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Chapter 20

Mercury-Redstone: The First American Man-Rated Space Launch Vehicle[1]

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The concept of using the Redstone ballistic missile as a launch vehicle for men into near Earth space occurred as early as 1956. In that year, the U.S. Army Ballistic Missile Agency (ABMA) considered the missile as a potential delivery system for a small number of soldiers in the battle area. The Redstone booster, with a modified second stage would loft a canister of men to an altitude of 230 km (143 mi) and a range of 885.1 km (550 mi), where it would be lowered to Earth by parachutes and retrorockets.[4]

Though nothing came of this mode of troop transportation, in April, 1958, ABMA made a similar proposal to the U.S. Continental Army Command for such use of the modified Redstone missile. For a year, ABMA engaged in a study of its rocket in a logistic mode. Optimistically, the agency concluded: "The cost versus effectiveness of rocket transportation compared to fixed-wing aircraft transportation appears to demand that rocket transportation be substituted for the conventional aircraft transport system in the immediate future." The Army's Transportation Corps Combat Development Group reached the same conclusion. However, nothing more came of the proposal. Certainly no missiles were modified or test fired.[5]

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[4] John B. Medaris, "The Army's Mission and the Role of Missiles," *Army Information Digest*, Vol. 7, No. 5, December, 1956, pp. 54-57.

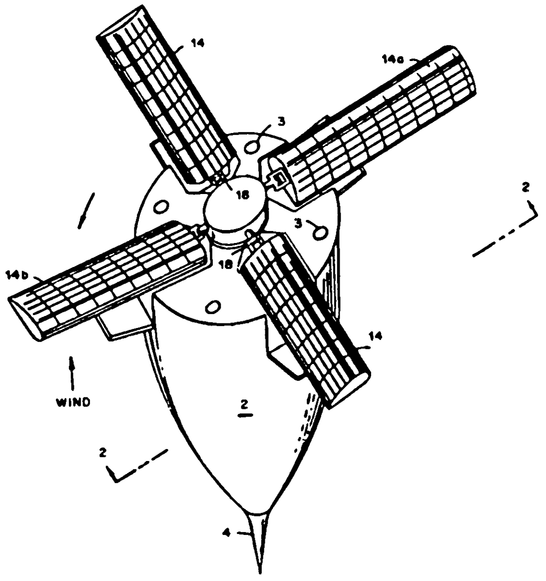

Figure 1 Details for rocopter concept.

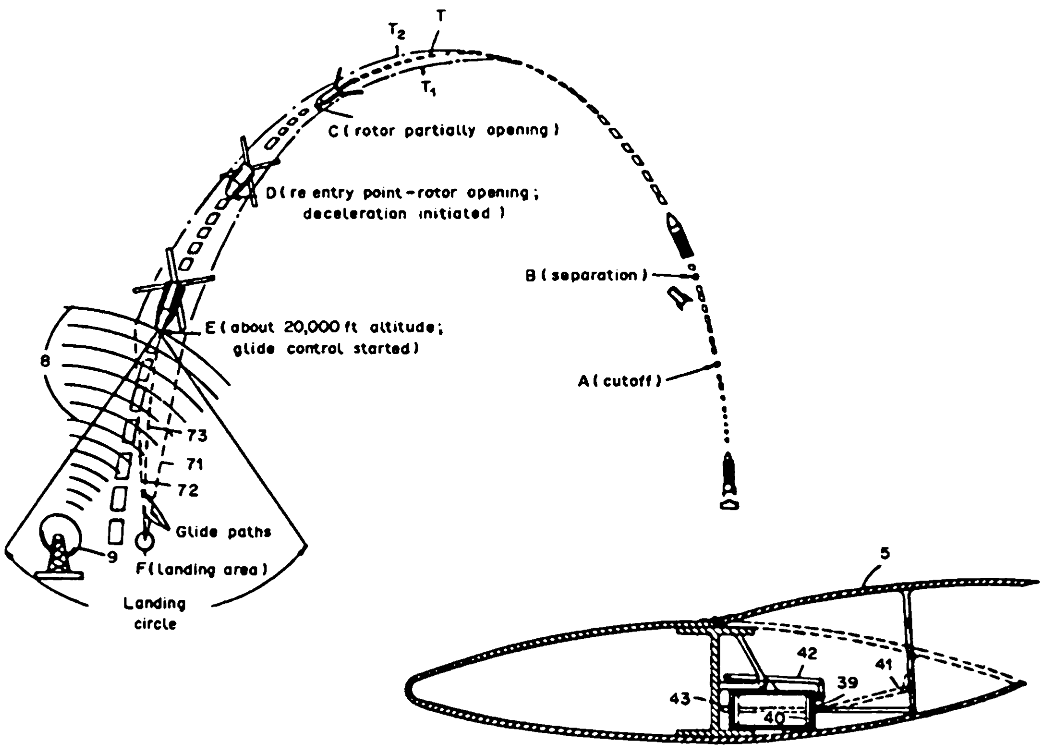

Figure 2 Rocopter concept for Redstone missile delivery of men or cargo.

[5] John W. Bullard, *History of the Redstone Missile System, Historical Monograph Project Number: AMC 23M*. Huntsville, Alabama: U.S. Army Missile Command, 15 October 1965, pp. 150-152.

The concept was studied for an additional year by ABMA and its contractor, the Space and Information Systems Division of North American Aviation, Inc. From this investigation, two patents were issued to Friederich G. von Sauma of ABMA.[6] See Figure 1. In describing his rocopter, Figure 2, von Sauma stated, "In the armed forces, such a safely reentered and accurately guided cargo carrier could be a means for supplying or reinforcing isolated troops or scientific units. An example for civilian use would be for very fast transport mail, freight, or passengers over long distances."[7]

Another early U.S. Army proposal for a manned suborbital flight on a modified Redstone missile is particularly important in its relationship to the Mercury-Redstone project. Project Adam, developed by ABMA, was submitted to the U.S. Army's Office Chief of Research and Development on 17 April 1958. The Secretary of the Army, in turn, forwarded it to the Advanced Research Projects Agency (ARPA) of the Secretary of Defense for approval and funding.

The objective of the project was: ". . . to carry a manned instrumented capsule to a range of approximately 150 statute miles; to perform psycho-physiological experiments during the acceleration phase and ensuing six minutes of weightlessness; and to affect [effect] a safe reentry and recovery of the manned capsule from the sea."[8] See Figure 3. The ambitious plan suggested the use of Jupiter C (described below) components no longer needed for nosecone reentry research and satellite launchings. See Figure 4. Four of the Jupiter C's left over from the twelve that were manufactured were then available.

The manned capsule (Figure 5) as proposed:

> . . . is a cylindrical structure of 5.5 feet in length and 3 feet in diameter. (The REDSTONE diameter is 70 inches). This will necessitate selection of a small passenger. The capsule will have double walls separated by plastic insulation for protection against vibration, noise and temperature. The end plates will be temperature-protected and will contain windows with side angle viewers. The internal structure will be a removable single unit, to be separated by a spring-loaded control lever. The capsule will be stress tested for 15 g.
>
> The human passenger will have an instrument panel informing him of conditions and events expected to be of interest to him. He will have UHF and VHF communication with launch point and recovery task force. The total weight of the occupied capsule will be 900 pounds.
>
> The climatic control of the capsule follows the concept of the "Man High" project with the exception that, in view of the short flight time, sea level pressure will be maintained.[9]

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[6] U.S. Patent No. 2,959,376 8 November 1960, "Rocopter and Landing Control Method," and No. 2,969,211, 24 January 1961, "Inflatable-wing Rotocopter."

[7] "Von Sauma Gets Patent on Cargo Delivery Device," *Marshall Star*, Vol. 1, No. 14, 4 January 1961, p. 6.

[8] "Development Proposal for Project Adam," Report No. D-TR-1-58. Redstone Arsenal, Alabama: Army Ballistic Missile Agency, 17 April 1958, p. 1.

[9] *Op. cit.*, p. 10.

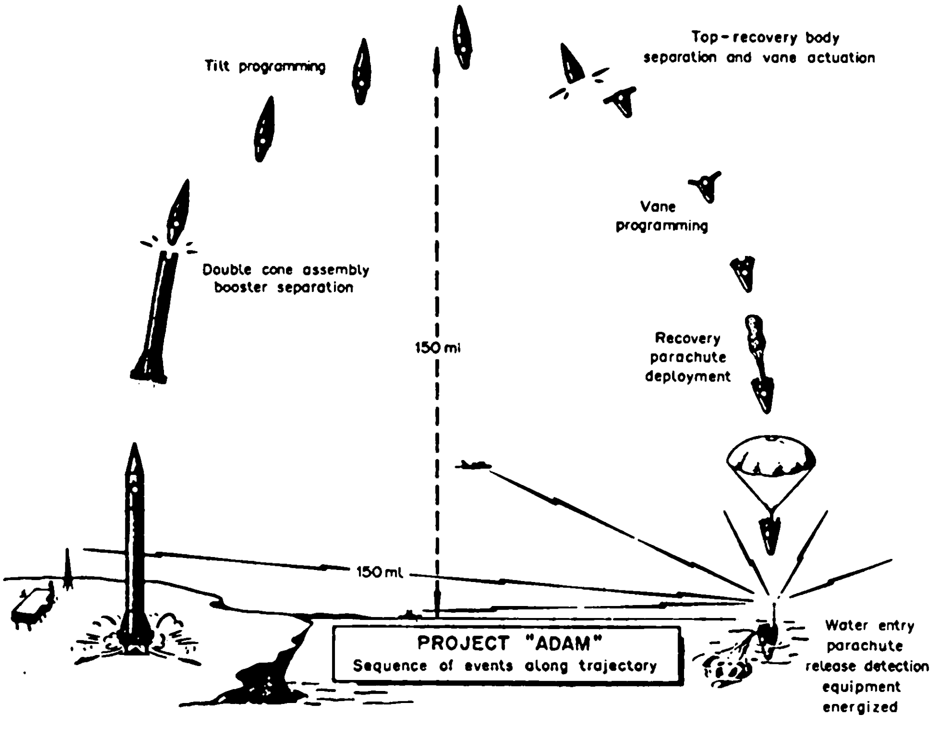

Figure 3 Trajectory of manned capsule in Project Adam.

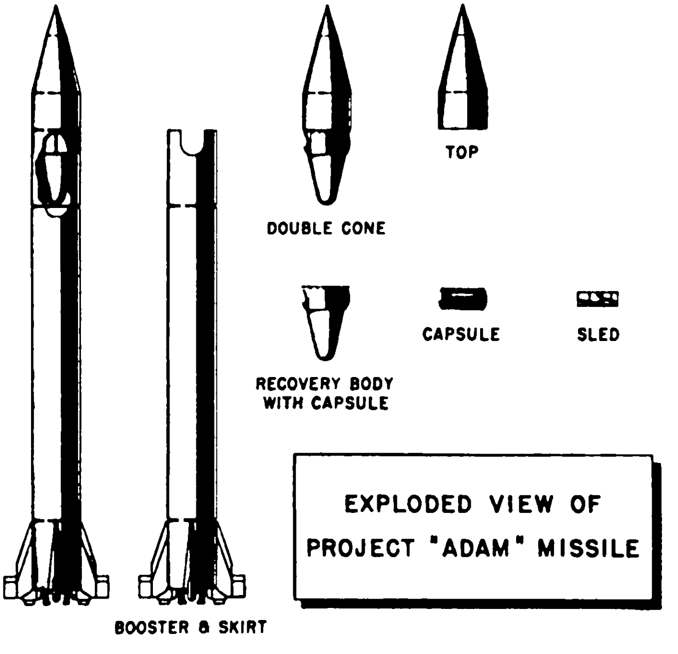

Figure 4 Components of Project Adam vehicle.

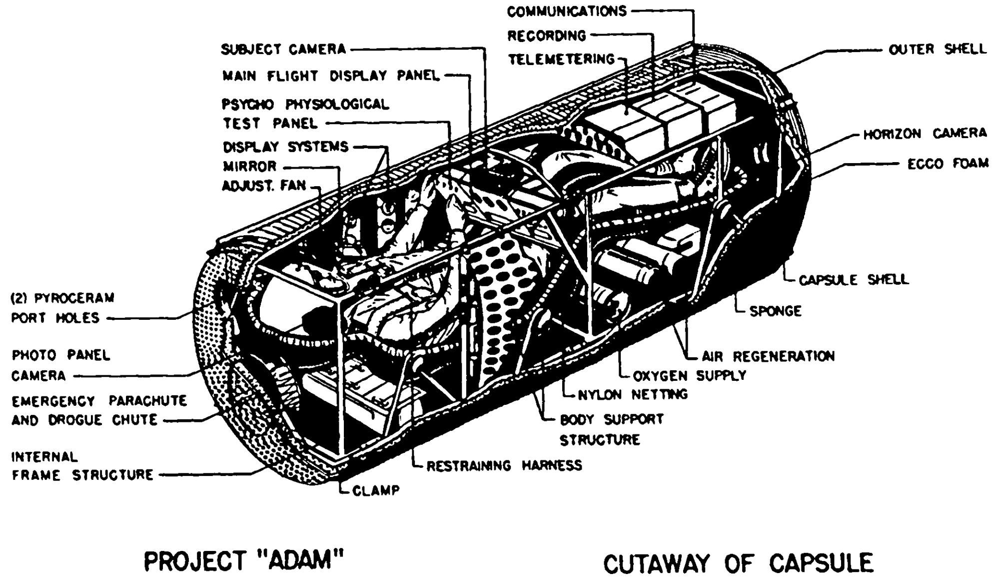

Figure 5 Project Adam manned capsule.

The capsule would have been designed by Lieutenant Colonel David G. Simons, U.S. Air Force, the pilot of Project Manhigh, in which a balloon-borne capsule, on 19 August 1957, lifted him to an altitude of 30.9 km (101,516 ft). Simons would also have been the astronaut for Project Adam.[10]

Actually, the manned compartment could be termed a "capsule within a capsule." See Figure 6. The design of the payload atop the modified Redstone was to have been a double cone, the lower half of which contained the manned capsule. The upper half was an aerodynamic shield. At apex of the trajectory, the upper half separated and the lower half began its descent to Earth, as shown in Figure 3. The recovery body was a heat-protected cone 2.6 m (8.5 ft) long and 1.7 m (5.5 ft) in diameter, as shown in Figure 7. The cone would be attitude controlled by a stabilized platform and reaction nozzles using compressed air.

Launch escape for the astronaut on the pad was simple, but it inspired more amusement than confidence in some. Briefly, the manned capsule, upon abort, would be thrust laterally through the recovery body and descend by parachute into a specially prepared pool of water near the launcher, as shown in Figure 8.[11] For all the effort that went into the proposal, it was rejected by ARPA on 17 July 1958. Still, many of its features eventually appeared in the Mercury-Redstone project three years later.

[10] Norman L. Baker, "USAF Won't Support Project Adam," *Missiles and Rockets*, Vol. 3, No. 7, June 1958, pp. 40-41.

[11] "Development Proposal for Project Adam," pp. 4-12.

