rates reached a frequency that made it necessary to move the launch team to Florida where they established homes.

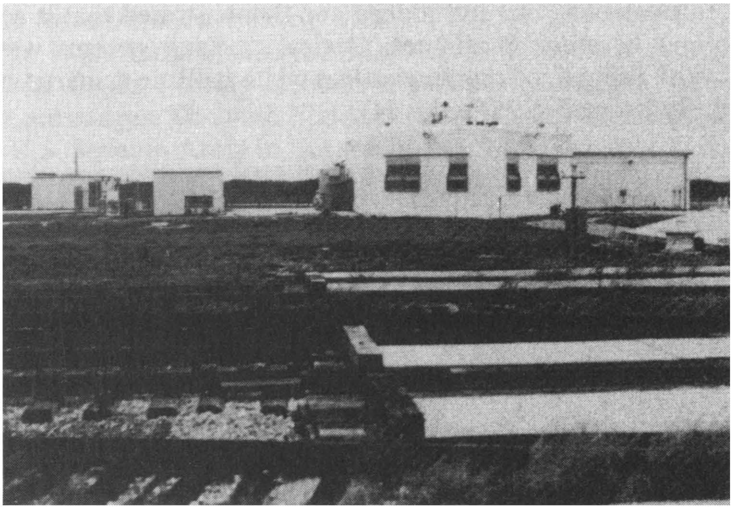

Figure 13 Early Cape blockhouse facing adjoining launch pads. Portable service structure moved on rails between pads.

The launch occurred at 9:37 A.M. Eastern time August 20, 1953. A 16-channel telemetering system was carried to yield performance data on structural temperatures and vibrations, the propulsion systems, flight mechanics, steering control, takeoff and cutoff signals and lateral force. Thrust build-up was normal and liftoff occurred at 2.7 seconds after mainstage initiation. Acceleration occurred rapidly and remained steady. The missile was stable and normal programing could be visually observed. At 42 seconds the missile passed through a layer of clouds and could not be seen. From the telemetry data, it was determined that the missile rolled shortly after the 50th second and went out of control. Due to erratic behavior, the flight safety officer transmitted cutoff command at 106 seconds, followed by automatic separation three seconds later. RS-1 had flown and produced a great deal of useful data including radar and telemetering for the entire flight, photographic coverage and visual observations.

It did not take long to ascertain the cause of the roll. Having retraced the launch preparations, we learned that an engineer from Huntsville, who wanted to ensure that connections had been tightened, mistakenly applied his screw driver to a potentiometer, thereby changing the electrically determined zero position of rudders. It was neither the first nor last of human errors which imperfect man commited.

Redstone Nr. 2, launched January 27, 1954, performed normally and the success ratio moved rapidly up the scale as three more missiles were launched that year, six in 1955 and 10 in 1956. Among the latter was the first produced by Chrysler. Thirteen were flown in 1957 and eight the following year. In 1954, Redstone began carrying the AZUSA transponder, named for the California town where it originated, which, linked to ground stations, enhanced the accuracy of the tracking. A new system called DOVAP, or Doppler Velocity and Position, was brought on line later in 1954 by Karl Sendler of our group. Later that year a modification of DOVAP, called Beat-Beat, was introduced and demonstrated that it could measure angular deviations of about 3 minutes. Optical tracking systems were employed from 1953 onward, using fixed metric cameras while ballistic cameras were installed beginning with Redstone Nr. 9 (Figure 14).

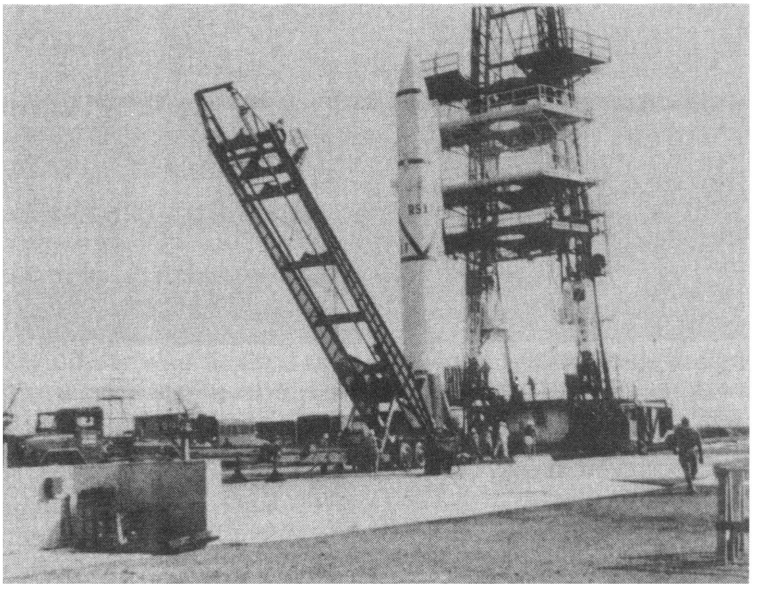

Figure 14 Redstone being erected at the launch pad. Vehicle at left served as combination transporter/erector.

A missile impact location system which utilized hydrophones to detect underwater sounds was added in 1955. As a result of the more efficient tracking systems and the impact locator, several Redstone boosters were recovered which had been targeted to impact in shallow water off Grand Bahama Island.

Advances in telemetry were of paramount importance. We had groped for answers at Peenemuende with primitive devices. Better results were obtained at White Sands with a pulse position modulation system which transmitted measurements on an amplitude modulated carrier. By 1953 a 16-channel system was available which was upgraded to 18 channels for the tactical Redstone. Eighteen different channel frequencies (subcarrier frequencies) could be applied to modulate the RF carrier either individually or one bit of data by timesharing or commutation. Sixty measurements could be taken on a Hermes flight, while the number increased to 116 for the Redstone system.

In mid-1955 the Army began training troops for eventual deployment of the missile system, concentrating instruction at Redstone Arsenal where a Guided Missile School had been established. To expedite fielding the missile, the troops utilized developmental missiles and later were equipped with a Redstone trainer built by Navy specialists. The 217th Field Artillery Battalion assigned soldiers to the test, launching and handling, systems analysis and reliability laboratories, and the Cape Canaveral site for on-the-job training with the missile and related ground equipment. The first troop launch occurred May 16, 1958, while the second was conducted at White Sands Proving Ground which was thereafter used for practice firings at reduced ranges. The 40th Field Artillery Missile Group deployed the system with the U.S. Seventh Army in Europe in July 1958. The 46th Group arrived in Europe April 25, 1959 in support of Seventh Army and NATO.

Redstone was destined to a brief lifetime as a weapon system and was overtaken by the two-stage, solid propellant Pershing. But it played significant roles in several other programs. As a carrier for components development, it enabled us to expedite the Jupiter missile which was brought from start to deployment within three years. Redstone boosted the first U.S. satellite in January 1958. Three years later it carried the first American astronaut, Alan Shepard. It is doubtful if any other single development program has ever produced such a rich harvest. (Figure 15)

THE JUPITER PERIOD

As the Redstone missile neared the halfway point in its development and flight test cycle, the military began to show an interest in a 1,600-kilometer (1,000-mile) missile capable of delivering an atomic warhead.

The Guided Missile Group had prepared a study along these lines, believing that the scientific and technical competence demonstrated in Redstone justified a challenging new project. The study proposed a two-stage ballistic vehicle, with the advantage of maneuverable warhead, and suggested further investigation to determine if a single-stage missile could satisfy the range requirement. There was still that physical barrier of reentry heating o be removed. In this connection, the development team pointed out that Redstone tests then in progress could help find the answer. Furthermore, North American Aviation was on the verge of demonstrating a power plant of 667,000 newtons (150,000 pounds) thrust. This could be applied to Redstone, or a new configuration.

While the Army weighed its missile development capabilities against competing demands for other future weapons, the Technological Capabilities Panel (otherwise known as the Killian Committee) recommended an immediate program leading to the development of small artificial satellites and an intermediate range ballistic missile system of the 2,400-kilometer (1,500-mile) class that would run parallel in development with the 8,000-kilometer (5,000-mile) intercontinental missile under Air Force sponsorship.

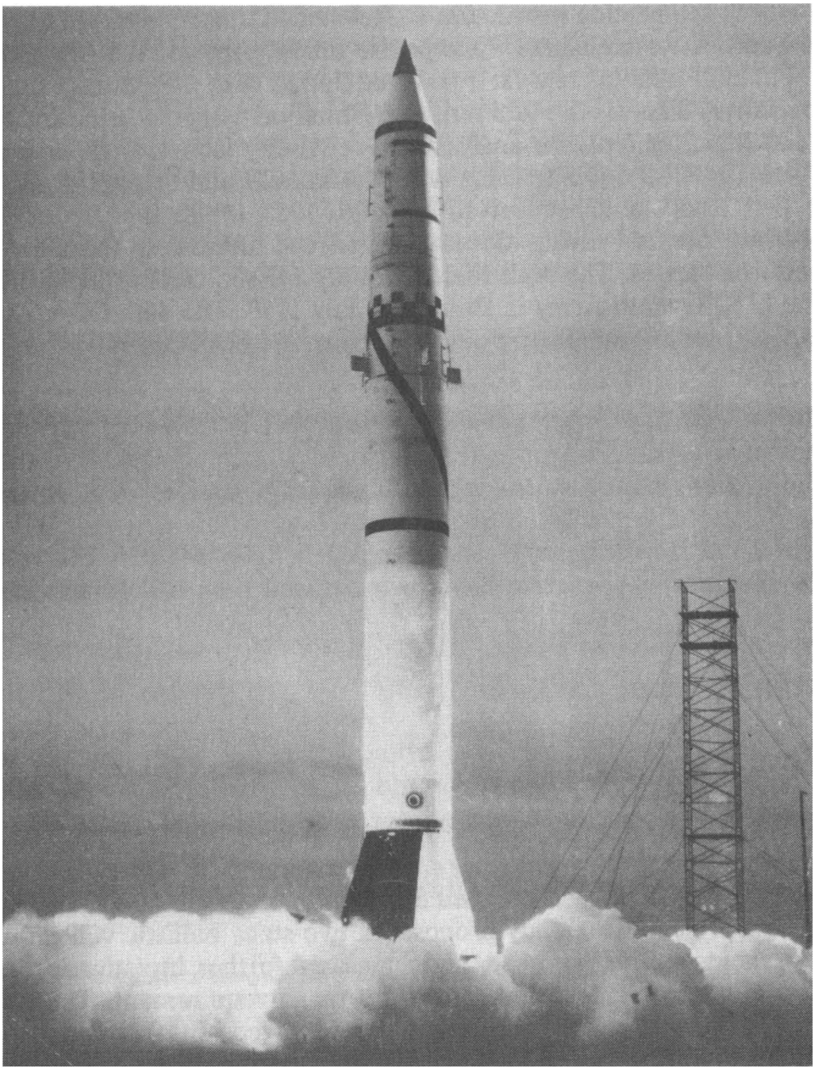

Figure 15 Liftoff of Redstone missile from Launch Complex 56 at Cape Canaveral.

In July 1955 the Guided Missile Center proposed a single-stage missile designed to carry a 907-kilogram (2,000-pound) payload over the 2,400-kilometer (1,500- mile) range. Nuclear technology had progressively reduced the size and weight of the atomic package which enhanced the feasibility of both intermediate and intercontinental range systems. The new NAA engine was adequate to the need, burning kerosene and liquid oxygen for 119.3 seconds maximum. Two vernier thrust nozzles releasing hydrogen peroxide at 4,450 newtons (1,000 pounds) thrust, and activated by the guidance and control system, would be used for steering and would eliminate fins. Six small nozzles would provide spatial control in pitch, yaw and roll. The engines could be hydraulically swiveled.

Following considerable debate in defense circles, Secretary Charles E. Wilson authorized parallel development programs. The Air Force would proceed with a Thor ballistic missile system for fixed site deployment. The Army proposal was accepted with a stipulation that its system must also satisfy the Navy need for a ship-based intermediate range missile. The dual requirement, of course, complicated the Jupiter development, as the system was named. The Army's concern was so acute that a new organization, the Army Ballistic Missile Agency, was created to absorb the Guided Missile Center team and the Redstone missile program as well. Major General J. B. Medaris assumed command at Redstone Arsenal February 1, 1956, with assurance of the highest national priority in support of Jupiter.

The former Guided Missile Center work force of 1,600 became the nucleus around which ABMA fleshed out total employment of about 5,000 civilians. Dr. von Braun was named director of the Development Operations Division which comprised a grouping of laboratories quite similar to the predecessor organization. I became director of the Missile Firing Laboratory. The City of Huntsville had tripled its population in the five years since the Army grouped its rocket developments at Redstone Arsenal. Now it had to prepare housing, schools, hospitals and other services for more thousands of Government and contractor employees. Chrysler Corporation was selected as prime Jupiter contractor. The Navy agreed to release additional space in the same plant in Michigan where Chrysler was producing Redstones.

New facilities were needed at Redstone Arsenal which had acquired a test stand, guidance and control laboratory, and a large engineering building under impetus of the Redstone program. A guided missile test shop, structures and mechanics laboratory, missile inspection assembly hangar, and a much larger test stand, were constructed while some of the 1954 buildings were enlarged. The Jet Propulsion Laboratory in Pasadena, California, an Army contractor for years, obtained a new engineering building in support of Jupiter. Another launch complex was built adjacent to the Redstone launch facilities at Cape Canaveral.

Six weeks after the establishment of ABMA, on March 14, 1956, the first Jupiter A missile was launched successfully. Actually this was Redstone in new guise as a test bed for Jupiter components while also supporting the development of the lighter and less powerful launch vehicle. Over the next two years 19 converted Redstones carried the Jupiter program forward.

We planned to assemble the first 10 Jupiter missiles at Redstone Arsenal, procuring major assemblies and components from prime contractors, fabricating others in-house or making modifications for special missions as required. Thereafter, through Prototype Nr. 18, Chrysler would build half and the Arsenal half at the rate of two vehicles per month to a total of 50.

The Navy would develop the ship equipment, while the Army developed and produced the missiles. The two services settled upon a configuration 17.7 meters (58 feet) in length and 267 centimeters (105 inches) in diameter, controlled by an all-inertial system with a 1,500-meter (4,920-foot) miss distance allowable at target. This would require propulsion cutoff within very close limits. For a while, a parallel development was pursued to supply a radio inertial guidance system based upon coded Doppler radar command. The army would provide transport vehicles for its own version of Jupiter which was to be a mobile system comparable in development to the Redstone concept. During the White Sands period, some of our group participated with the Navy in a ship-borne launch of the V-2. We had that meager a knowledge of the environment.

Twelve Redstone vehicles were earmarked for modification as composite reentry test configurations. The missiles would carry a tub-like shell within which scaled-down, solid propellant Sergeant rockets would be housed, 11 for the second stage and three for the third stage. Atop the tub, model nose cones were to be carried to test reentry heating solutions. Even as these plans were becoming firm, the Department of State and Defense Department requested demonstration of a ballistic missile at more than 1,600 kilometers (1,000 meters) range.

We knew that the higher Mach rate developing on the down leg of ballistic trajectory at 2,400 kilometers (1,500 miles) would melt steel in the thermal barrier. So the Arsenal laboratories set about researching candidate materials while concurrently exploring four possible protection schemes to protect the warhead within the nose cone from these extreme temperatures. Heat sink, radiation, transpiration and ablation techniques were investigated. The ablation, or melting ice principle, won out. The Air Force development organization preferred the heat sink mode and conducted extensive development. In the end, however, Air Force space vehicles also employed the ablation technique. Then the search concentrated on plastics, fibers, ceramics, metals or combinations, all of which were tested in jet burners.

It was clearly understood that solving the reentry problem would be a breakthrough of major consequence having implications beyond the immediate IRBM requirement. Hence the work was conducted in secrecy and the first flight of a model nose cone with ablative protection was classified Secret. The launch vehicle consisted of a high-performance Redstone as first stage and two clustered stages of solid-propellant motors developed by the Jet Propulsion Laboratory as the second and third stages. The solid motors were about 122 centimeters (four feet) long and 152 millimeters (six inches) in diameter and were scaled versions of the Sergeant missile motor. Eleven of the rockets were clustered in a ring forming the second stage, while three identical rockets were fitted inside this ring as the third stage. Each solid motor would generate about 7,100 newtons (1,600 pounds) thrust in space.

The booster was modified to increase tankage so that it held more fuel and oxidizer and thus extended the engine burning time.

The engine was modified to burn a more powerful fuel called Hydyne (unsymmetrical dimethylhydrazine). This increased first-stage thrust to 370,000 newtons (83,000 pounds). The forward section of Redstone was strengthened to support the launcher containing the upper stages, and a spatial attitude control system was designed to align the instrument section and upper stages precisely with the local horizon at the trajectory apex following booster separation.