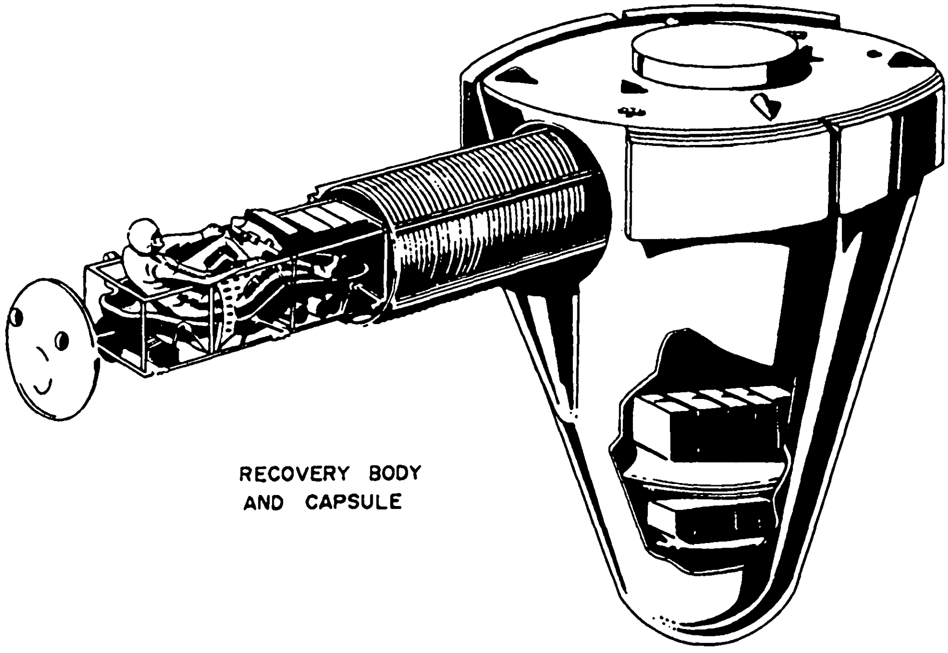

Figure 6 Project Adam manned capsule in recovery capsule.

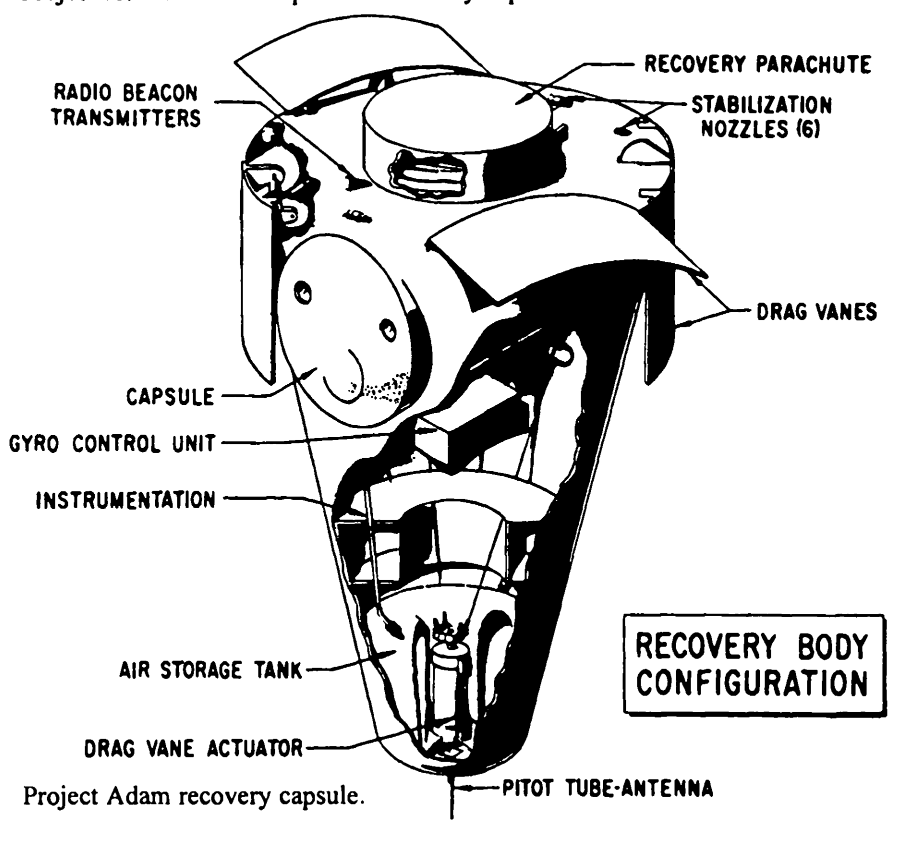

Figure 7 Project Adam recovery capsule.

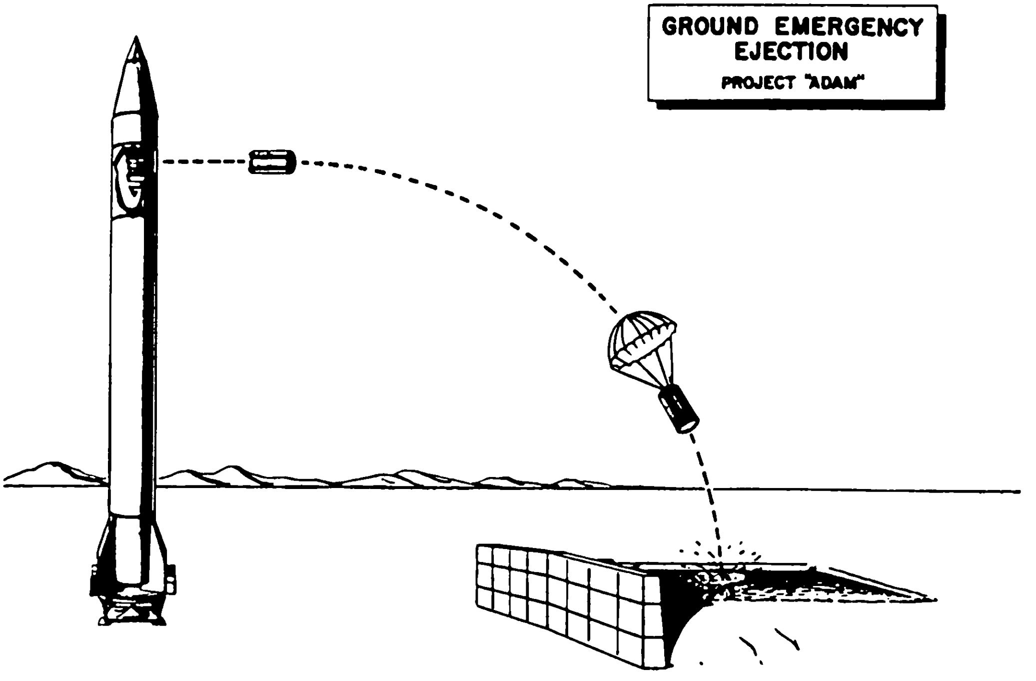

Figure 8 Launch pad recovery of astronaut in Project Adam.

Rocket Developments in World War II Germany

The immediate technological forebears of the Mercury-Redstone stem from the development of a series of research and military rockets realized in Germany during the years just prior to, and during, World War II. Among these rockets one can mention several of the A (aggregate) series designed and developed by the German Army with the important cooperation of German industry and institutions of higher learning. These rockets are in chronological order of development, the A-3, A-5, and A-4.[12] They are shown in Figure 9.

Briefly, it is helpful, from the viewpoint of developing rocket technology leading to the Mercury-Redstone, to review the characteristics of these early German rockets. The A-3 was a small rocket, not intended for tactical military use, designed in 1935 and successfully launched from Greifswalder Island in the Baltic Sea in 1937. It was developed and statically test-fired at Kummersdorf as a "purely experimental apparatus to test

[12] Material on the A series of rockets can be found in Ernst Klee and Otto Merk, *Damals in Peenemünde*, Oldenburg and Hamburg: Gerhard Stalling Verlag, 1963; Walter Dornberger, *V-2*, New York: Viking Press, 1954; David Baker, *The Rocket, the History and Development of Rocket and Missile Technology*, New York: Crown Publishers, 1978; Willy Ley, *Rockets, Missiles, and Men in Space*, New York: Viking Press, 1968; Frederick I. Ordway III and Ronald C. Wakeford, *International Missile and Spacecraft Guide*, New York: McGraw-Hill Book Co., 1960; and H. A. Schulze, *Technical Data on the Development of the A-4 (V-2)*, Huntsville, Alabama U.S.A.: Marshall Space Flight Center, 25 February 1965.

liquid-fueled rocket propulsion for missile-like bodies and for trials of the guidance system."[13] It was 6.74 m (22.11 ft) long, 63.3 cm (24.92 in.) in diameter, and it weighed 750 kg (1653.4 lb). The propellants were liquid oxygen (LOX) and ethyl alcohol. The pressure-fed engine produced 14,784 N (3,300 lb) of thrust to send the rocket vertically to an altitude of 11 km (7 mi).

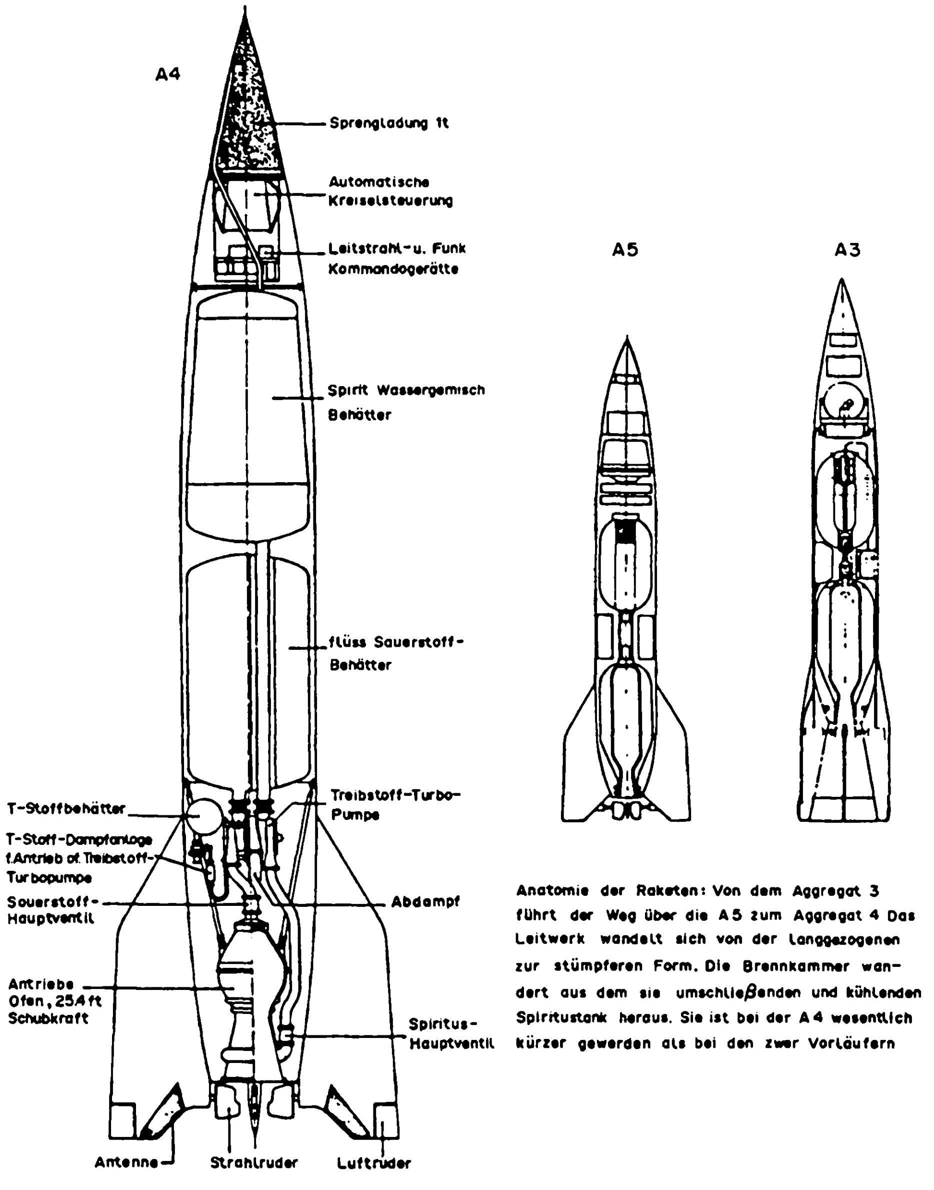

Figure 9 German guided missiles A-4, A-5, and A-3.

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[13] Klee and Merk, *op. cit.*, p. 22.

From the viewpoint of the history of rocket technology, as it led to the Mercury-Redstone launch vehicle, the A-3 is significant in that the rocket was a test bed for a rudimentary, 3-dimensional, gyroscopic control system with associated hydraulically activated jet vanes for flight path maintenance. Its launcher also was a prototype for that of the A-4 and, hence, Mercury-Redstone. However, of its four launchings none could be called successful, primarily because of the premature deployment of the recovery parachute system and the inability of the control system to counteract the rotation of the rocket about its longitudinal axis in the crosswinds experienced during flight.[14]

The A-5 retained the propellants and propulsion system of the A-3 but had a completely new guidance and stabilization system. The rocket was 7.4 m (24.2 ft) long, 75.8 cm (2.5 ft) in diameter, and it weighed 800 kg (1,760 lb). It was developed as a test bed for components that would later be used on the A-4 and looked forward to an improved control system (LEV-3) used by the Mercury-Redstone, i.e., graphite vanes in the engine exhaust for thrust-vector control. Successful launchings were realized in 1939, with the A-5 reaching an altitude of 13 km (8 mi) and a range of 18 km (11 mi). Some 70 to 80 of the rockets were launched from Greifswalder Island, in the Baltic Sea, between 1939 and 1942.[15]

The development and deployment of the A-4 (V-2) missile have been treated in a variety of books and articles and need not be summarized here. The point stressed is, that this one missile provided most of the basic design philosophy and engineering technology that were to be later used in the Mercury-Redstone vehicle.[16] Thus, the Mercury-Redstone launch vehicle clearly had its technological antecedents in the pioneering work of wartime German research in rocketry.

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[14] Dornberger, *op. cit.*, pp. 55-56; Schulze, *op. cit.*, pp. 5-6.

[15] Schulze, *op. cit.*, pp. 13-14; Dornberger, *op. cit.*, pp. 56-63, 69, 144.