The upper stages sat in an aluminum tub-like container which rested on a conical projection atop the instrument section. Two electric motors spun the tub, which was rotated at high speed to provide ballistic stability and reduce the effects of thrust dispersion. The principle is the same as rifling which spins a bullet as it travels through the barrel of the rifle (Figure 16).

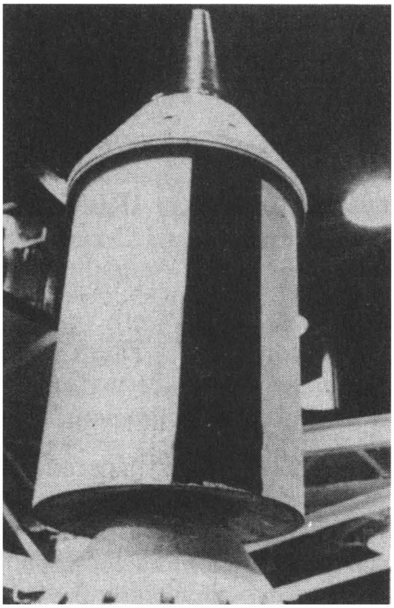

Figure 16 This is the spin tub cluster boosted by the modified Redstone vehicle which formed the Jupiter Composite Reentry Test configuration. The second and third stages were made up of solid propellant, scale size Sergeant rockets carried within the tub. Atop is a scale model nose cone.

Jupiter C was launch the first time September 20, 1956. The rocket hurled its payload 1,098-kilometer (682-mile) into space and 5,366-kilometer (3,335-mile) down the Atlantic range, surviving reentry beyond question. Thus the hybrid vehicle established a distance record that stood until the intercontinental ballitic missiles appeared. A second firing May 15, 1957, carried a scale Jupiter IRBM nose cone. While a guidance malfunction carried the cone out of the target area and prevented recovery, telemetry indicated that the cone withstood the reentry heat. A third Jupiter C, launched August 8, 1957, tested a one-third scale model of the Jupiter IRBM nose cone. The cone was picked up by the Navy after a 1,930-kilometer (1,200-mile) trip and a penetration of 966-kilometer (600-mile) in space. This was the first manmade object ever recovered from outer space. The flight also proved the feasibility of the ablative treatment; i.e., the outer covering slowly burned away, carrying off excessive heat, and left intact the object within the cone. The same principle has been applied in other military missiles and the U.S. manned space flight program. This completely successful test resulted in termination of the series since there was no further reason to demonstrate that the ablative material would indeed safeguard the warhead of the full scale Jupiter. A little surprise awaited General Medaris. We had placed a letter addressed to him inside the cone and later presented it to the ABMA Commander as the first true rocket-carried mail which traveled over IRBM range. That letter is displayed in the Smithsonian Institution in Washington, D.C.

Less pleasant news came from the office of the Secretary of Defense, December 8, 1956. The Navy was permitted to withdraw from the Jupiter program in order to proceed with development of a solid-propellant vehicle, Polaris, which would be carried in submarines and which would have the same range capability. Nine months of work by the ABMA team in navigation, ship motion, missile guidance, launching and handling, submarine applications and fuzing requirements for the ship-carried Jupiter system were lost. The Navy did, however, continue to work with the team in guidance and control development and supported nose cone recoveries. The Department of Defense also assigned IRBM vehicles to the Air Force and Navy while limiting the Army to systems of 322 kilometers (200 miles) range. It was no coincidence that this was the Redstone capability.

For some months, while the Jupiter work proceeded, a cloud of uncertainty hung over the Arsenal and its contractors. There was apprehension that the program might be canceled since the Air Force was proceeding with its Thor system and the Navy had initiated the Polaris development.

While the Department of Defense considered the alternatives, events were shaping up elsewhere that were to have a strong bearing on the outcome. The United States, the Soviet Union and other nations were participating in an International Geophysical Year devoted to scientific research. In October 1957 the Soviet Union made a notable contribution by launching the first artificial satellite, Sputnik, and startled the United States by this display of technological prowess. Soon after, the President approved a recommendation by the Secretary of Defense to accelerate development of both Thor and Jupiter, which would be fielded by the Air Force.

Following the Navy's withdrawal, the configuration underwent changes. Jupiter would be 17.7 meters (58 feet) long, with a diameter of 2.67 meters (8 feet, 9 inches). It would be made up of three units: the ablative heat-protected nose cone, warhead, fuzing and arming devices and their power supply; an aft unit containing the guidance and control system, vernier engines and jet nozzles, and a thrust unit containing propellant tanks, engine and tail section. The gimbaled engine would respond to seven degrees, plus or minus, in pitch and yaw. Its electro-hydraulic actuator system would receive signals from the guidance and control unit. Two turbine-operated pumps would be propelled by a gas generator burning kerosene and liquid oxygen supplied by the main tanks. The radio inertial guidance scheme was dropped in favor of the all-inertial system (Figure 17).

There were some innovations. The thrust unit effected roll control by deflecting exhaust gases from the turbine and swiveling the turbine exhaust nozzle. Fine control of cutoff velocity of the body section, after separation of the thrust unit, was provided by a solid-propellant unit rated at 2,224 newtons (500 pounds) thrust for

20 seconds, which energized a vernier thrust system mounted on the aft section. Outside the atmosphere, and separated from the thrust unit, the missile was controlled by eight jet nozzles equally spaced on its body for pitch, yaw and roll. They were powered by nitrogen supplied from storage bottles within the body. Two spin rockets at the base were activated to impart a 60-rpm rotation at the correct attitude, after which nose cone separation occurred. No controls were applied to the nose cone.

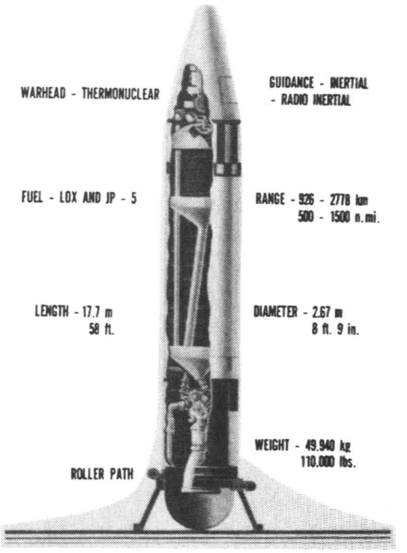

Figure 17 Jupiter Specifications.

At full range, total flight time was 1,016.9 seconds. Main engine cutoff occurred at 157.8 seconds at a velocity of Mach 13.04. The thrust unit separated at 161.8 seconds when vernier start occurred and vernier cutoff came at 173.8 seconds. The nose cone separated at 339.3 seconds. Reentry at Mach 15.45 began at 950 seconds about 100 kilometers (62 miles) above the Earth. At impact, aerodynamic drag reduced the velocity to Mach 0.49.

Jupiter was launched for the first time March 1, 1957. The missile lifted off normally and followed the planned trajectory 74 seconds to an altitude of 14,630 meters (48,000 feet) when it broke up. The failure was caused by overheating in the tail section. On April 26, the second vehicle was fired to test the airframe and propulsion system. The flight terminated at 18,290 meters (60,000 feet) altitude and 93 seconds because of propellant sloshing which caused instability.

How the development organization reacted to the sloshing problem illustrates the interplay between its elements. We knew that the large mass of propellants had been excited by pitching the vehicle into its programmed turn. As the sloshing continued the momentum overrode the capabilities of the control system to compensate for the load. During the next 24 hours there were meetings between the guidance and control specialists, the structures experts, representatives of the Test and Aeroballistics Laboratories and others who could make a contribution. Within

48 hours it was decided to construct a test rig. This consisted of full-scale tanks from a Jupiter mounted on a railway truck which rode on tracks. It could be driven at various speeds with fully loaded tanks to duplicate the sloshing phenomenon. The total cost of the rig was less than $40,000. The "fix" took the form of cylindrical cans which floated in the fuel. The lower portion of the can was perforated. These cans were dropped into the tanks to stabilize the liquid. Subsequently, baffles were installed in the tanks.

Jupiter Nr. 3, carrying the "beer cans" as they were called, was launched May 31, 1957 to test propulsion and control systems. All phases of flight were successful. Impact occurred short of the estimated 2,600 kilometers (1,400 nautical miles) target area. It was the first IRBM firing in the Western world and it occurred 15 months after the Army Ballistic Missile Agency had initiated the development program (Figure 18).