[16] Details of the A-4 (V-2) can be found in those works cited in footnotes above as well as the following sources which relate specific areas of A-4 (V-2) engineering technology to the Mercury-Redstone vehicle: Ernest Steinhoff, "Development of the German A-4 Guidance and Control System 1939-1945; a Memoir," in R. Cargill Hall, ed., *History of Rocketry and Astronautics, AAS History Series*, Vol. 7, Part II, San Diego, California, Univelt, Inc., 1986, pp. 203-215; Fritz K. Mueller, "A History of Inertial Guidance," *Journal of the British Interplanetary Society, Astronautics History*, Vol. 38, No. 4, April, 1985, pp. 180-192; James S. Farrior, "Inertial Guidance, Its Evolution and Future Potential," in Ernest Stuhlinger *et al.*, eds., *Astronautical Engineering and Science from Peenemünde to Planetary Space*, New York: McGraw-Hill, 1963, pp. 148-158; Frederick I. Ordway III and Mitchell R. Sharpe, *The Rocket Team*, New York: Thomas Y. Crowell, 1979, See also David Irving, *The Mare's Nest*, London: William Mimber, 1964; Philip Henshall, *Hitler's Rocket Sites*, New York: St. Martin's Press, 1985; James McGovern, *Crossbow and Overcast*, William Morrow, 1964; R. V. Jones, *The Wizard War, British Scientific Intelligence 1939-1945*, New York: Coward, McCann & Geoghegan, 1978; Dieter K. Huzel, *Peenemünde to Canaveral*, Englewood Cliffs, New Jersey: Prentice-Hall, 1962; Wim Dannau, *Les Dossiers "Escape" de Wim Dannau*, Tournai: Casterman, 1966; Colin Campbell, "Rocket Arsenal," *Royal Air Force Flying Review*, 1958, pp. 31-33; and Fritz Zwicky, *Report on Certain Phases of War Research in Germany*, Vol. 1, Pasadena, California: Aerojet Engineering Corp., 1 October 1945.

Related Rocket Developments in Post-War U.S.A. (Fort Bliss, Texas)

With the relocation of some 127 former scientists and engineers from Peenemünde to Fort Bliss, Texas, in 1945 and 1946, the fundamental work on the American vehicles to follow the German A series was begun.[17] In Fort Bliss, as it had in Germany, the group found itself working for the military. However, it was now employed by the Ordnance Department of the United States Army. The group's mission was to assist civilian contractors of the General Electric Co. (GE), which had signed a contract with the Ordnance Department on 20 November 1944, to cover the "investigation, research, development, and engineering work leading to the design of a series of long-range guided missiles as required by the Army."[18] The GE effort was known as Project Hermes.[19]

Project Hermes (V-2 Phase)

The first task assigned to some of the German group was to assist GE and military personnel in the assembly, check-out, launch, radar and photographic tracking, and data reduction and analysis of 67 A-4 (V-2) missiles between 1946 and 1952. Most of this work was done at the White Sands Missile Range in New Mexico.[20]

The objectives of the V-2 phase of the Hermes program were concise but had implications of more advanced missiles that would follow. Briefly, the objectives were:

1. To obtain experience in the handling and firing of large missiles,
2. To provide vehicles for experiments directly concerned with the design of future missiles,
3. To provide vehicles for operational tests of components for future missiles,
4. To obtain ballistics data,
5. To provide vehicles for upper atmosphere research projects.[21]

Also included in this phase of the Hermes project was the modification of the V-2 to accept a second stage. With the V-2 as a first stage and a Wac Corporal rocket as the second stage, the initial Bumper (as the combination was called) was launched on 17 May 1948 at White Sands Missile Range. Its second stage reached a peak altitude of

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[17] This redeployment under the auspices of Project Paperclip is covered in detail in Ordway and Sharpe, *op. cit.*, pp. 310-362; Clarence Lasby, *Project Paperclip German Scientists and the Cold War*, New York: Antheneum, 1971; and Huzel, op. cit.

[18] "Army Ordnance Department Guided Missiles Program," Washington, D.C.: U.S. Army, 1 January 1948, p. 38.

[19] "GE Reveals Hermes Missile Milestones," *Aviation Week*, Vol. 60, No. 10, 8 March 1954, pp. 26-32.

[20] Ordway and Sharpe, *op. cit.*, pp. 344-362.

[21] L. D. White, "Final Report, Project Hermes V-2 Missile Program," Report No. R52AO510, September, 1952, Guided Missile Department, General Electric, Schenectady, New York.

127.3 km (79.1 mi). Bumper 5, on 24 February 1949, set an altitude record by reaching 392.7 km (244 mi).[22] Bumper 8 had the distinction of being the first missile launched from the newly completed Atlantic Missile Range (AMR) launch facility at Cape Canaveral, Florida (now Kennedy Space Center), on 24 July 1950. An earlier attempt, on 19 July, had failed, when it was found that exposure to the salt air had corroded some of the electrical components.

The Bumper project is important as an antecedent to the Mercury-Redstone, because it helped to develop the technology of separating a booster from its upper stage, i.e., the Redstone missile from its warhead compartment and the Mercury-Redstone booster from its Mercury spacecraft.[23] From the objectives of the Hermes (V-2 phase) listed above, it can be seen that several looked forward to future missiles such as Redstone.

Other studies, at Fort Bliss and Schenectady, New York, by the engineers of GE under the Hermes contract led to planning for, among other missiles, one capable of lifting a 456.6-kg (1,000-lb) warhead over a distance of 1,603.9 km (1,000 mi) at a velocity of 4,184.2 km/hr (2,600 mph). Yet, despite such ambitious plans, the realization of them was handicapped not so much by funds, as by "the lack of engineering data on performance at high Mach numbers in such areas as aerodynamics, temperatures, configurations, weights, and ranges."[24]

Related Launch Vehicle Developments at Redstone Arsenal

The German rocket team, GE personnel, and members of the U.S. Army's 9330 Ordnance Technical Service Unit, which had supplied military personnel for their activities, were relocated from Fort Bliss to Redstone Arsenal in Alabama in 1950. With them went various missile projects on which they had been working, except the launching of V-2s under the Hermes project, which ended a year later.

The Hermes C1 Study

Among the Hermes projects begun at Fort Bliss by GE, and transferred to Redstone, was an ambitious study known as Hermes C1.

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[22] Ordway and Wakeford, *op. cit.*, p. 10. See also, "Hermes Guided Missile Research and Development Project 1944-1955," U.S. Army Ordnance Corps/General Electric Co., prepared for Technical Liaison Branch; Office, Chief of Ordnance, Department of the Army, Washington, D.C., 25 September 1959, p. 4.

[23] Charles D. Benson, and William B. Faherty, *Moonport, a History of Apollo Launch Facilities and Operations*, NASA SP-4204, Washington, D.C.: National Aeronautics and Space Administration, 1978, pp. 6-7.

[24] Kurt H. Debus, "From A-4 to Explorer I," in Kristan R. Lattu, ed., *History of Rocketry and Astronautics, AAS History Series*, Vol. 8, San Diego, California, Univelt, Inc., 1989, pp. 215-262 (delivered at the Seventh International History of Astronautics Symposium, XXIVth International Astronautical Federation Congress, Baku, U.S.S.R., 8 October 1973).

The relationship of the Hermes C1 to the later Redstone missile is described by R. J. Snodgrass, a historian with the Historical Branch of the Army's Office, Chief of Ordnance:

> This portion of the Hermes program was of special importance because it laid the foundation for the later development of Ordnance's Redstone missile. Under its broad research and development contract, General Electric began the study of extremely long-range, multi-stage, glider and ballistic-type missiles in July 1946. [This vehicle configuration was similar in some respects to the A-9/A-10 concept studied by the von Braun team at the Peenemünde rocket center in 1943 and 1944.] In the aerodynamic, configuration, temperature, weight, and range studies for such missiles, the lack of basic engineering data on performance at very high Mach numbers severely handicapped the scientists. Nevertheless, General Electric completed a study late in the 1940s, which, briefly, recommended a three-stage missile that would glide through the third stage after having been powered through the first two. The take-off weight of 250,000 pounds was to be pushed through the first stage by a booster with a 600,000-pound thrust. [Actually, this thrust was to have been delivered by six rocket engines in three bays of a fin-stabilized, ground-launched booster. Each of the bays would house two engines and an associated propellant pumping system.] After about one minute, [the booster was to be separated and destroyed, and] the second stage was to continue for one minute under its own 100,000-pound thrust. With the completion of the second-stage powered flight, the missile was to glide along its trajectory to an ultimate range of about 2,000 miles.
>
> General Electric contemplated further study on this missile, known as the C1, but the urgency of other work after the start of the Korean conflict did not permit the contractor to mark a more detailed analysis of multi-stage missiles. Consequently, in the fall of 1950, Ordnance transferred the Hermes C program to Redstone Arsenal where the preliminary data obtained on the C1 missile study was utilized in a new study for a later missile which became known as the Redstone.[25]

An even earlier study by GE, concluded on 1 July 1946 that a glider stage, called the Hermes BC/G1, was technically feasible and would have a gross weight of 950.75 kg (2,096 lb), of which the payload, i.e., an atomic warhead, would account for 453.6 kg (1,000 lb), the control systems and related components 226.8 kg (500 lb), and the structure of the stage 270.3 kg (596 lb). Studies in the high Mach-number areas listed by Debus in footnote 21 continued through January, 1947, were discouraging to the GE engineers and their German colleagues and severely limited progress on preliminary design.[26]

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[25] R. J. Snodgrass, "DRAFT — Ordnance Guided Missile Program 1944-1954," Historical Branch, Office, Chief of Ordnance, 1954. Copy available in the archives of the History Division, U.S. Army Missile Command, Redstone Arsenal, Alabama. See also: Martin Schilling, "The Development of the V-2 Propulsion System," in T. H. Benecke and A. W. Quick, eds., *History of German Guided Missile Development, AGARD First Guided Missiles Seminar, Munich, Germany, April 1956.* Brunswick: Verlag E. Appelhaus, 1957, pp. 281-296.

[26] "Hermes Guided Missile Research and Development Project 1944 - 1955," pp. 10-11.

The role foreseen for the Hermes C1 was of a military nature only. It was to be an artillery support weapon with an atomic warhead for the field army and have a range between 277.8 km (150 naut mi) and 1,387.5 km (750 naut mi). The proposed military characteristics of the missile changed several times, much to the dismay of the engineers at the Ordnance Guided Missile Center at Redstone Arsenal, who were in the throws of trying to settle into their new facility and perform an exacting study of the proposed missile simultaneously.

The pacing factor in their efforts was the immediacy (caused by the advent of the Korean War) of developing and fielding the Hermes C1, a task which dictated that the developers consider utilizing as many of the missile components as were currently available, extensively tested, and sufficiently reliable. A review of such components led the engineers at Redstone Arsenal to consider several propulsion systems and guidance systems:

The first of the chosen power plants had been developed by North American Aviation, Inc. in its Project MX-770. This rocket engine, designated the XLR43-NA-1, had originally been developed for use as a booster in the Navaho missile project of the United States Air Force. Basically, it was a redesigned and improved version of the V2 rocket engine (Figure 10), that could be used in a single-stage ballistic rocket or as a booster for a ramjet missile.

The other rocket engine project to merit serious consideration was a proposal by the Aerojet Engineering Corporation. This proposed rocket engine, designated the AJ 10-18, was expected to develop 160,000 pounds of thrust from a unit of four swivel-mounted thrust chambers burning a liquid propellant. Little more than a preliminary evaluation could be made on this proposal, though, as it reached the Guided Missile Center (later ABMA) when the preliminary study had been almost concluded. Even so, this rapid evaluation did show that this type of power plant would be more adaptable for use in a two-stage ballistic rocket.

All findings in the study pointed to the use of the North American engine as being more advantageous. For one reason, it was available, while the Aerojet engine was only in the planning stage. For another, it was expected to be ready for quantity production by the late summer of 1951. Also, it could be adapted for use in both single-stage ballistic rockets and ramjets. And last, it more nearly satisfied the power and performance requirements of the 500-mile missile.[27]

Various types of guidance systems were studied:

Foremost among these systems were the General Electric Company's phase-comparison radar, the Consolidated Vultee Aircraft Corporation's Azusa system, and the Ordnance Guided Missile Center's own inertial guidance system [i.e., that of the A-4 (V-2)].

During the preliminary study, it became apparent that, while the phase comparison radar appeared acceptable for use in ballistic rockets, its vulnerability to countermeasures made it undesirable for use in the Redstone. The Azusa system, on the other hand, did seem to have a sufficient accuracy potential. But it was only in the development stage and had been neither tested nor proven. Having found these two systems wanting,

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[27] Bullard, *op. cit.*, pp. 29-30.

the study group turned to the inertial guidance system as the logical choice for use in the proposed missile. The group pointed out that its own inertial guidance system would provide an accuracy of 500-yards circular probable error. Besides being available and reasonably accurate, it was adaptable both to ballistic rockets and to ramjet systems. Since its 274.3-m (500-yard) circular probable error exceeded the military requirement, the study group considered the possibility of adding a homing guidance system to achieve greater accuracy.

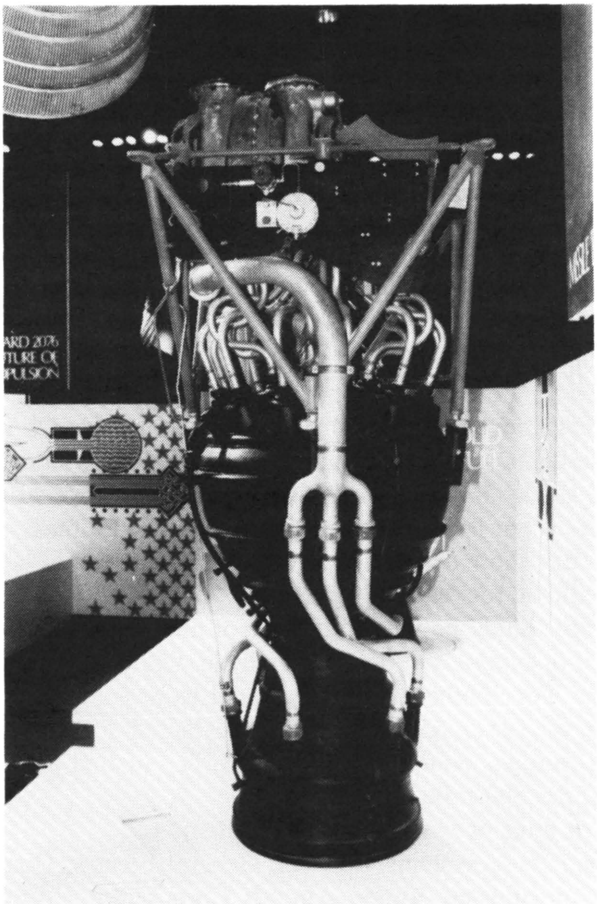

Figure 10 Propulsion system for German A-4 (V-2) guided missile.

In December 1950, a preliminary study of the Hermes C1 was completed. The substance of it was:

> In determining which type of missile to recommend for development as the 500-mile missile, the preliminary study group weighed all the factors involved. They considered the requirements outlined in letters and verbal instructions to the Guided Missile Center by the Chief of the Research and Development Division in the Office, Chief

> of Ordnance. Then, they determined where these requirements could be met and where sacrifices would be necessary. Only then did they reach their conclusion that the 500-mile missile should be developed as a single-stage, liquid-fueled ballistic rocket, powered by the North American Aviation XLR43-NA-1 rocket engine. The inertial guidance system, supplemented by a radio navigation system, would provide an accuracy of 500-yards circular probable error for ranges of 400 nautical miles. Perfection of the homing guidance system, however, would reduce the circular probable error to 150 yards.[28]

Scarcely had this report been published and a presentation on it had been made to the thirtieth meeting of the Committee on Guided Missiles, in Washington, than the scope of the Hermes C1 missile changed yet again in February, 1951. The change reduced the range from 804.6 km (500 mi) to 249.4 km (150 naut mi). The decrease in range resulted from a decision by higher authorities to employ a warhead that weighed 3,129.8 kg (6,900 lb), instead of the earlier weights of 680.4 kg (1,500 lb) to 1360.8 kg (3,000 lb) that were considered. The reason for the heavier warhead was that it had proven to be the most effective device.[29]

By this time the configuration changes had prompted the need for a new name, since Hermes C1 no longer existed in concept or reality. There followed a period in which the emerging missile was known variously as Ursa, Major, XSSM-G-14, XSSM-A-14; and, on 8 April 1952, it was officially designated the Redstone. (One of the original German members of the team suggested that perhaps the name Ursa was dropped because it might offend the U.S.S.R.)

The Redstone Missile

Development of the Redstone began on 1 May 1951. The engineering phase lasted some seven and a half years, and it was essentially completed with the successful launching of the last research and development missile on 3 November 1958.

In addition to becoming the U.S. Army's highly reliable short-range, tactical missile, the vehicle was the test bed for a developing rocket technology. With relatively minor modifications, the Redstone also became the launch vehicle for the first American artificial satellite of Earth, as well as for its first astronaut.

The Redstone was developed under an unusual philosophy. It was to be a highly accurate and reliable missile and to be deployed as soon as possible using existing technology and components.

The preliminary design characteristics were soon formulated and are shown in Table 1.

Originally the plan at ABMA for developing the Redstone was to follow as much as possible the Army's traditional weapons approach. Design, fabrication, assembly, quality control, and testing would be performed "in house," i.e., within the facilities of ABMA at Redstone Arsenal. However, by October 1951, it became obvious that the leadtime needed to develop components and fabrication posed a threat to the overall

[28] Bullard, *op. cit.*, p. 30.

[29] Debus, *op. cit.*, p. 21; Bullard, *op. cit.*, pp. 35-36.

time schedule for the program. Thus, ABMA realized that it would have to rely on large industrial companies to provide major assemblies and components from the beginning, rather than having small companies furnish the minor components as originally planned.

Under the pressure of time and the dictates of higher headquarters, ABMA turned to industry for the rocket propulsion system. As mentioned above, the engine selected was the XLR-43-NA-1 of the Rocketdyne Division, North American Aviation. The company undertook a program to modify that engine as the booster for the Redstone. To develop the engine, the contractor proposed a "general technical program for the design, modification, development, and testing of a 75,000-pound [333,600 N] thrust rocket engine having a rated duration of 110 seconds and with special thrust decay features at thrust cutoff."[30]

Table 1

PRELIMINARY REDSTONE DESIGN CHARACTERISTICS

Dimensions	
Length, m (ft)	
Tail unit	2.53 (8.3)
Center section	8.9 (29.2)
Body unit	7.71 (25.3)
Total	19.15 (62.83)
Diameter, m (ft)	
Thrust unit	1.8 (5.83)
Body unit	1.61 (5.3)
Weights, kg (lb)	
Empty weight of missile	7842.74 (17,290)
Oxygen	9761.47 (21,520)
Alcohol	7711.20 (17,000)
Hydrogen peroxide	308.45 (680)
Total weight at liftoff	25,623.86 (56,490)
General data	
Thrust, N (lb)	333,600 (75,000)
Specific impulse, s	218.8
Burning time, s	110
Peroxide consumption rate, kg/s (lb/s)	2.72 (6)
Propellant consumption rate, kg/s (lb/s)	155.54 (342.9)
Performance data	
Range, km (nmi)	287.06 (155)
Approximate flight time, s	370
Approximate cutoff velocity, m/s (ft/Δ)	1479.80 (4855)
Approximate peak altitude, km (nmi)	94.5 (51)
Approximate range of booster, km (nmi)	268.54 (145)

Designated the NAA 75-110, the engine underwent numerous modifications to enhance performance and components. Seven models were produced and were numbered

[30] Bullard, *op. cit.*, p. 57. See also, H. R. Palmer, "Rocket Power, Redstone to Saturn V., Now Space Shuttle, 20 Years of Development," 32nd Annual Conference, Society of Allied Weight Engineers: London, pp. 25-27, June 1973. See also: "Interim Report on the Development of the XLR 43-NA-1 Rocket Power Plant," Report No. AL-1226. Downey, California: North American Aviation, Inc., 15 May 1951; "Design Report of the XLR 43-NA-3 and XLR 43-NA-1 Power Plants," Report No. AL-1513. Downey, California: North American Aviation, Inc., 1 September 1952.

sequentially as NAA 75-110-A-1 through NAA 75-110-A-7. Each different engine had the same basic operational procedures and was designed for the same performance characteristics. All models were interchangeable, and only minor modifications and adjustments were needed to mate the engine to the missile. During development, the contractor introduced such improvements as a LOX pump inducer to prevent cavitation, full-flow start, gage pressure thrust controller, and absolute gage thrust controller. The A-6 version was utilized on the tactical Redstone, while the A-7 was used with the Mercury-Redstone vehicle.[31]

Figure 11 illustrates the technology of propulsion systems from V-2 through Saturn 5. By December 1951, ABMA had completed design for the airframe of the Redstone and needed a manufacturer for it.

The airframe, Figure 12, consisted of three major sections: the body, with the radar fuze, warhead compartment, instrument compartment, and skirt section; the power unit, with a center section, housing the alcohol and oxygen tanks; and the tail unit. The body provided control for the entire missile and delivered the warhead to the target. The warhead section was made of alloy steel skin and ring frames, while the aft unit had a steel skin with aluminum ring frames. The power unit and tail unit also had aluminum skin and ring frames.[32]

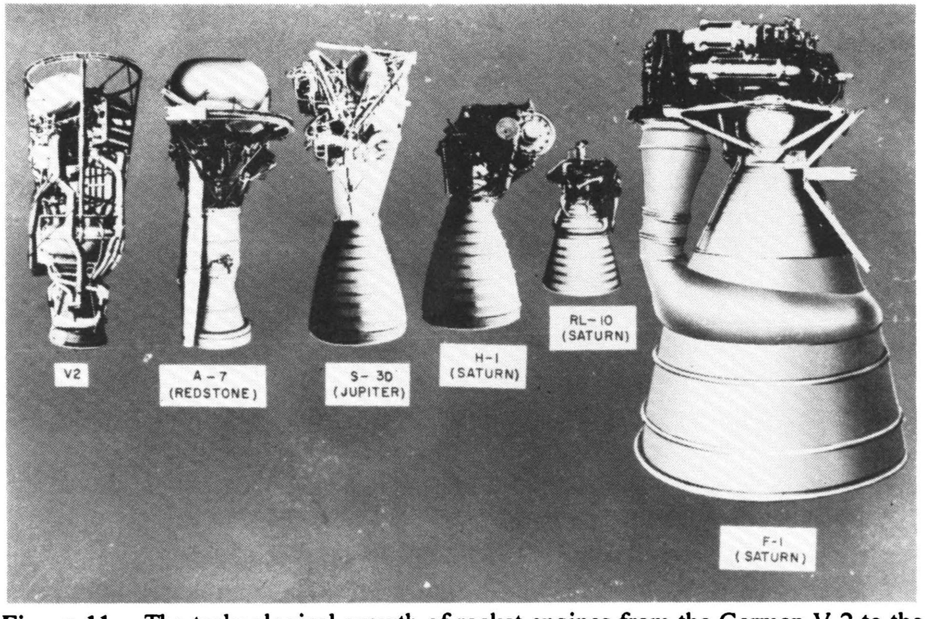

Figure 11 The technological growth of rocket engines from the German V-2 to the F-1 engine of the Saturn 5 space launch vehicle.

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[31] Bullard, *op. cit.*, pp. 58-61. See also: "Model Specification for a Rocket Engine NAA Model 75-110 (75,000 pound thrust unit)," Report No. AL-1227a. Downey, California: North American Aviation, Inc., 16 October 1952.

[32] *Operators Manual, Introduction and Description (Field Artillery Guided Missile System Redstone*, DA TM 9-1400-350-10. Washington, D.C.: Headquarters, Department of the Army, October, 1960, pp. 42-67.

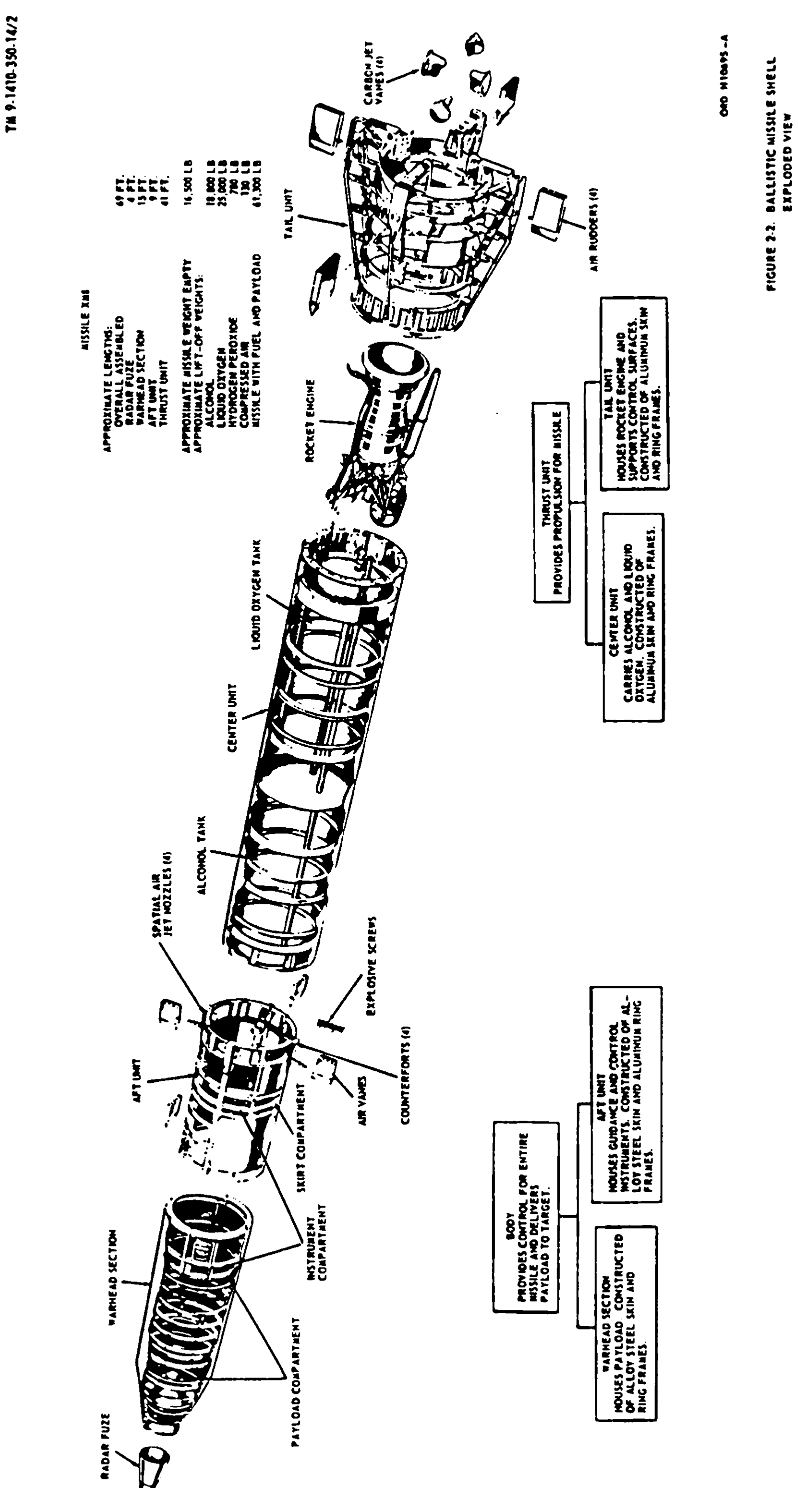

Figure 12 Airframe of the Redstone ballistic missile.

ABMA kept its hand in the production of the early development Redstone missiles, manufacturing missiles 1 through 12 and 18 through 29. The Chrysler Corp., prime contractor, manufactured missiles 13 through 17 and all missiles after number 30. The airframe components for both the early development missiles, as well as the later tactical missiles, were supplied to the prime contractor by the Reynolds Metal Co. These components were manufactured in the company's Sheffield, Alabama, plant, only 112.6 km (70 mi) from ABMA.

Because of the specified time-frames, the guidance and control system proved to be the pacing component in the developmental phase of the Redstone.

The former engineers of Peenemünde drew upon the experience gained in developing the guidance and control system for the A-5 missile and its refinement for the A-4. Their experience was passed along to an American manufacturer, when the original German components used during the V-2 phase of Project Hermes were exhausted. While the ST-80 stabilized platform for the Redstone was in design and development, the LEV-3 autopilot, Figure 13, was used in the early research and development flights of the Redstone:

> The use of the LEV-3 autopilot control system permitted the early qualification of the propulsion system, the missile structure, the expulsion system for warhead separation, and other subsystems of the missile. Most importantly, however, it provided the means by which the ST-80 guidance system could be developed and qualified by having its components tested as passengers on the flight test missiles.[33]

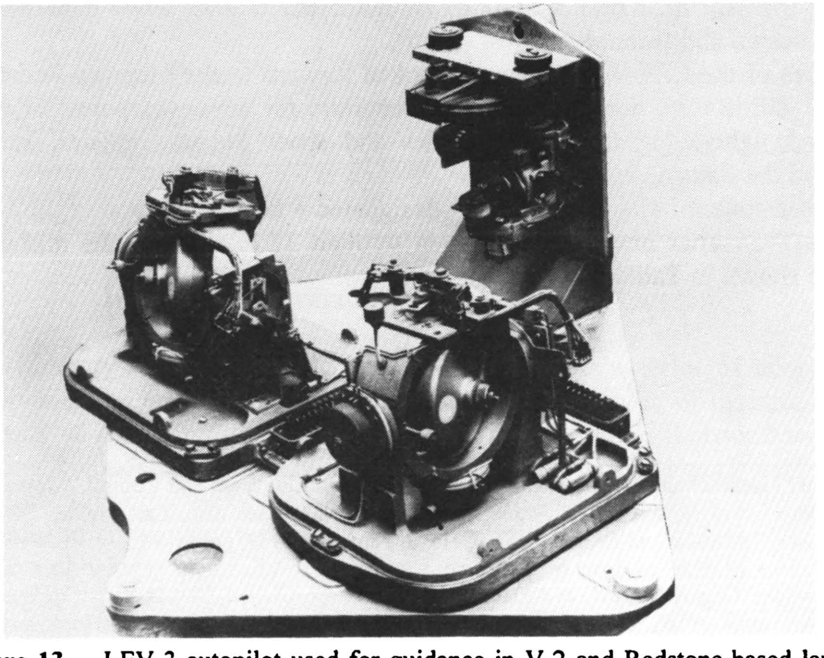

Figure 13 LEV-3 autopilot used for guidance in V-2 and Redstone-based launch vehicles.