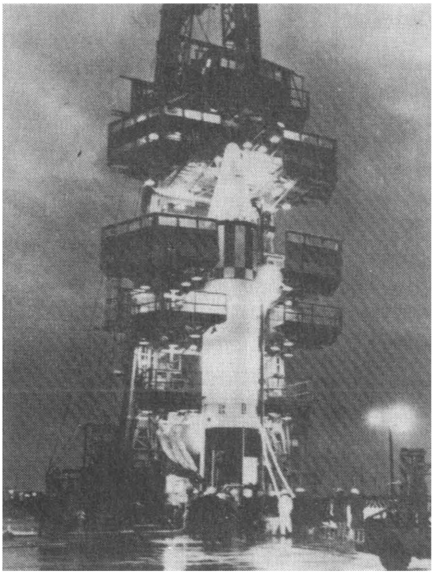

Figure 18 Jupiter missile enclosed by service structure at Cape launch pad.

The turbo pump caused two subsequent Jupiter missiles to fall short of nominal performance. Missile Agency laboratories were able to reproduce the failure and pinpoint the cause. It was an off-the-shelf type gear procured by the engine maker who was a bit unhappy until he saw the facts. Then the gear was replaced. The same item had contributed to the failure of Thor in research and development flights; essentially, the same engine powered both IRBM's.

Tracking and telemetry improvements were introduced at Cape Canaveral during the Jupiter series. Beginning in 1957 an ultra-high frequency Doppler transponder was carried which, while very similar to the DOVAP arrangement, provided greater resolution, less ionospheric refraction effects and less flame attenuation. Electronic sky screens determined angular missile deviations by means of phase comparison on the telemetry transmitter signal, permitting measurements of deviations of about 1.5 minutes. The extended range Doppler system was installed in 1958 using a common coherent reference frequency for both uprange and downrange stations. A submarine cable was laid from the launch site to downrange stations, along which a 32 kHz sine wave was propagated from a central timing station for synchronization purposes. This served as a common reference frequency and was converted at the stations to the proper comparison frequency. It afforded continuous coverage so long as the missile was within line of sight to the transmitter and three or more receivers.

Improved radar became available also in 1958. This was a high-precision, C-band monopulse system designed specifically for missile tracking. Radar ground stations determined the vehicle's position by measuring range, azimuth angle, and elevation angle. Range was derived from pulse travel time, while angle tracking was conducted by amplitude comparison. As many as four stations could track the beacon simultaneously. Accuracy in range was about five meters (16.4 feet) and coverage extended to 1,800 kilometers (1,118 miles). In the optical field an engineering sequential camera was developed which provided angle readout, and offered a choice of long-range photographic coverage of high definition. The telemetry system was also upgraded and yielded 211 measurements in flight, roughly double the capacity of the Redstone telemetry.

Our close relationship with the Agency's management and the other ten development laboratories in the Arsenal complex enabled a free flow of information to and from the launch organization which contributed to problem solving and improvements which could be introduced during the flight test phase of development. We participated in the design of systems and components so that the influence of the launch environment was reflected in the type of hardware delivered to the Cape for flight test and that which eventually reached the user in the military. One should not underestimate the importance of that interplay which may appear obviously necessary in the case of production-line weapons systems but is equally vital when dealing with the one-of-a-kind vehicle or spacecraft flown purely for research missions.

More than 25 Jupiters were launched, including flights of the ablative nose cone, when the development program terminated February 4, 1960. Combat training launches by military crews followed. The Air Force formed three Strategic Missile Squadrons to field the weapon system. They were trained at Redstone Arsenal and Cape Canaveral. The system was deployed in Italy and Turkey (Figure 19).

Jupiter, like its predecessor Redstone, also played a part in advancing the U.S. space program. In a modified configuration it carried early satellites, and on one Jupiter R&D flight, in 1959, its passengers were the first two monkeys to survive over IRBM range.

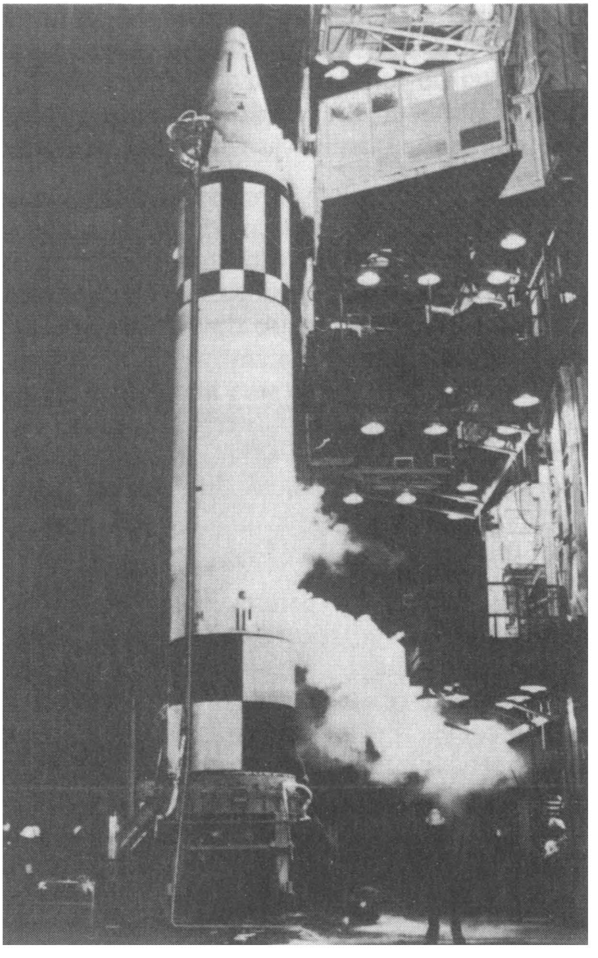

Figure 19 Jupiter missile shown with service structure partially withdrawn.

EXPLORER I

Even as the successful flight testing of Redstone continued, and while the Army pursued studies of longer-range missiles, the development team opened discussions with other Government and scientific groups concerning the same goal we had reached for at Peenemuende only to be sidetracked for a decade by the awful reality of war.

In June, 1954 Dr. von Braun visited the Naval Research Office in Washington, D.C. where he advanced a proposal to utilize the Redstone as booster for a four-stage configuration that could carry a five-pound satellite into circular orbit 300 kilometers (186 miles) above Earth. He recommended small, solid motors known as Loki for the upper stages since they were available and could supply the required thrust. With the help of the Navy Office and the Jet Propulsion Laboratory of the California Institute of Technology, a joint proposal was developed titled "A Minimum Satellite Vehicle Based Upon Components Available from Missile Development of the Army Ordnance Corps." The document was transmitted to the Department of Defense January 20, 1955. Five days later, President Dwight D. Eisenhower announced that the United States would launch a small Earth satellite as a contribution to the International Geophysical Year. But the joint Army-JPL-Navy Research Project was not selected. Instead, the choice went to the Naval Research Laboratory's Vanguard project which would utilize the Viking rocket and new stages to carry an eight-pound, spherical orbiter.

Our satellite hopes were put aside. However, the hardware and the concept could be usefully applied for other purposes. The staging idea and study work performed by ABMA and the Jet Propulsion Laboratory for "Project Orbiter" became the basis for the Jupiter Composite Reentry Test Vehicle, or Jupiter C, which I mentioned earlier. This was the carrier to test the ablative-type fiberglass nose cone adopted for the Jupiter IRBM missile. You will recall that I reported three Jupiter C launches from Cape Canaveral in 1956 and 1957, the last of which demonstrated that the scale model cone survived reentry heating of 2000 degrees Fahrenheit. The same configuration, with the addition of a fourth stage, had a satellite capability. But with the successful 1957 test, the remaining Jupiter C vehicles were placed in storage.

The Soviet Union achieved a dramatic "first" October 4, 1957, by placing Sputnik in orbit. This technological feat had profound impact within the United States. As one possible consequence, the Department of Defense instructed ABMA to prepare for a satellite launch attempt but to stand by awaiting an effort by the Vanguard Project. Early the next month the USSR launched an even heavier spacecraft with the dog, Laika, as passenger. On November 8, 1957, The Department of Defense transmitted specific instructions to the Agency to modify two Jupiter C vehicles and attempt to launch a satellite by March, 1958. The task was accomplished 84 days later (Figure 20).