[33] Bullard, *op. cit.*, p. 69.

The LEV-3 autopilot was built to ABMA design and specifications by the Waste King Corp., Los Angeles, California, a manufacturer of household appliances such as garbage disposals, dish washers, and waste incinerators. The first three research and development missiles were flown, in 1953 and 1954, with the LEV-3 for control purposes only. There was no guidance system.[34] Flights four and five, in 1954, had the LEV-3 as a control system; and the ST-80 flew as a passenger.

The ST-80 all-inertial guidance and control system, weighing 71.7 kg (158 lb), was located in the aft unit of the body section. It fitted into a spherical mount only 61 cm (24 in.) in diameter and had a maximum drift rate of 0.2 deg/hr. The ST-80 unit also provided guidance for the warhead section of the Redstone after stage separation. Correction signals sent to four air vanes, mechanically coupled to roll-control nozzles, maintained proper path guidance after reentry. The four nozzles furnished 48.9 N (11 lb) of thrust each, using compressed air from two bottles in the skirt section. The supply provided 110 sec of the gas. During booster stage of flight, the vanes were connected to the graphite rudders of the Redstone propulsion system by a chain drive.

The ST-80 system was manufactured by the Ford Instrument Co., Long Island City, New York, with gyroscopes and other components supplied by the Sperry Farragut and Sperry Gyroscope Divisions of the Sperry Rand Corp., Great Neck, Long Island, New York.[35]

The ST-80 was a technologically refined version of the SG-66 stabilized platform developed for the V-2 missile. The SG-66 weighed only 45.7 kg (100 lb), was 50.8 cm (20 in.) in diameter, and had a drift rate of only 4 deg/hr. However, the SG-66 became operational too late in World War II to be used; but it was flown experimentally to perfect the design and technology.[36]

The use of the LEV-3 in this mode looked forward to the Mercury-Redstone vehicle. The ST-80, in turn, became a point of departure for the development of even more accurate and lightweight units for missiles and space launch vehicles, such as the Pershing and the Saturn.

The Redstone missile was officially designated a tactical weapon in the U.S. Army on 18 June 1958 after having been proven through 37 test flights. Its missile characteristics are shown in Table 2.

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[34] Walter Haeussermann, "Developments in the Field of Guidance and Control," *Journal of Guidance and Control*, Vol. 4, No. 3, May-June, 1981, pp. 225-239. See also, Earl Finkle, "Workhorse of Inertial Guidance," *Missiles and Rockets*, Vol. 3, No. 2, February, 1958, pp. 91-93.

[35] *Operators, Organizational, and Field Manual, Ballistic Guided Missile XM8 Guidance and Control System Description (Field Artillery Guided Missile Redstone)*. Washington, D.C.: Headquarters, Department of the Army, September, 1960, pp. 45-46, 75-76.

[36] F. K. Mueller, *A History of Inertial Guidance*. Redstone Arsenal, Alabama: U.S. Army Ballistic Missile Agency, n.d., pp. 7-14. See also, O. Mueller, "The Control System of the V-2," in T. H. Benecke and A. W. Quick, *op. cit.*, pp. 80-101.

Table 2
REDSTONE TACTICAL MISSILE CHARACTERISTICS

	Maximum	Minimum
Trajectory, km (nmi)		
Range	323.7 (175)	92.5 (50)
Altitude	105.4 (57)	62.9 (34)
Circular probable error, m (ft)	91.4 (300)	
Payload, kg (lb)	2859.9 (6305)	
Thrust, N (lb)	346,944.9 (78,000)	
Length, m (ft)	21 (69)	
Diameter, cm (in.)	177.8 (70)	
Weights, kg (lb)		
Empty	7489.8 (16,512)	
Body (top section)	4699.2 (10,360)	
Liquid oxygen	11,380.8 (25,090)	
Alcohol	8527.7 (18,800)	
Peroxide, compressed gases	428.2 (944)	
Missile at ignition	27,826.5 (61,346)	
Specific impulse, s	235	
Time, s		
Total flight	375.1	288
Maximum dynamic pressure (ascent)	76	74
Cutoff	119.5	98
Stage separation	135	
Zenith	227	173
Reentry	348.6	256
Maximum dynamic pressure (descent)	369	277
Impact	375.1	288
Velocity, Mach		
Cutoff	4.8	2.9
Reentry	5.5	3.0
Impact	2.3	1.2
Acceleration, Maximum *g*	4.6	2.3
Deceleration, Maximum *g*	7.7	3.7
Warheads	Nuclear, special	
Fuzing	Proximity and impact	
Guidance system	Inertial	

Immediate Forerunners of Mercury-Redstone

The Mercury-Redstone vehicle had its beginning in a series of adaptations and modifications of the tactical Redstone missile to meet a number of research and development tasks at ABMA in the 1950s. These variations of the Redstone were used in flight testing components and materials for future missile and launch vehicles and to place satellites into orbit about the Earth and send probes to the Moon.

In order to circumvent technicalities and restraints placed on ABMA by the Army and higher authorities, generally with regard to funding and roles and missions of the armed service, the Redstone variants were given confusing names, e.g., Jupiter A, Jupiter C, and Juno 1.[37]

[37] Andrew Wilson, "Jupiter C/Juno 1 — America's First Satellite Launcher," *Spaceflight*, Vol. 23, No. 1, January, 1981, p. 13.

Jupiter A (Figure 14)

The Jupiter A was a developmental Redstone used as a test bed for components that would be incorporated into the ABMA's Jupiter missile, a follow-on to the Redstone with a range of 2,575 km (1,600 mi). Twenty five of the Jupiter A missiles were flown to obtain design data, to prove the guidance system, to evolve stage separation procedures, and to gather other information that would be used in the Jupiter program. Essentially, it was a Redstone modified internally to provide space for such components. Its characteristics were basically the same as those in Table 2.

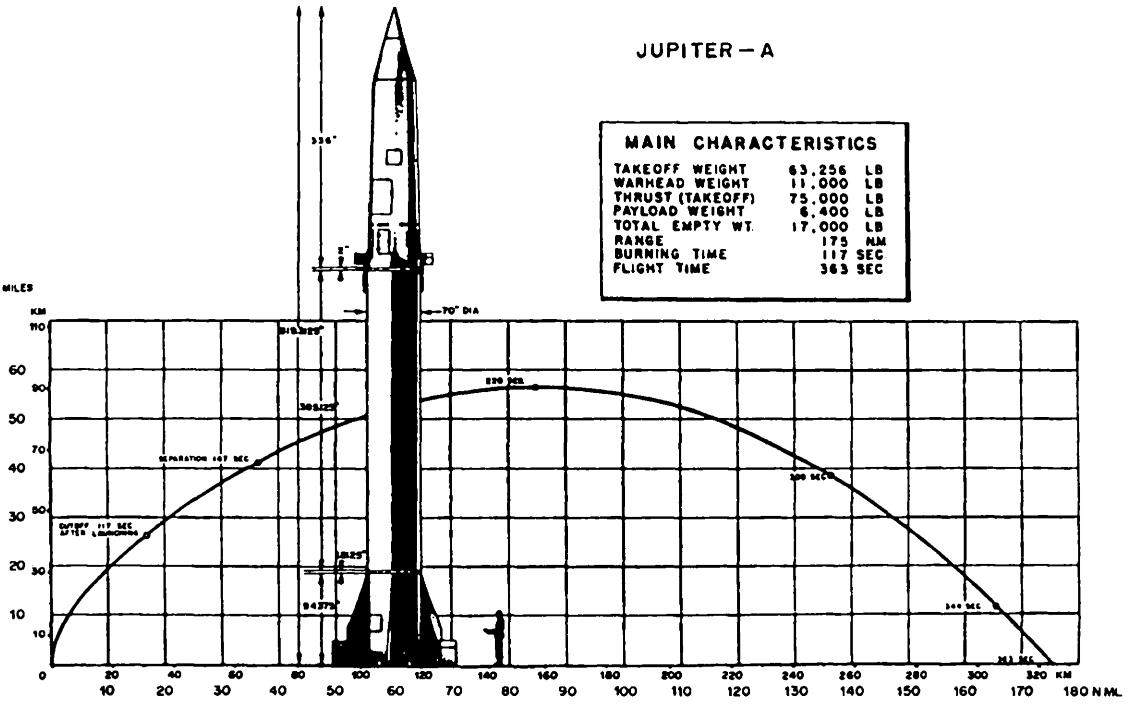

Figure 14 Jupiter A research vehicle.

Jupiter C (Figure 15)

A more extensively modified Redstone was the Jupiter C (Composite Reentry Test Vehicle). It was a multistage vehicle developed to prove the ablative nosecone of the Jupiter intermediate range ballistic missile against the heat generated during its reentry into the Earth's atmosphere. It was 20.6 m (67.5 ft) long and weighed 27,449.1 kg (60,514 lb) at launch.

Major changes to the basic Redstone, to convert it to the Jupiter C configuration, were the lengthening of the propellant tanks and the provision of a cluster of solid-propellant rockets as upper stages. The larger propellant tanks were possible, because their modification weighed considerably less than the Redstone warhead. The tankage was also made of a thinner gage to further reduce overall vehicle weight. The additional 2.4

m (8 ft) length of the tanks increased the burning time of the NA-75-110-A7 engine from 121 sec to 155 sec.

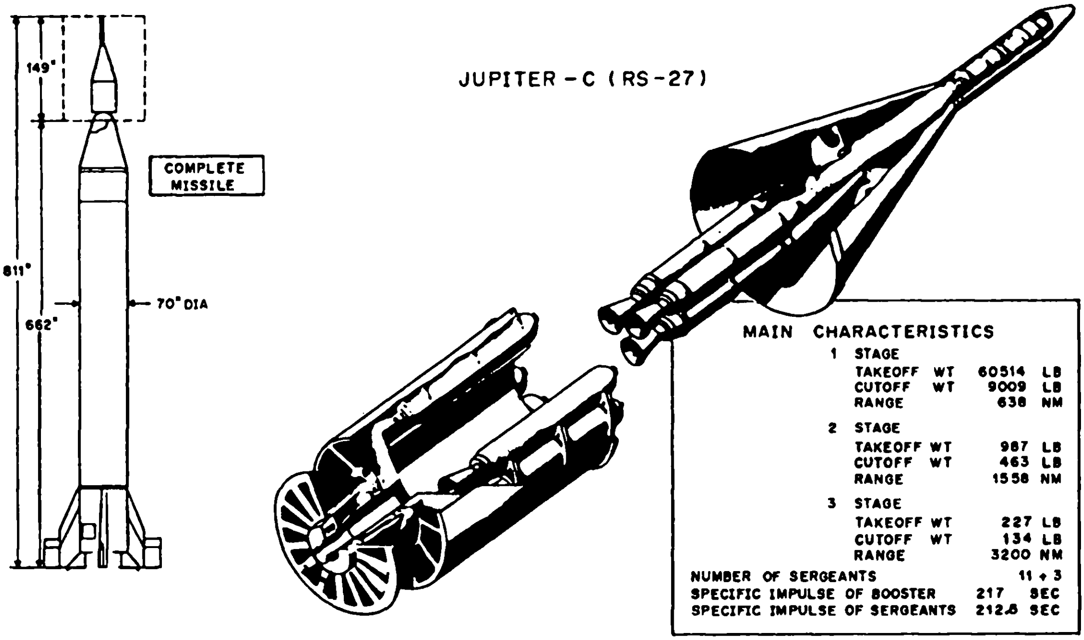

Figure 15 Jupiter C launch vehicle.

To enhance engine performance, the alcohol of the Redstone was replaced by Hidyne, a 60/40 mixture of unsymmetrical dimethylhydrazine and diethylenetriamine. This fuel, with the increased tank volume, produced a lift-off thrust of 369,184 N (83,000 lb) with a specific impulse of 242 sec. To realize the increased burning time, an additional storage tank for hydrogen peroxide for the propellant turbopump was added to the propulsion system.

It was necessary to redesign the instrument compartment of the Redstone to accommodate the solid-propellant upper stages. A tapered aluminum structure was developed, that would support the stages and house the LEV-3 autopilot. The Redstone attitude-control system, of jet nozzles and air vanes was also redesigned. The nozzles were replaced with those having a proportional control system rather than the "bang-bang" type of the Redstone, which was first developed in World War II Germany for the Fritz X and HS 293C guided missiles. Two nozzles were used for pitch and two for yaw control, while all four were used for roll control. Each nozzle produced 22.2 N (5 lb) of thrust. The attitude control system was capable of an accuracy of 0.1 deg. The air vanes, not being required since stabilization took place outside the atmosphere, were removed.

To separate the instrument compartment from the booster stage, the pneumatic pistons of the Redstone were replaced by explosive bolts and springs, which imparted 79.2 cm/sec (31.2 in./sec) velocity to the compartment at booster burnout.[38]

[38] Wernher von Braun, "Rundown on Jupiter C," *Astronautics*, Vol. 3, No. 10, October, 1958, pp. 32-33, 80-84.

Jupiter C had two upper stages. They were developed by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. The high-speed stages consisted of clusters of scaled-down Sergeant solid-propellant rocket motors. Choice of these motors was based primarily on the considerations of reliability, since the performance and reliability of the motors had been proven in some 200 static tests. The solid propellant was formulated at JPL and loaded by the Aerojet Engineering Corp. It was of the case-bonded, radial-burning type, with a star-shaped cavity running nearly the full length of the 1.2-m (4-ft) long, 15.2-cm (6-in.) diameter motor.

The second stage consisted of 11 motors assembled in a cylindrical ring formation by three transverse bulkheads and attached to a rotating tub by an inner circumferential tube. Each motor produced 6,672 N (1,500 lb) of thrust with a specific impulse of 217 seconds. Within this tub nested the third stage of three motors bundled together by transverse bulkheads.

Rotation of the tub to 750 rpm was initiated by an onboard electric motor before launch and programmed during first-stage burning. After separation from the first stage at burnout, the instrument compartment and upper stages coasted in free flight until proper attitude, using air jets described above, was reached at the apex of the trajectory. The motors had a burning time of approximately 5 sec, and each stage was fired sequentially with a few seconds interval between.

The Jupiter C required a minimum-weight, low-signal-level detection tracking and telemetering system. To meet this need, JPL developed a phase-lock-loop radio system called Microlock. Its main feature was the ability to lock on to an extremely low-level signal. The lightweight missile-payload transmitter consisted of a crystal-controlled oscillator, which was phase-modulated by telemetry signals.

The primary unit of the ground station was a phase-lock receiver that detected the beacon signal and which tracked the Doppler shift automatically. The Microlock antenna system had fixed helical antennas, either singly, in multiple array, or in conjunction with a two-antenna interferometer system for determining angular position. Microlock stations were located at various points throughout the world, along the payload trajectories, to determine quickly and accurately the flight paths and to record telemetered data.

As an indication of performance, Jupiter C(RS-27), launched 20 September 1956, attained an altitude of 1,097.5 km (682 mi) and a a range of 5,471.6 km (3,400 mi).