Under heavy pressure, the Vanguard team tried to launch December 8, 1957. The vehicle broke up on the pad. We were then negotiating with the Atlantic Missile Range for a launch opportunity January 29, 1958. RS 29, as the booster was identified, was taken out of storage. It had been static-tested the last week of October, 1956.

As previously mentioned in connection with the Jupiter project, this version of Redstone carried longer propellant tanks for Hydyne, which yielded 15 percent higher specific impulse than alcohol, and liquid oxygen. These changes boosted Redstone's thrust from the nominal 334,000 to 370,000 newtons (75,000 to 83,000 pounds) and extended burning time from 121 to 155 seconds. In turn, that required adding another hydrogen peroxide tank to keep the turbo pump operating longer. The elongated booster was made possible because the upper Jupiter C high-speed stages weighed much less than the 3,130 kilograms (6,900 pounds) warhead of the tactical Redstone.

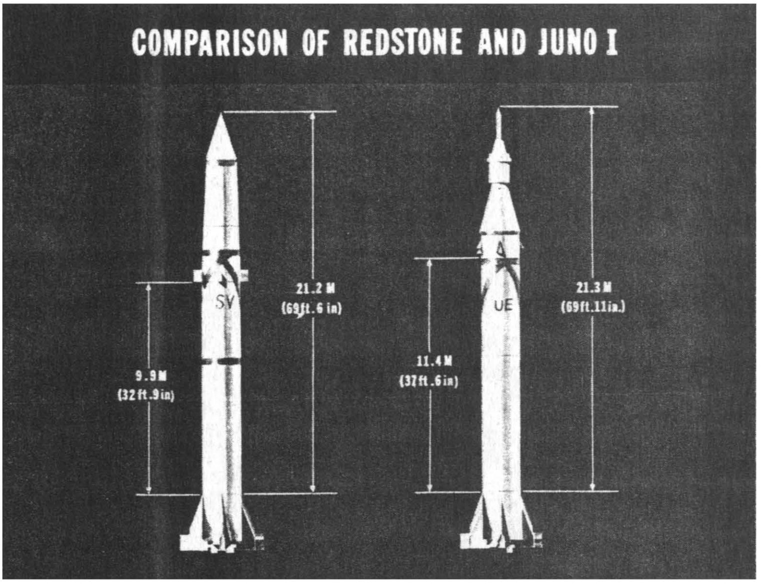

Figure 20

The booster was 13.87 meters (45.52 feet) long with an instrument compartment 3.17 meters (10.39 feet) in length. The spin cluster was 3.69 meters (12.12 feet) long so that, overall, the vehicle measured 20.74 meters (68.03 feet) and had a diameter of 178 centimeters (5 feet, 10 inches). Liftoff weight was 28,834 kilograms (63,568 pounds). At booster cutoff, 990 kilometers (535 nautical miles) from the pad, the upper portion, separated from the first stage, weighed 4,573 kilograms (10,082 pounds). The second stage cut off at 2,222 kilometers (1,200 nautical miles) out while the third stage increased the range to 2,895 kilometers (1,563 nautical miles) (Figure 21).

Atop the tank section was the compartment which housed guidance and control equipment for the booster and a spatial attitude control system which aligned the compartment and forward stages horizontally at apex of the trajectory. Air nozzles integral to the attitude control system were spaced around the bottom of the compartment. Six explosive bolts, each surrounded by a preloaded coil spring, joined the compartment and upper stages to the booster. The bolts were triggered electrically and released the springs which imparted a velocity increment of 79 cmps (2.6 fps) of the compartment and forward stages. Quick disconnect couplings simultaneously released cabling and tubing between the compartment and first stage.

The stainless steel compartment shell was coated with aluminum oxide stripes which served as antennas for telemetering, Doppler tracking, and radio command.

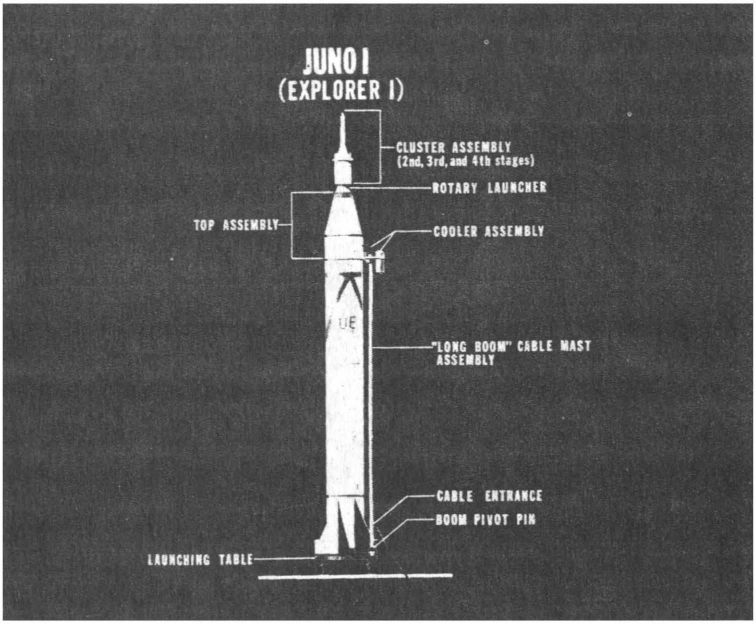

Figure 21

No access hatch was provided in the compartment, hence the entire outer shell had to be removed to reach the equipment. The same difficulty in access arrangements for checkout and testing was to crop up again many times over the years. It would be unacceptable in a quick-response military rocket, but in a research project one could accept such penalty in order to save additional pounds of metal in the interest of increasing payload capability.

The attitude control system had to align the instrument compartment and upper stages exactly horizontal with the Earth's surface. Each of the air nozzles could deliver maximum thrust, right or left, of 22 newtons (five pounds). A small electric motor drove a sprocket wheel which regulated the air flow. The cogs of the wheel engaged the teeth of a push-pull needle driven by the motor. As it moved right or left, more or less air entered either nozzle. This afforded proportional control which operated to an accuracy of one-tenth degree in rocking and other analog pre-flight testing.

How to make this control system linear under vacuum conditions was one of the most difficult problems we encountered. In vacuum, even at very low rates of air flow, the result would be supersonic. This tended to cause an S-shaped response curve. The ABMA Mechanical Laboratory found a way to straighten out the curve. Four of the double-nozzle air-flow units were attached to the instrument compartment, two for pitch and two for yaw maneuvers. Roll control signals were fed to all four electromotors in the form of differential signals.

Directly above the control devices sat an aluminum tub containing the second and third stages and the fourth stage which was the satellite. The second stage consisted of a ring of 11 scaled-down Sergeant solid-propellant rockets. Nested within the ring were three more of these rockets comprising the third stage. The fourth-stage motor had a slightly different propellant (Figure 22).

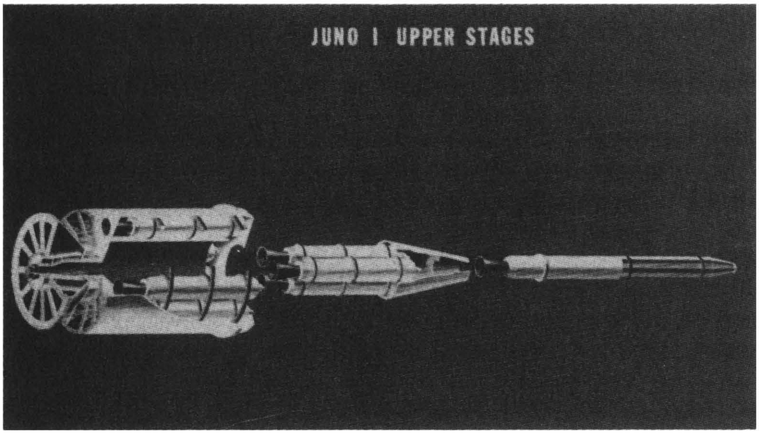

Figure 22

The tub, fabricated in the ABMA shops, had matching sets of grooved bosses top and bottom to support and guide lugs on the second-stage cluster. This provided a zero length support. The second stage ring could make lateral moves of several inches without contacting the tub shell. The same arrangement applied to third-stage clearance relative to the second stage. Finally, the fourth stage with the satellite attached to its front bulkhead rested in a conical holder attached to the forward end of the third stage. The Jet Propulsion Laboratory packaged these stages and the satellite.