Juno 1 (Figure 16)

The Juno 1 launch vehicle was simply a Jupiter C with an additional fourth stage. This stage was mounted on a hollow, truncated cone attached to the forward end of the third stage. It was a scaled-down Sergeant motor with the dimensions of those described above; however, it had a higher-performance propellant that produced 8,006.4 N (1,800 lb) of thrust, with a specific impulse of 230 sec. It was a Juno 1 that launched *Explorer I*, the first American satellite, into orbit on 31 January 1958.

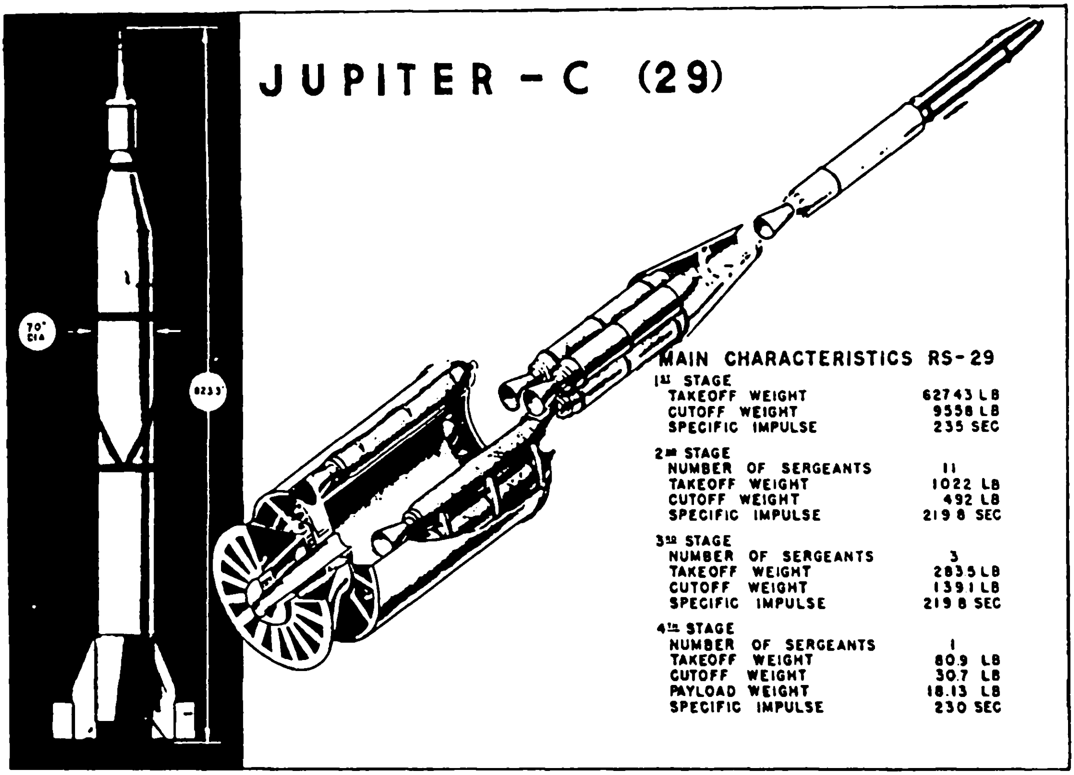

Figure 16 Juno 1 launch vehicle, mislabeled Jupiter C. Note the fourth stage rocket attached to satellite payload.

The Mercury-Redstone Launch Vehicle

Considerable time and effort went into the planning for placing an American into space before the decision to use any specific launch vehicle was made. Discussions and planning began over three years before the first American did enter space. In March 1958, a working group of engineers on the National Advisory Committee on Aeronautics, at Langley Aeronautical Laboratory, in Langley, Virginia, completed a study on various manned satellite plans, and they concluded that the first such spacecraft should be orbited using existing intercontinental ballistic missiles (ICBM) as the launcher. In the following month, engineers from NACA's Lewis Flight Propulsion Laboratory in Cleveland, Ohio, joined in the effort. A working group was formed to outline a manned satellite program.

In September, the U.S. Department of Defense's Advanced Research Projects Agency (ARPA) joined the NACA planning, and a Joint Manned Satellite Panel was established. This group reviewed NACA plans and proposed Army inputs. In October, the director of ARPA and the administrator of NASA (which succeeded NACA on 1 October 1958) approved the plan; and a Space Task Group (STG), Figure 17, was formed at the Langley Center, which began operations on the man-in-space program.

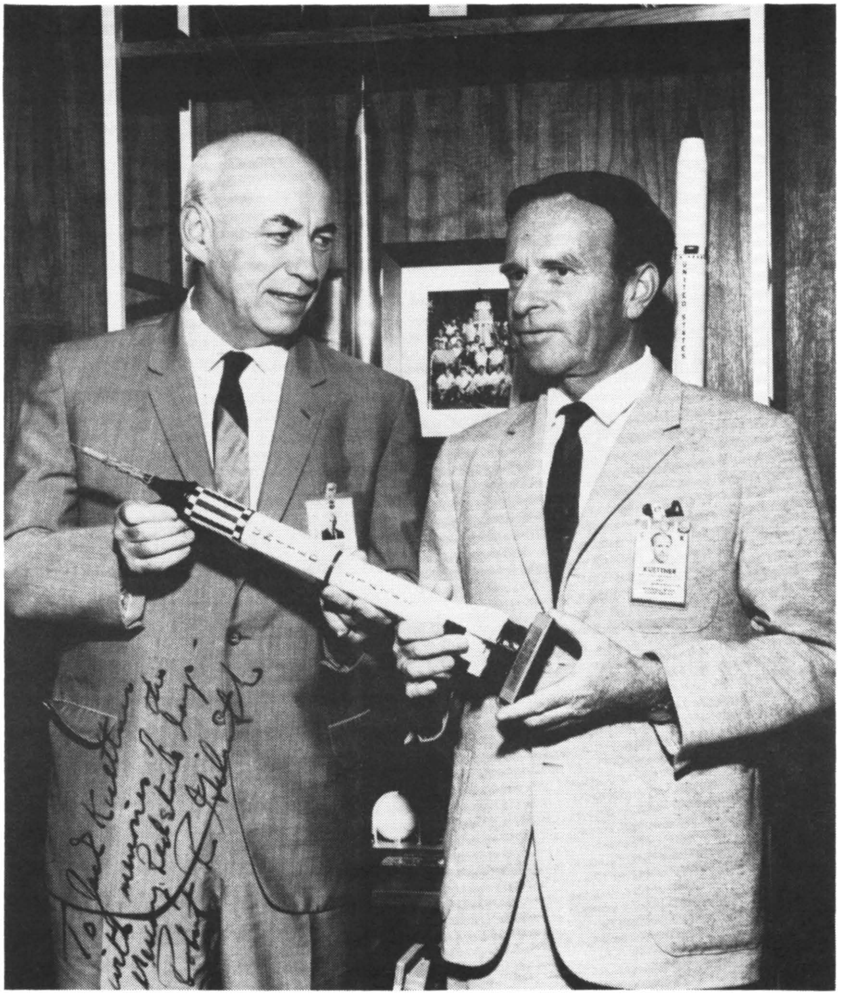

Figure 17 Robert R. Gilruth, left, chairman of STG, discusses Mercury-Redstone vehicle with Dr. Joachim P. Kuettner, ABMA.

A meeting was held at ABMA, at the request of NASA, on 6 October, to discuss the use of Redstone and Jupiter missiles in support of the newly established manned space program. As a result, the Army tentatively agreed to furnish NASA with 10 Redstone and 3 Jupiter missiles on 17 October.[39]

On 2 December, members of the STG met with ABMA personnel in Huntsville "to determine feasibility of using the Jupiter booster for the intermediate phase of the manned satellite project; discuss Redstone program . . . [von Braun] gave a brief and sincere sales pitch for the Jupiter on the basis that NASA would be working with the same team involved in the Redstone flights . . . 'The Redstones' scheduled for the

[39] "The Mercury-Redstone Project," TMX 53107. Huntsville, Alabama: Marshall Space Flight Center, December, 1964, pp. 1-9. See also, "Mercury-Redstone Chronology to December 31, 1960," MSFC Historical Report No. 2. Huntsville, Alabama: Marshall Space Flight Center, May, 1961, p. 4.

manned satellite program are Jupiter-C boosters similar to those used for the Explorer . . . Dr. von Braun mentioned that the adapter section would be lengthened 2 or 3 feet to accommodate a booster recovery system. He did not elaborate on his reason for this recent decision."[40]

It was also decided that sufficient impact accuracy 3.2 km (2 mi) could be obtained by using the LEV-3 autopilot rather than the ST-80 stabilized platform. A development and funding plan for the eight Redstones and three Jupiters was forwarded to NASA by AOMC.

Figure 18 Meeting at McDonnell Aircraft Co. finds Wernher von Braun, second from left, and Dr. Joachim P. Kuettner, third from right, examining Mercury spacecraft escape tower.

NASA authorized, on 16 January 1959, the funding to AOMC for eight Redstone and two Jupiter vehicles. The two Jupiter vehicles were to be launched in November, 1959 and January, 1960. At a meeting, Figure 18, attended by personnel from NASA, ABMA, and the McDonnell Aircraft Corp., contractor for the Mercury spacecraft, on 20

[40] "Memorandum for Asst. Director for Advanced Technology, Subject: Visit to ABMA regarding boosters for Manned Satellite and Juno II Programs." Washington, D.C., 4 December 1958, signed Warren J. North.

March, a decision was made about scheduling. Robert Gilruth, Chairman of STG and later director of NASA's Manned Spacecraft Center, Houston, Texas, "stated the MR-1 and Mercury-Jupiter No. 1 (MJ-1) would be capsule [spacecraft] only, MR-2 and MJ-2 would carry a large primate, and MR-3 through MR-8 would be manned."[41] MR-1 and MR-2 would be assembled by ABMA and the others by the Chrysler Corp. in Detroit, Michigan.

On 31 July 1959, NASA informed AOMC that the two Jupiter missiles would be dropped from the Mercury program because the data gained would be marginal; and better data could be obtained from Mercury-Atlas flights.[42]

As 1960 began, NASA commenced reconsidering the ABMA proposal to recover the Redstone boosters for refurbishment and reuse. Feeling that such an operation had no benefit for the Mercury program and could endanger the life of the astronaut if it deployed prematurely, ABMA was informed on 19 January that it would not obligate further NASA funds for the recovery effort. (On 20 July, the project was dropped officially).

Developing the Mercury-Redstone

While men had flown using reaction propulsion since World War II, in aircraft such as the ME-163 and experimental craft such as the American X-series (X-1, X-2, and X-15), their vehicles were generally capable of maintaining flight without propulsion, and the quantities of propellants were relatively small. In contemplating the Mercury-Redstone, ABMA engineers had to consider and resolve new problems including:

1. High-explosive yield of [large quantities of] propellants,
2. Acceleration, noise, and vibration environments,
3. Safety for ground personnel and facilities,
4. Water-recovery of the payload,
5. On-pad emergency egress of astronaut,
6. Abort sensing and implementation procedures,
7. Abort parameter limits to maximize safety without jeopardizing mission reliability.[43]

The major redesign changes to the Redstone or Jupiter-C to resolve these problems consists of:

1. Increased performance through propellant tankage elongation, resulting in an increased engine burn time from 123.5 sec to 143.5 sec,

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[41] "MEMORANDUM for Project Director, Subject: Project Mercury meeting on March 20, 1959, at Langley Field, Virginia," NASA - Space Task Group, Langley Field, Virginia, 26 March 1959, signed by Walter J. Kapryan.

[42] James A. Grimwood, *Project Mercury, a Chronology*, NASA SP-4001, Washington, D.C.: National Aeronautics and Space Administration, 1963, p. 65.

[43] "The Mercury-Redstone Project," *op. cit.*, pp. 2-1.

2. Simplicity through use of the LEV-3 autopilot rather than the ST-80 guidance system; [with 311.6 kg (687 lb) of ballast to increase vehicle stability]; new pressurized instrument compartment and no separation of aft unit from forward section at engine burnout. [The accuracy of the LEV-3 was considerably increased by the use of an air bearing in the pitch gyroscope and in the integrator gyroscope that generated the cut-off signal for the propulsion system.][44]
3. Astronaut safety enhancement through installation of an automatic, in-flight, abort system; return to use of LOX and alcohol rather than the more toxic Hidyne fuel.

Even though more than 800 changes were made before the Mercury-Redstone project was completed, the changes listed above increased the vehicle's reliability to the extent that the automatic abort system, discussed below, was never necessary. The majority of these changes were made after extensive ground tests and as a result of flight tests.

The Process of Man-Rating the Mercury-Redstone

From the safety viewpoint, the presence of a man aboard a rocket-propelled vehicle is not comparable to a pilot in an aircraft. Most emergencies in the aircraft occur in time for the pilot to react and take corrective action. However, this situation is not true for the astronaut; an automatic abort system was necessary to separate the spacecraft from the booster in case of an emergency in the booster.

The need for an automatic abort system was delineated in a memorandum that Kuettner wrote to various laboratory directors of ABMA on 14 January 1959, shortly after NASA had selected the McDonnell Aircraft Co. as the contractor to build the Mercury spacecraft. After pointing out:

> In view of the human life involved in this project the measuring program should be exceptionally detailed. . . . It will be necessary to be able to track down any conceivable malfunction during each flight.

With specific reference to an automatic abort system, he further wrote:

> One or more *automatic* ejection systems are needed. (The suggested sensors of thrust-chamber pressure and attitude are examples only.) A study of this problem by the Guidance and Control Laboratory should incorporate the trigger-delay time.[45]

The automatic, in-flight, abort sensing system developed to further insure the man-rating of the Mercury-Redstone was largely the product of Friederich W. Brandner, of MSFC's Guidance and Control Division, who wrote:

[44] Interview with Dr. Fritz Mueller, Huntsville, Alabama, 17 September 1989, by Mitchell R. Sharpe.

[45] U.S. Army Ballistic Missile Agency, Disposition Form: "Mercury-Adam Project," 14 January 1959, signed by Joachim Kuettner.

This system has to rely on emergency sensors. There are an enormous number of missile components which may conceivably fail. Obviously, it would be impractical and actually unsafe to clutter up the missile with emergency sensors. However, many malfunctions will lead to identical results; and, in sensing these results and selecting the proper quantities, one can reduce the number of sensors to a few basic types. A high degree of passenger (pilot) safety, on the Mercury-Redstone vehicles, can be established by monitoring the performance of: control system (attitude and angular velocity), electrical power supply (60-volt control voltage - 28-volt general network), and propulsion system (chamber pressure).

If preset limits of these functions were exceeded, the system sent a signal to the spacecraft which activated engine shutdown. The Mercury spacecraft was boosted free of the launch vehicle by the escape tower before a catastrophic explosion. [Typical of these limits was a drop in engine combustion chamber pressure from the nominal 1,437 Nm^2 (300 lb/ft^2) to 1,005.9 Nm^2 (210 lb/ft^2 +/-15 lb/ft^2). Similarly, abort would occur if the control voltage fell from 60 vdc to 50 vdc.][46]

The system could be manually activated by the astronaut, a ground observer, the range-safety officer in the launch pad blockhouse, or personnel in the NASA Mercury Control Center.