A conical stool supported two heavy ball bearings which allowed the tub to spin. Two electric motors installed under the stool turned the tub by means of sprocket- type rubber belts similar to those employed in motorcycles. A spin test facility was built to check out the tub and its stages for static and dynamic balance. During the test electric motors drove the tub which was encased in a cage suspended on four rods within a frame. Any mass imbalance caused the inner cage to vibrate within the frame. The amplitude and pattern of vibration could be measured by stroboscope which pinpointed locations where balance weights should be attached. The same technique is used in industry to balance gyros and fly wheels.

Late in countdown, the tub would be spun up to 550 revolutions per minute. Seventy seconds after liftoff, a governor controlled by tape program inside the instrument compartment changed the regulator setting from 550 to 650 rpm. At 115 seconds of flight the rate increased to 750 rpm. This acceleration was calculated to prevent resonance between spin frequency of the high-speed stages and the bending frequency of the Redstone booster which became lighter as propellant was consumed. The maximum spin rate of 750 rpm was attained 20 seconds prior to propellant cutoff and did not change during the coast to apex. It was essential to maintain that rate when the second stage fired.

Another factor had to be considered. The constant spin rate was governor-controlled and this imposed varying loads on the electric motors. Those loads exerted a reaction torque on the instrument compartment attached to the tub. In coast flight the torque had to be compensated by air nozzles of the attitude control system. Without this dampening, the compartment would acquire a spin with resulting gimbal lock and spilling of the gyroscopes. So there had to be sufficient thrust in the air nozzle system to cope with these forces.

The attitude control system must tilt the spinning cluster and instrument compartment, essentially a non-rotating mass with a large gyro on its nose. During tilting, the gyro would cause precession forces. In order to tilt in the pitch direction, therefore, air was expelled out of the nozzles which pointed in the yaw direction. Thus the precession force was applied to tilt in the pitch direction. Incidentally, this was worked out in analog simulation.

Mounted on top of the second stage was a conical structure that contained a timer and batteries for igniting the third and fourth stages as well as supporting the fourth-stage motor. The motor was identical in configuration with the other solid-propellant stages, but used a propellant of improved performance with a nozzle exit diameter a little smaller to allow adequate launch clearance. The newer type propellant placed the lowest requirement on its physical properties because it spun on its own axis and kept radial loads to a minimum. The stage was 117 centimeters (46 inches) long with a diameter of 15 centimeters (six inches). The satellite was rigidly attached to the bulkhead of this motor through an insulating ring which formed an antenna gap for one of two radio transmitters. The second transmitter operated across a similar gap between the cylindrical port and nose cone of the satellite. After burnout the empty stage weighed 5.75 kilograms (12.67 pounds) while the instrument compartment, 86 centimeters (34 inches) long, weighed 8.22 kilograms (18.13 pounds). Hence the total weight in orbit was 13.97 kilograms (30.80 pounds).

Josef Boehm of ABMA had designed the cylindrical satellite several years earlier. JPL packed the instruments. Dr. William H. Pickering, the JPL Director, represented the project with the National Academy of Sciences which supervised U.S. participation in the International Geophysical Year. The cylindrical shape was not suited to some Vanguard Project experiments designed for a spherical orbiter. But there was room for the cosmic radiation experiment of Dr. James Van Allen of the State University of Iowa, who built his equipment around the Geiger-Mueller counter. The Air Force Cambridge Research Center provided another experiment designed to measure micrometeroid impacts. During the planning for the ill-fated Project Orbiter, ABMA had developed computer programs which were now brought into play to measure atmospheric densities, the oblateness of Earth and high- altitude ionization. The collection of these data relied, in part, upon the Vanguard tracking network which supported the project.

JPL treated the exterior of the satellite so that heat absorbed from solar radiation and reflection from Earth, plus heat generated within the spacecraft would balance heat radiated by the satellite to space. This maintained temperature ranges within the payload in which electronic components could function. Sensitive components were also thermally insulated. As it developed, the temperature ranged between 43 and 104 degrees Fahrenheit.

Two minimal weight transistorized radio transmitters were carried in the spacecraft. The low power device radiated 10 mw while the other radiate 60 mw. The latter signal could be heard by sensitive amateur receivers but the low-power transmission could be tracked only by the more sophisticated narrow-band microlock and minitrack receivers. In addition to providing a tracking signal, which was the primary function, the transmitters also telemetered scientific data including the temperature measurements, cosmic ray intensities and micrometeroid impacts (Figure 23).

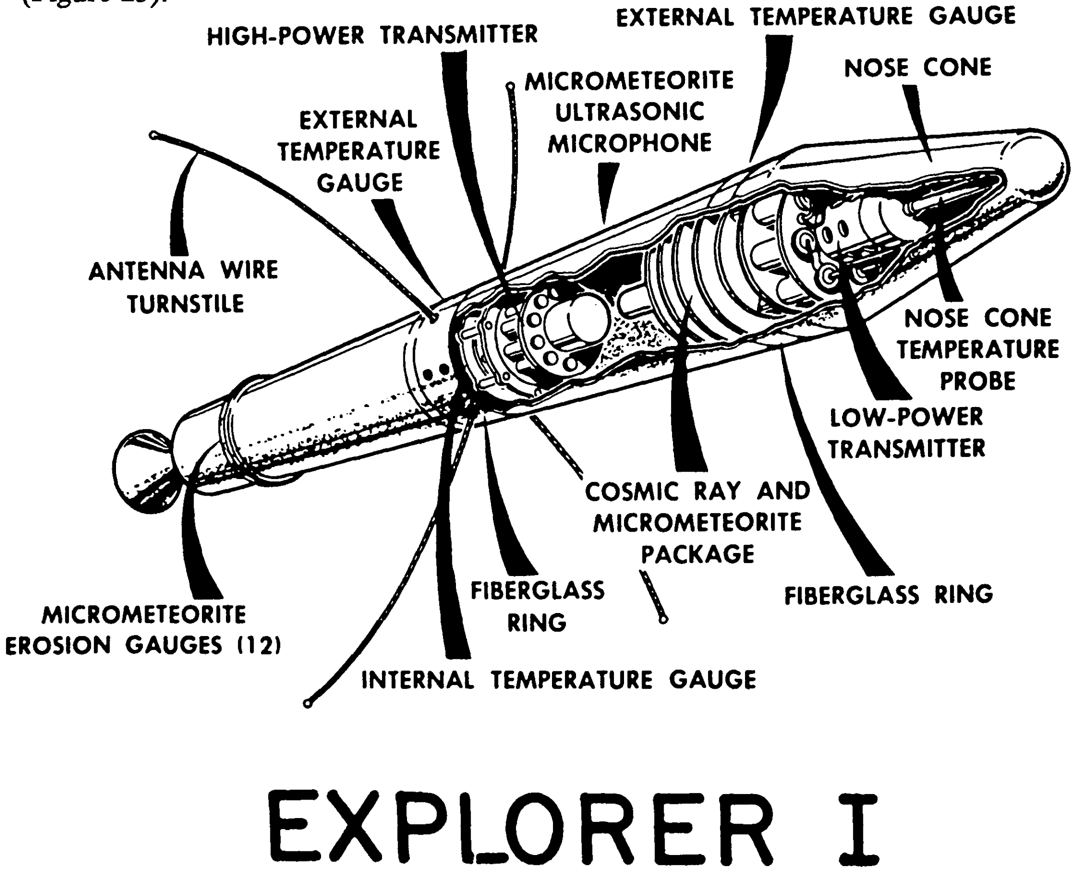

Figure 23

It is necessary to explain the circumstances surrounding the launch in order to justify some rather unusual arrangements. The United States suffered a blow to national pride, at very least, by the stunning demonstration of Soviet competence. The subsequent Vanguard failure served to heighten the almost hysterical reaction in some quarters. Vanguard, of course, later succeeded in placing several satellites in orbit. The adverse response was all the more severe because Vanguard had been conducted as an "open" program with showers of publicity. So it was decided at the highest levels that the Army would avoid any buildup of interest and expectation in connection with the launch. Resident newsmen in the Cape area were briefed by the Air Force Commander on this and other launches on their promise not to release the information until and if a missile engine was ignited. No fire, no story. But when fire appeared they were free to report what they saw from a vantage point inside the Cape or what they were told by a briefing officer or other source.

We took extraordinary precautions. The Redstone booster arrived by C-124 aircraft from Huntsville, December 20, 1957, and was kept under guard in a Patrick Air Force Base hangar during inspection and checkout. The JPL upper stages had been spin-tested and awaited mating with the booster. On January 13, heavily shrouded, the rocket was trucked to Hangar D of the Cape Industrial Area for additional preparations. It was erected on the launch pad after dark January 24--without benefit of searchlights. The gantry was moved into position, the spin cluster was installed, and canvas shrouds were draped from the service structure to conceal most of the space vehicle. Only the lower tail section, which was the familiar Redstone, could be seen.

The vehicle rested on a launch table open at the top to allow flame to pass and strike a conical deflector positioned under the engine which spread the jet horizontally. The pad crews exhibited some nervousness about some rumored toxic properties of UMDH, and speculated that this mysterious chemical would (a) burn flesh to the bone upon contact, (b) deprive a man who inhaled the fumes of his reproductive potential, or (c) cause one's hair to fall out. In defiance of these rumored dangers, Isom Rigell, the chief engineer, walked to the pad during test, climbed down in the cable pit and examined the circuitry. He wanted to make sure that an electrical bus, if it failed to drop out as it should, could not inhibit launch. He still has hair.

General Medaris flew in from Huntsville while von Braun went to Washington to await launch with Dr. Pickering and Dr. Van Allen at the National Academy of Sciences. Wernher resented but obeyed the Army's order because he wanted to be at the Cape. Telephone circuits were installed so that talkers in the blockhouse could report the countdown to the press, 2,286 meters (7,500 feet) away, and to a distinguished group in the Pentagon including Secretary of the Army, Wilbur Brucker, and the Chief of Staff, General Maxwell Taylor.

The shrouds were to come down before we loaded the tanks. As we planned to do this on January 29, Lt. John L. Meisenheimer, the Range weather officer, reported that the jet stream which flows west to east across the United States had unexpectedly moved southward across Florida. Wind velocities of 270 kmph (146 knots) and more were measured at altitudes of 11,000 to 12,200 meters (36,000 to 40,000 feet). The shear gradient was too much for the Juno I configuration (Jupiter C became Juno I with the addition of the fourth stage), so we postponed the launch one day. The countdown began on the 30th while we kept in close touch with

Weather. Before flowing liquid oxygen into the booster, it became clear that the jet stream had increased in velocity and so we postponed again.

By this time, the press had carried some brief mention of a satellite launch attempt, and the anticipation was beginning to be felt elsewhere. Approximately 200 newsmen representing wire services, magazines, newspapers and radio gathered in the area to watch the launch under military escort at the press site.

The launch window on January 31 opened at 10:30 p.m. and would close at 2:30 a.m. It was necessary to launch during this interval in order to balance exposure of the satellite to sunlight and Earth shadow which would conserve battery power for the radio transmitters. We picked up the count despite less than encouraging weather data. Lieutenant Meisenheimer said we might experience local thunderstorms. He flew more balloons during the day at my request. Most of those close to the activity were pessimistic; however, the weather officer declared that he would stake his reputation on a forecast that the wind shear would drop to tolerable limits by liftoff time. I persuaded General Medaris to accept this and we proceeded. (Figure 24)

Well before launch the blockhouse was filled to capacity by some 54 operational personnel plus General Medaris. Dr. Jack Froelich and Phil Tardani of JPL were there. As the countdown moved steadily onward, Robert Moser, the test conductor, called out status reports coming in from key positions. At T minus 20 minutes Albert Zeiler, in charge of fueling, came in from the pad area with his crew. The blockhouse door was sealed against the toxic gases which would form at ignition. Dr. Gruene, my deputy, Albert Zeiler, General Medaris and I took positions at the small rectangular windows looking out on the vehicle. Within seconds of ignition, Moser suddenly called out "We have a jet vane deflection, shall I hold?" I had looked at the vane in question and did not see any motion. This had to be, therefore, an indication only. I waved my hand to continue.

The missile flamed into life at 10:58 p.m. Eastern time and roared off into darkness. We clustered around the recorder panels watching the needles trace the trajectory and listening to the high-pitched Dovap signal.

The vehicle lifted vertically. When burning time ended, it had moved into a trajectory inclined 40 degrees to the horizon. We did not use programmed cutoff but elected the depletion technique. After 140 seconds of flight a probe was energized in each propellant discharge line. The first probe to sense "no pressure" excited a relay which closed both main valves to the propellant tanks. Cutoff actually occurred at 157 seconds, or two seconds later than expected. Five seconds later a timer ignited the explosive bolts. This delay permitted thrust to decay completely before separation, otherwise residual thrust might shove the booster into colliding with the upper assembly if separated at cutoff. Then the spatial attitude system took over to align the upper stages during coast until apex was reached at about 404 seconds.

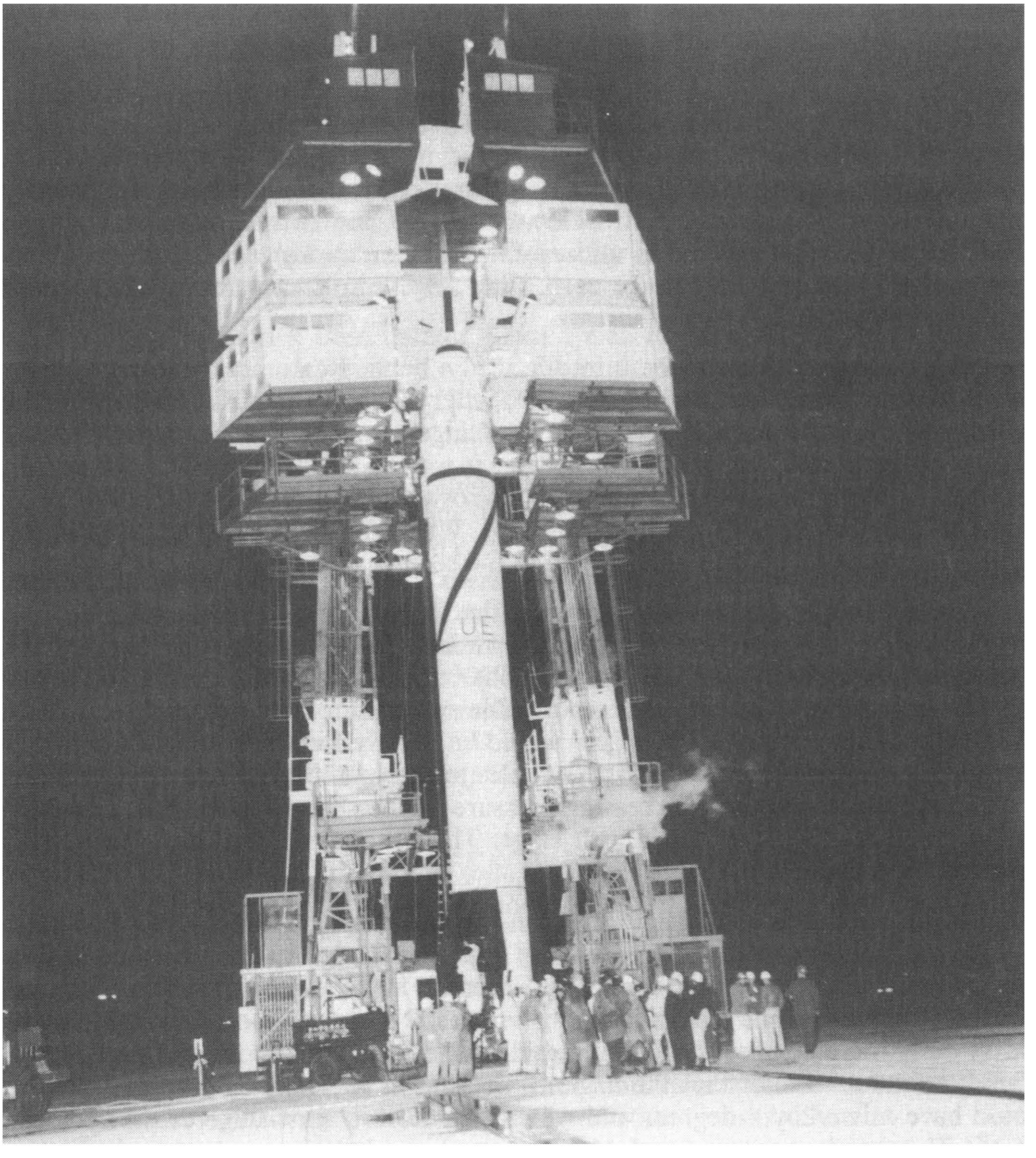

Figure 24 Pre-launch pad activities for the Juno I/Explorer I mission. The successful launch placed the first U.S. satellite in Earth orbit.