A block diagram of the automatic, in-flight, abort sensing system is shown in Figure 19.

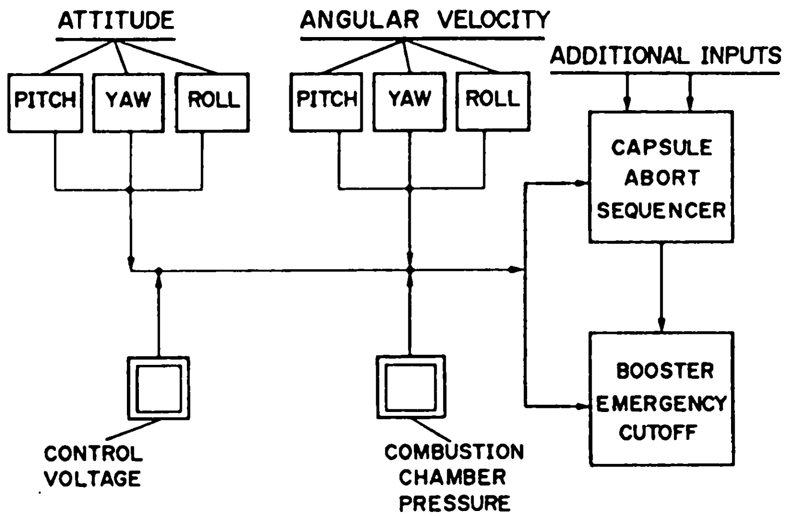

Figure 19 Functional block diagram of automatic abort system. Double lines indicate redundant sensors.

Equally important in the man-rating procedure for the vehicle was the reliability program developed for it. The program consisted of reliability testing, abort system reliability testing, reliability studies,

[46] F. W. Brandner, "Proposal for Mercury-Redstone Automatic Inflight Abort Sensing System," Rpt. No. DG-TR-7-59. Redstone Arsenal, Alabama: U.S. Army Ballistic Missile Agency, 5 June 1959, p. 1.

Tests included:

1. Factory testing of aft and tail sections and the propulsion system,
2. Structural load simulation of the thrust unit and transportation loads,
3. Static firings with noise and vibration testing,
4. Capsule [spacecraft] and adapter mating compatibility and separation ring testing as well as flight adapter checkout,
5. Component qualification and development testing.

The abort system reliability test program consisted of systems and subsystems testing by the Chrysler Corp. and qualification component testing by MSFC.

Following the MR-2 flight, the reliability of the Mercury-Redstone was reexamined before committing it to manned flight missions. Three separate studies were made: "The first was based on the running average of flight success probabilities which would place the payload at the proper injection point. The second study was based on an artificial configuration using the flight record of all components, weighing their failures according to the number of flights made by each component . . . . [the] third and more refined reliability study was made [of component malfunction and whether the type of malfunction had been eliminated for future flight.]"[47]

Thus, the probability of Mercury-Redstone success was estimated to be between 78 percent and 84 percent at a 75 percent confidence level.

Closely allied to the reliability activities was the Mercury awareness program. It "inspired all individuals to do their best. Mercury stamps, Figure 20, were issued to trained personnel to use with discretion on approved documentation and hardware. Publicity and awards focused attention on the good work of conscientious people . . . The importance of the Mercury stamps should be noted. Since the Redstone was built as a military weapon, the Mercury stamps identified the hardware that would carry men into space. In addition to identification of Mercury flight components, the stamps promoted a psychological awareness of the ultimate use within each handler of the part . . . The stamps further identified preliminary and final status by circular and square enclosures, respectively. Use of any parts or documents not identified by square stamps was prohibited. This identification procedure further assured that the 100 percent inspection directive for Project Mercury was carried out."[48]

Astronaut Gordon Cooper expressed his view of these stamps in more personal terms:

> The small parts from the hundreds of subcontractors who contribute to the Chrysler-built Redstone are handled with special care. To set these parts aside from the run-of-the-mill perfection of ordinary Redstone missiles, all Mercury-Redstone components are stamped with the symbol of the Roman god Mercury striding over the earth with a rocket clutched under one arm. When a workman handles one of these parts he knows an astronaut's life depends on it. To personalize this awareness, we like to

[47] "The Mercury-Redstone Project," pp. 5-31 to 5-35.

[48] "The Mercury-Redstone Project," pp. 5-39 to 5-40.

spend some time on the production line whenever we visit a contractor's plant. That way we get acquainted with the people who literally hold our lives in their hands.[49]

Figure 20 Mercury awareness reliability program stamp.

The Unmanned Mercury-Redstone Missions

The unmanned missions and their objectives are listed in Table 3. All flights, manned and unmanned, in the series were conducted from Launch Complex 56 at the Atlantic Missile Range, Cape Canaveral, Florida. In addition to testing and proving the Mercury-Redstone vehicle and Mercury spacecraft, these launches prepared a cadre of ground support personnel in launch procedures and duties that would be applied to future manned launches. With the MR-1, MR-1A, and MR-BD missions the abort sensing system was operated in an "open loop" mode, i.e, no abort would occur even if conditions required an abort. This step was taken to preclude a mission failure of the abort sensing system itself.

The only significant malfunction in the unmanned series of flights occurred with MR-1. The firing command was given and ignition of the engine took place. However, at first motion of the vehicle from the launcher, an engine shut-off signal was sent to the engine. Prior to complete shutdown, enough thrust was generated to allow the MR-1 to rise 9.6 cm (3.8 in.), then settle back onto the launcher. The shut-off signal automatically caused the spacecraft launch escape tower to fire, Figure 21, and the recovery parachutes of the Mercury to deploy.

[49] Gordon Cooper, "First Rocket We Will Ride," *LIFE*, Vol. 12, No. 6, 3 October 1960, p. 84.

Table 3
MERCURY-REDSTONE UNMANNED MISSIONS AND TEST OBJECTIVES

Mission	Launch date	Objectives
MR-1A	19 December 1960	• Qualify the spacecraft-booster combination for the Mercury–Redstone mission which includes attaining a Mach number of approx. 6.0 during powered flight, a period of weightlessness of about 5, and a deceleration of approx. 11 *g* on reentry • Qualify the posigrade rockets • Qualify the recovery system • Qualify the launch, tracking, and recovery phases of operation • Qualify the Automatic Stabilization and Control System, including the Reaction Control System
MR-2 Primate	31 January 1961	• Obtain physiological and performance data Primate Aboard on a primate in ballistic space flight • Qualify the Environmental Control System and aeromedical instrumentation • Qualify the landing bag system • Partially qualify the voice communication system • Qualify the mechanically-actuated side hatch • Obtain a closed-loop evaluation of the booster automatic abort system
MR-BD Booster Development Flight	24 March 1961	• Investigate corrections to booster problems as result of the MR-2 flight: —Structural feedback to control —System producing vane "chatter" —Instrument compartment vibration —Thrust control malfunction

The cause of the anomaly was traced to a "sneak" electrical circuit, created when two electrical connectors disconnected from the vehicle in reverse order. It was found to be the result of the use of a tactical Redstone missile control cable in place of the Mercury-Redstone model. The 29-millisec interval caused thrust to be terminated and the escape tower to be jettisoned. (One wonders if the cable had no Mercury awareness stamp.)

The spacecraft did not separate from the launch vehicle, because the g-load sensing requirements from the Mercury were not met. The parachutes were released because barometric sensors indicated a spacecraft altitude of less than 3,048 m (10,000 ft), a preset value.

MR-1A was flown after modifications were made to preclude the conditions which resulted in the failure of MR-1.

While MR-2 was an unmanned mission, there was one of man's anthropological cousins aboard the Mercury spacecraft. He was Ham, Figure 22, a 44-month old chimpanzee, who was qualified on 30 July 1960 with 217 hr of training, including rides on a centrifuge that simulated the 6-g acceleration of the Mercury-Redstone vehicle at launch.

Ham wore bioinstrumentation that telemetered physiological data on electrocardial activity, respiration, and body temperature. He had been trained to perform specific behavioral tasks in the spaceflight environment. There were no physiological or behavioral deviations from expected limits noted.[50]

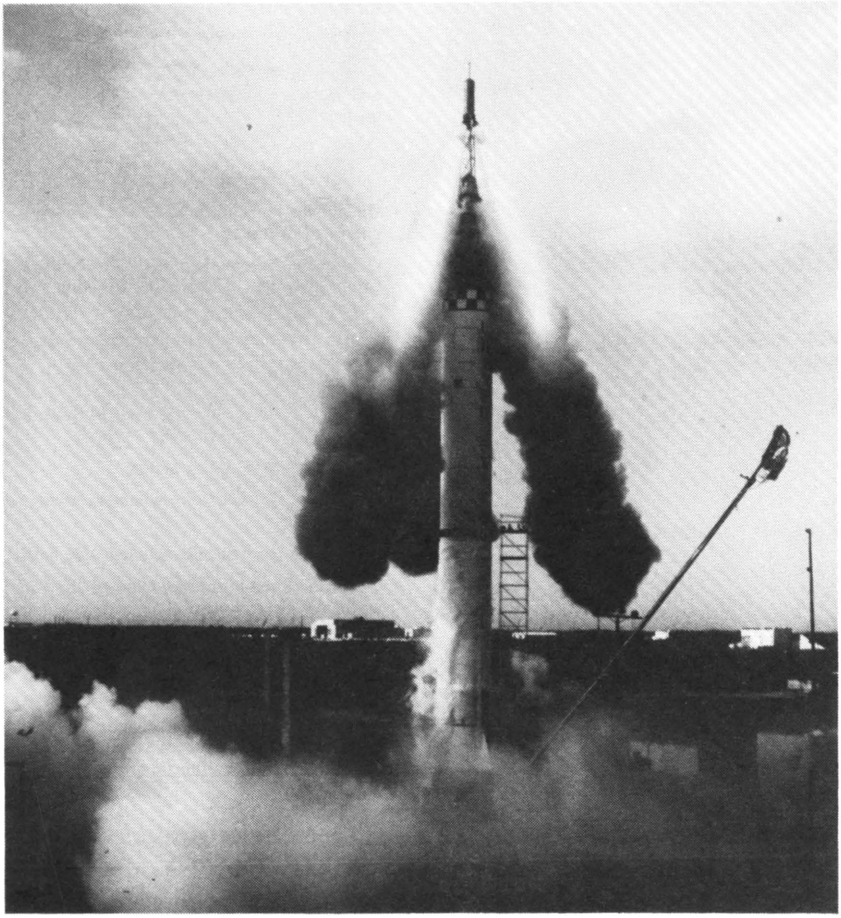

Figure 21 Attempted launch of unmanned MR-1 vehicle.

However, Ham's flight was marred by an anomaly in the performance of the MR-2 vehicle. The mission had been programmed for the Mercury spacecraft to reach a peak altitude of 183.4 km (114 mi) and a range of 468.3 (291 mi), but it actually attained an altitude of 251 km (156 mi) and a range of 667.8 km (415 mi). These conditions produced a reentry deceleration load of 15 g on Ham. The cause of the higher thrust was traced to a mixture-ratio serve control valve that failed in the open position, causing early LOX depletion. The propellant consumption rate was also increased by higher hydrogen peroxide pressure, which drove the turbopump faster.[51]

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[50] James P. Henry and John D. Mosely, eds., "Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights," NASA SP-39. Washington, D.C.: National Aeronautics and Space Administration, 1963, pp. 21-34.

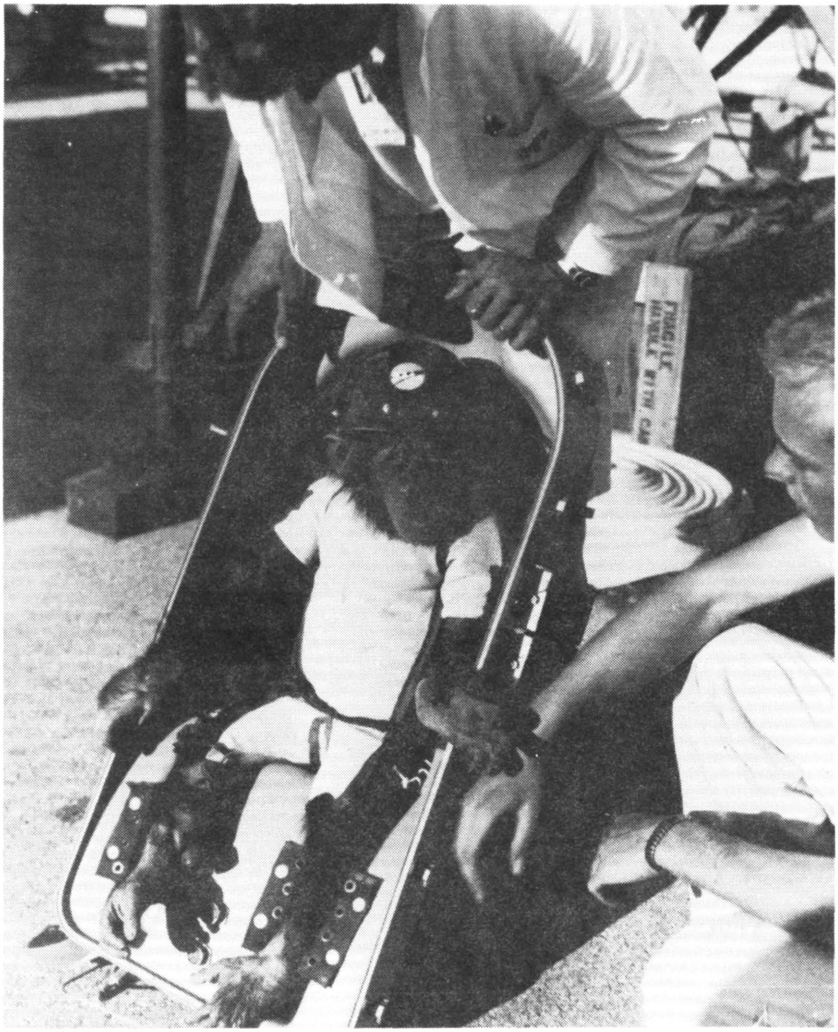

Figure 22 Chimpanzee Ham before his mission aboard MR-2.

The original launch schedule for the Mercury-Redstone program called for the fourth mission to be manned. However, the first three launches had uncovered several problems and weak areas in design, as was to be expected. Some of these solutions had been tested in flight but not all. Doubt existed among the various personnel at MSFC, STG, and NASA Headquarters as to whether a man should be risked on the fourth mission. The decision was left to MSFC which, after a detailed analysis of reliability data, recommended yet another unmanned mission. It would be the MR-BD. Not all at MSFC concurred in the decision. One was Dr. Joachim P. Kuettner, who later stated:

> After what was to be the last test flight before the first manned mission, a small (non-critical) electronic error was found which could be easily corrected. In the cru-

[51] "The Mercury-Redstone Project," pp. 8-9.

cial meeting with all laboratory directors and von Braun—the seven astronauts were waiting outside—I proposed the next mission to be manned. All MSFC lab directors backed me up, but Debus (Cape Canaveral) objected. I argued that nothing statistically worthwhile would come from another unmanned flight. I showed them also the anticipated U.S.S.R. launch schedule. After a long discussion von Braun decided against me and another unmanned launch had to be scheduled. In this way Gagarin flew just ahead of our first U.S. manned flight.[52]

The Manned Mercury-Redstone Missions

The manned Mercury-Redstone missions and their objectives are given in Table 4.