The same gyros which stabilized the rocket through booster jet vanes up to cutoff now controlled the compressed air nozzles in the tail of the instrument compartment. The thrust imparted by this system tilted the cluster faster than the tilt of the trajectory, which allowed time for residual attitude error to decay and thus gain the highest possible accuracy in alignment. The comparatively crude cutoff technique made it impossible before launch to predict the exact moment of apex, or to determine how much horizontal travel might occur between takeoff point and apex. Auxiliary tracking had to be introduced to acquire additional data since the assembly must be exactly horizontal over the local horizon. Only by catching the apex moment and ensuring accurate tub alignment could the upper stages be fired in the right direction to attain orbit.

Three independent methods were employed to determine apex. The missile was tracked by radar and the radar plot helped predict apex time and the point in space where it occurred. Next, an accelerometer relayed via telemetry the velocity increment of the vehicle. Cutoff velocity was fed into a computer which then predicted apex. The third mode utilized the Doppler tracking network. Liftoff occurred at 0.59 second after range zero. First-stage cutoff came at 156.71 seconds and separation at 162.31 seconds.

The three predictions were introduced in a manual calculator located in Hangar D, three miles from the launch site, where Dr. Walter Haeussermann, the ABMA guidance chief, and Dr. Ernst Stuhlinger evaluated their quality. If one prediction was based on poor quality data, it was to be disregarded or its weight reduced in determining the average. A microswitch began moving along wire at liftoff at a rate directly proportional to time. When the switch reached a stop, the ignition command would be transmitted to the second stage.

JPL also built redundant systems into the cluster assembly. To assure ignition, the igniter was designed and tested to fire reliably in laboratory vacuum, then the rocket motors were sealed to retain atmospheric pressure before launch, and finally the igniter was housed in a container capable of retaining atmospheric pressure in event of a motor seal leak. The signal would be received in the command transmitter within the instrument compartment. Batteries in the guidance compartment would energize the igniter. Increasing pressure in the second stage started a timer in the conical support of the fourth stage. The timer fired the third stage eight seconds later, and eight seconds after that, also fired the fourth stage. As each fired, it broke shear pins holding it to the assembly, releasing the stage to fall back.

In reality, it was planned to ignite the upper stages prior to exact apex. Each of the three upper stages would burn 5 to 6 seconds and there was that time interval between burnout of one and ignition of the next. By firing ahead of apex, the vertical velocity increment of the cluster would be exactly zero at fourth-stage cutoff. The data indicated later that the angle of the cluster was only 0.81 degree off. We could have missed by 4 degrees and still attained orbit. First-stage cutoff occurred at 156.71 seconds, separation of 162.31 seconds, and the second stage ignited at 403.75 seconds. The satellite was injected into orbit shortly thereafter.

We have provided more assurance. While Haeussermann and Stuhlinger commanded ignition by timer relay, a backup link was installed in the blockhouse where Henry Paul, an Army officer, watched the plus count, then tolled off "one thousand one, one thousand two," and pressed a button. Sufficient interval for this backup command had been calculated to assure that one transmitter did not capture the command receiver and block out the other's signal. Still later, a third signal was transmitted by Kelly Fiorentino, one of our engineers, through a command system on San Salvador Island. We observed the staging sequence on the blockhouse recorders and then drove to the JPL offices in the Cape Industrial Area to await orbital confirmation.

Dr. von Braun called from Washington and asked for news. General Medaris told him to keep the line open and "share a cup of coffee with us." We stood by until JPL acquired the signal by a California tracking station and confirmed that the satellite was in a very satisfactory obit. The period was 114.78 minutes with apogee of 2,565-kilometers (1,594-miles) and perigee of 362-kilometers (225-miles). Secretary Brucker phoned congratulations to the ABMA team and told General Medaris the satellite was Explorer I. The Secretary and General Taylor had picked the name and kept it secret until then.

We drove to Patrick Base theater about 1 a.m. for a press conference. As the group entered, the newsmen stood, cheered and applauded. Then we all awaited the official announcement from the White House which came soon after. One does not easily forget such a moment.

Despite its limited capacity. Explorer carried the nation into the Space Age and returned important scientific data. Telemetry could be collected only during its pass over ground stations in Florida, Nigeria, Singapore, California and several locations along the 65 degree west meridian. Much of the orbit could not be observed and much of the data was lost. Nevertheless, the Van Allen experiment, which was set to bracket anticipated intensity of 30 to 40 cosmic ray counts per second, encountered densities above 966-kilometer (600-mile) altitude so intense as to saturate the instruments. It was concluded that the intensity was at least 1,000 times higher than expected. From this information, Dr. van Allen mapped the radiation belts above Earth which carry his name. This became the major discovery of the IGY.

The Cambridge micrometeorite experiment determined that these particles offered no undue hazard to space ships but also indicated that 1,814-metric-ton (2,000- ton) of cosmic dust rain down on Earth annually. The temperature data showed that man could, by design, control temperature in a space vehicle. The density of air 200- to-300-kilometer (124-to-186 mile) from Earth was found to be 40 percent higher than expected. The Earth spheroid turned out to be one-half to 1 percent flatter than previously reckoned. Irregularities in the decrease of Explorer's velocity suggested the pressure of enormous air mountains at altitudes where these masses fluctuated constantly due to changing irradiation from the Sun.

The satellite's lifetime was initially predicted at two or three years. Explorer continued to revolve around earth for 12 years and reentered March 31, 1970. Its signals ceased 63 days after launch due to battery depletion.

As to the nation's reaction, this has been reported many times. In effect, it was the reverse of the state of shock induced by Sputnik. The ABMA team had made good its promise of three years earlier. For the former Peenemuende engineers, it was the long-awaited fulfillment of a dream.

In retrospect, the group that came to the United States and chose citizenship in a new land became the nucleus around which a missile development organization grew up which carried two large missile systems from design to deployment, advanced the state of the art in all related fields, and laid the foundation for the heavy class Saturn boosters which would follow (Figure 25).

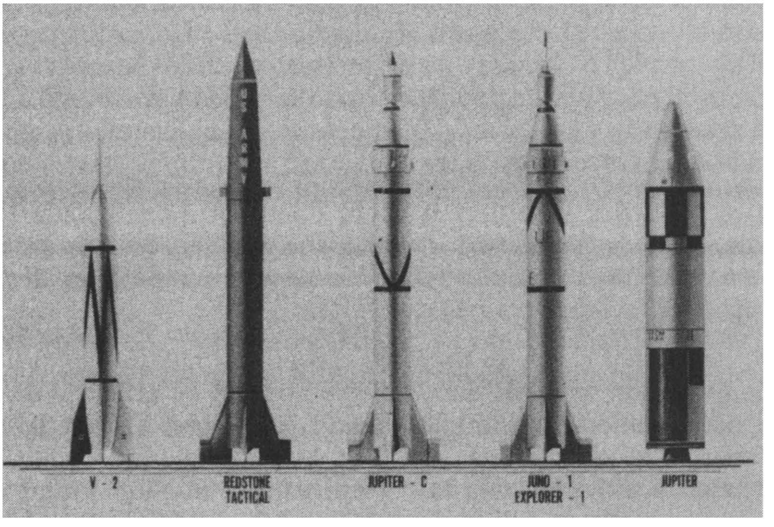

Figure 25

Table 1
LAUNCH CHRONOLOGY – 1953-1958

Redstone	Jupiter A	Jupiter C	Jupiter
Aug 20, 1953			
Jan 27, 1954			
May 5, 1954			
Aug 18, 1954			
Nov 17, 1954			
Feb 29, 1955			
Apr 20, 1955			
May 24, 1955			
Aug 30, 1955			
Sep 21, 1955			
Dec 5, 1955			
	Mar 14, 1956		
May 15, 1956			
	Jul 19, 1956		
Aug 8, 1956			
		Sep 20, 1956	
Oct 18, 1956			
Oct 30, 1956			
Nov 13, 1956			
Nov 29, 1956			
Dec 18, 1956			
Jan 18, 1957			
			Mar 1, 1957
Mar 27, 1957	Mar 14, 1957		
			Apr 26, 1957
		May 15, 1957	
	Jun 26, 1957		
	Jul 12, 1957		
	Jul 25, 1957		
		Aug 8, 1957	
	Sep 10, 1957		
	Oct 2, 1957		
			Oct 22, 1957
	Oct 30, 1957		
			Nov 26, 1957
	Dec 10, 1957		
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