Table 4

MERCURY-REDSTONE MANNED MISSIONS AND TEST OBJECTIVES

Mission	Launch date	Objectives
MR-3 Manned	5 May 1961	• Familiarize man with a brief but complete spaceflight experience including the lift-off, powered flight, weightlessness flight (for a period of approx. 5 min), reentry, and landing phases of the flight
		• Evaluate man's ability to perform as a functional unit during space flight by:
		—Demonstrating manual control of spacecraft attitude before, during, and after retrofire
		—Use of voice communications during flight
		• Study man's physiological reactions during spaceflight
		• Recover the astronaut and spacecraft
MR-4	21 July 1961	• Familiarize man with a brief but complete spaceflight experience including the lift-off, powered, weightless (for a period of approx. 5 min), atmospheric reentry, and landing phases of the flight
		• Evaluate man's ability to perform as a functional unit during space flight by:
		—Demonstrating manual control of spacecraft during weightless periods
		—Using the spacecraft window and periscope for attitude reference and recognition of ground check points
		—Study man's physiological reactions during space flights
		—Qualify the explosively-actuated side egress hatch

In July 1959, the seven Mercury program astronauts, Figure 23, were given special assignments, based largely on their military aviation experience, to participate in the development of their spacecraft and its rocket launch vehicles. L. Gordon Cooper, Figure 24, was thus given the task of following modifications to the Redstone vehicle and the development of systems that were necessary for its man-rating.

Virgil I. Grissom, who had a degree in mechanical engineering, became the "expert" in the Mercury spacecraft's electromechanical, automatic, and manual attitude-control systems. Alan B. Shepard, because of his experience as a naval aviator, was given the task of participating in, and helping to develop, the tracking and recovery procedures for the spacecraft. John Glenn, who was backup pilot for both Grissom and Shepard, specialized in cockpit layout, since he had flown a large number of different types of high-performance aircraft.[53] The three astronauts are seen in Figure 25.

[52] Letter from Kuettner to Mitchell R. Sharpe, 20 August 1989.

Figure 23 Mercury astronauts being briefed at MSFC by Dr. Joachim P. Kuettner.

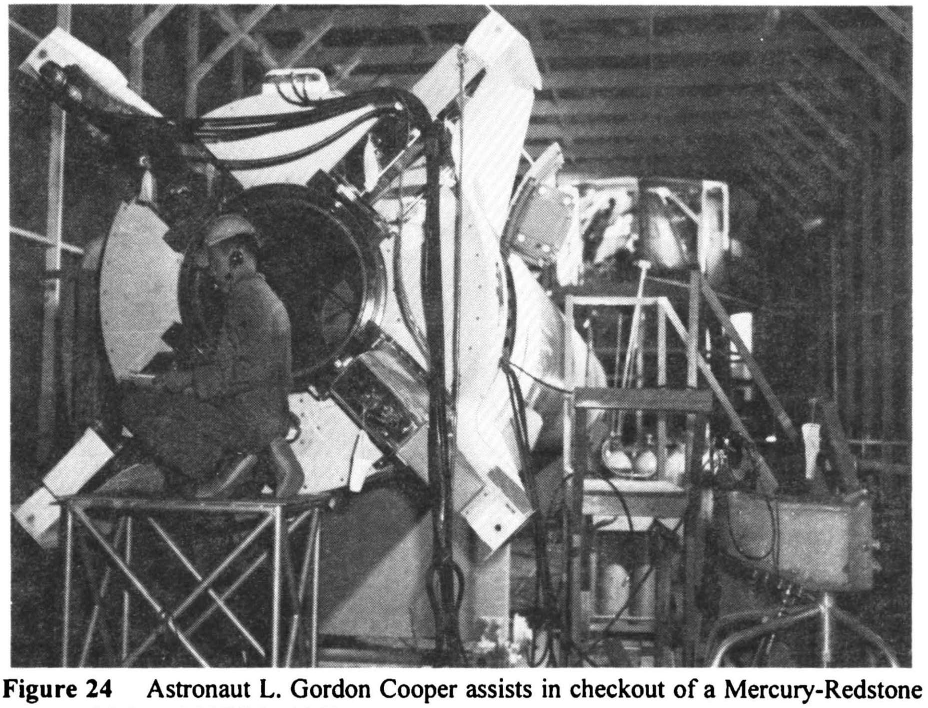

Figure 24 Astronaut L. Gordon Cooper assists in checkout of a Mercury-Redstone vehicle at MSFC in 1960.

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[53] Lloyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean, a History of Project Mercury*, NASA SP 4201, Washington, D.C.: National Aeronautics and Space Administration, 1966, pp. 235-236.

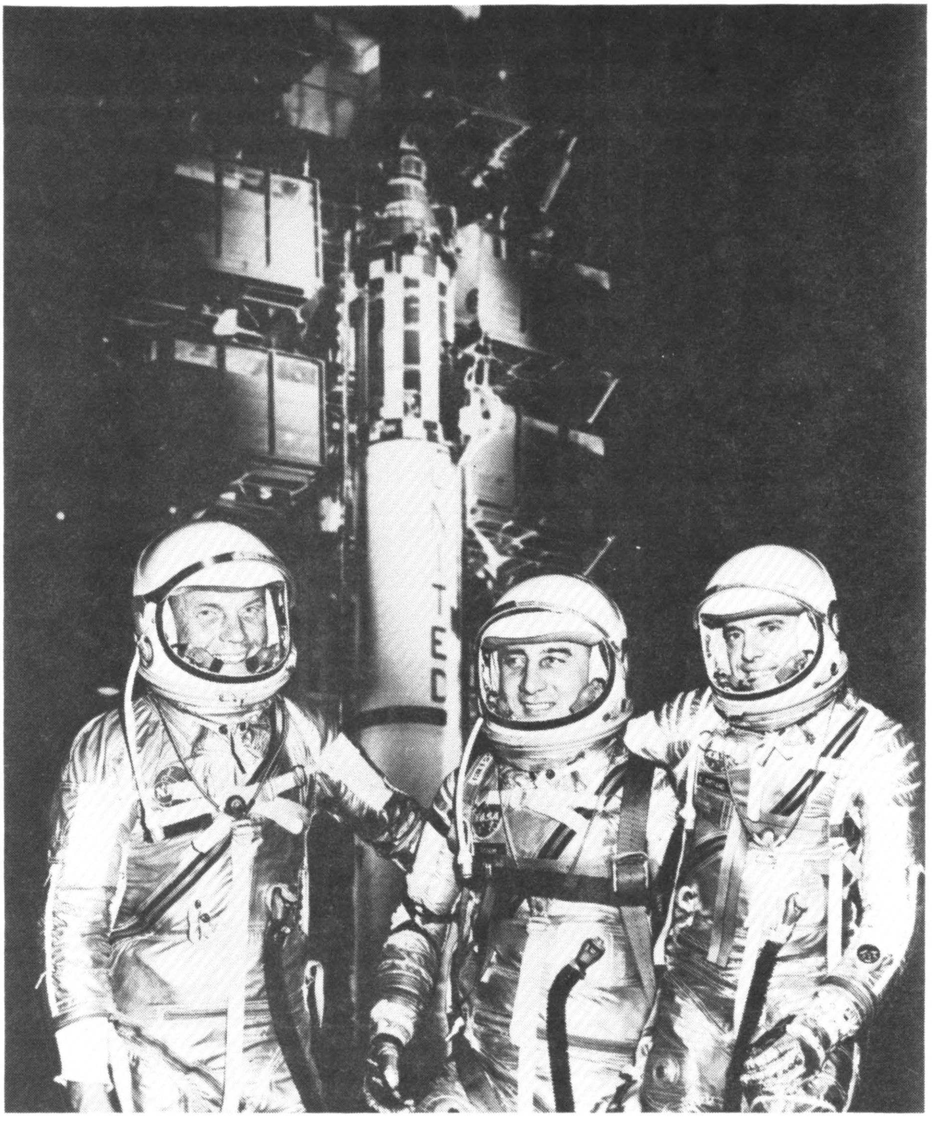

Figure 25 Left to right, back-up Astronaut John Glenn, MR-4 Astronaut Virgil I. Grissom, and MR-3 Astronaut Alan B. Shepard at Cape Canaveral.

While Cooper was specifically assigned to the Mercury-Redstone launch vehicle, Grissom was equally involved. The two astronauts were involved in all aspects of the development, assembly, and testing of the vehicle in both MSFC and at the Chrysler Corp. facility.

At a static firing of a Mercury-Redstone with its Mercury spacecraft in place, at MSFC in 1960, Cooper attempted to convince the test conductor to allow him inside the spacecraft during the firing. He wanted to experience the vibrations that would occur during the powered phase of flight. Having failed in this effort, Cooper, upon leaving

MSFC to return to the Johnson Space Center, flew at tree-top level over the test stand and then pulled sharply upwards to feel the accelerative forces that would be expected during the Mercury-Redstone launch.[54]

A summary of the MR-3 mission is given in Table 5.

Table 5

MERCURY-REDSTONE 3 (MR-3) CHARACTERISTICS[55]

Date of launch (ETR pad No.)	5 May 1961 (5)
Spacecraft designation	Mercury capsule 7
Unofficial spacecraft designation	Freedom 7
Launch vehicle designation	Mercury-Redstone 7
Spacecraft weight (kg)	1832.5
Spacecraft shape, dimensions (m)	Conical Width at base, 2.1 Length, 3.4
Crew	Alan B. Shepard Jr
Backup crew	John H. Glenn Jr
Cap com	Donald K. Slayton (Mercury Control Center)
Max. alt. (km)	187.42
Range (km)	487.26
No. of orbits	Suborbital
Length of mission	00:15:22
Missions events (date, time, ground elapsed time)	
Launch	5 May, 9:34:13 a.m., EST
Main engine shutoff	9:36:35 00:02:22
Capsule separation	9:36:45.5 00:02:32.5
Initiation of retrofire	9:38:57 00:04:44
Splashdown	9:49:35 00:15:22
Distance traveled (km)	1006
Time in weightlessness	approx. 00:04:00
Landing point	27°13.7'N, 75°53'W (5.6 km from target)
Recovery ship	*U.S.S. Champlain* (crew on-board in 15 min)
Mission objectives	During a suborbital flight evaluate Mercury astronaut's performance and advance the qualities of the capsule and its systems
Results	Mission was performed as planned

The 15-minute flight was uneventful, and there were no malfunctions. While Shepard, Figure 26, reported buffeting during powered flight, vibration telemetry showed that levels were well below those of the MR-2 and MR-BD flights. The addition of approximately 149.7 kg (330 lb) of ballast in the recovery and instrument compartments of the launch vehicle provided the dampening to accomplish the lower levels. The launch of MR-3 is shown in Figure 27.

Events of MR-4 are given in Table 6. The launch is shown in Figure 28.

[54] Interview of James C. Pearson by Mitchell R. Sharpe in Huntsville, Alabama, 2 September 1989.

[55] Linda Neuman Ezell, *NASA Historical Data Book, Vol. II, Programs and Projects 1958-1968*, NASA SP-4012. Washington, D.C.: National Aeronautics and Space Administration, 1986, p. 143.

Figure 26 Astronaut Shepard prior to his MR-3 flight (NASA photo 61-MR3-73).

Unfortunately, the *Liberty Bell 7* spacecraft was lost when the side-egress hatch ejected prematurely, allowing water to enter it. Astronaut Grissom, Figure 29, was forced to leave the spacecraft and to spend three or four minutes in the water until recovered by helicopter.

Grissom's impressions and memory of what happened were given to the press the day after his mission:

> While he [the recovery helicopter] was coming in, I decided to go ahead and get a little head start on him, and [I] took off the cover of the detonator that blows the explosive hatch off and tossed it down toward my feet. I then pulled the safety pin that holds the detonator out. You have to pull it before you can fire it. So that I was all set and waiting for him, and laid [I lay] back down on the couch, and he gave me

a call and said he was on final and I knew that he would pick me up in ten or fifteen seconds. I was just laying [lying] there minding my own business, and Pow!—the hatch went. I looked up and I saw nothing but blue sky and water starting to come in over the sill. So I tossed my helmet off. The only two moves I remember making were tossing my helmet off and grabbing the instrument panel; I don't remember going out the door. The copter pilot said the door came off, immediately followed by myself, almost [in] one motion. Without a doubt that was the biggest shock all day, to me—to see that door go off. I went into the water. Luckily I had the neck dam [of the spacesuit] up. I felt I was in pretty good shape. I was floating quite high in the water, about armpit high, because the suit does not float quite well in the water, with the neck dam on. I saw the helicopter there, very close. He had already cut the antenna. The antenna was gone and he was grappling for the loop on top of the capsule, and it was sinking rather rapidly. It looked like to me [like] he was having difficulty getting hold of it, but actually I guess he wasn't. This was the first time he had tried to snag it. So I clambered over to the capsule which was only four or five feet away and was going to maybe help him put the hook on it, but before I got there he actually had it hooked.

I saw him lift this pole, and the hook was on, and the hook dropped off the pole, which is normal, but at this time it did not look very normal to me, and I thought, "Oh, he lost it again." The capsule actually sank and went below the water. The helicopter pulled it free, and as he pulled it up, I thought, "Well, we are in good shape again, we have got it all, and he would [will] pick me up soon as it gets free of the water." The helicopter moved on away slightly; probably he moved a little bit and I got caught in the rotor wash and got blown away. I got blown outside of his rotor wash and he was having difficulty, as you probably already heard, getting the capsule out of the water. He couldn't lift it. He ran into an engine problem, at least we think now it was an engine problem. He couldn't lift it free. There were three helicopters there. I guess actually there were four—I don't remember seeing but three. I was caught in the center of all three of them and couldn't get to any of them.

I saw the second helicopter move in, put his horse collar [astronaut recovery device] down to pick me up—this thing hanging down in the water to pick me up. I tried to get over to him, but I was having difficulty getting through his rotor wash, and also I'd neglected to close a port down on my suit, where the inlet hose comes in, and [I] was getting water in my suit. I was getting lower and lower in the water all the time, and it was quite hard to stay afloat. But eventually, the helicopter got in close enough to me—he was having trouble getting any closer to me because the other helicopter still had hold of the capsule and couldn't get in to him. But some way or other the Marine copter pilot did get in close enough for me to get hold of the sling, and everything was pretty good for me from then on. They picked me right out of it and got me onto the U.S.S. *Randolph*, of course.[56]

[56] "National Aeronautics and Space Administration News Conference, Virgil I. Grissom, Project Mercury Astronaut, Liberty Bell 7 Pilot," 22 July 1961, Cocoa Beach, Florida, pp. 8-9.

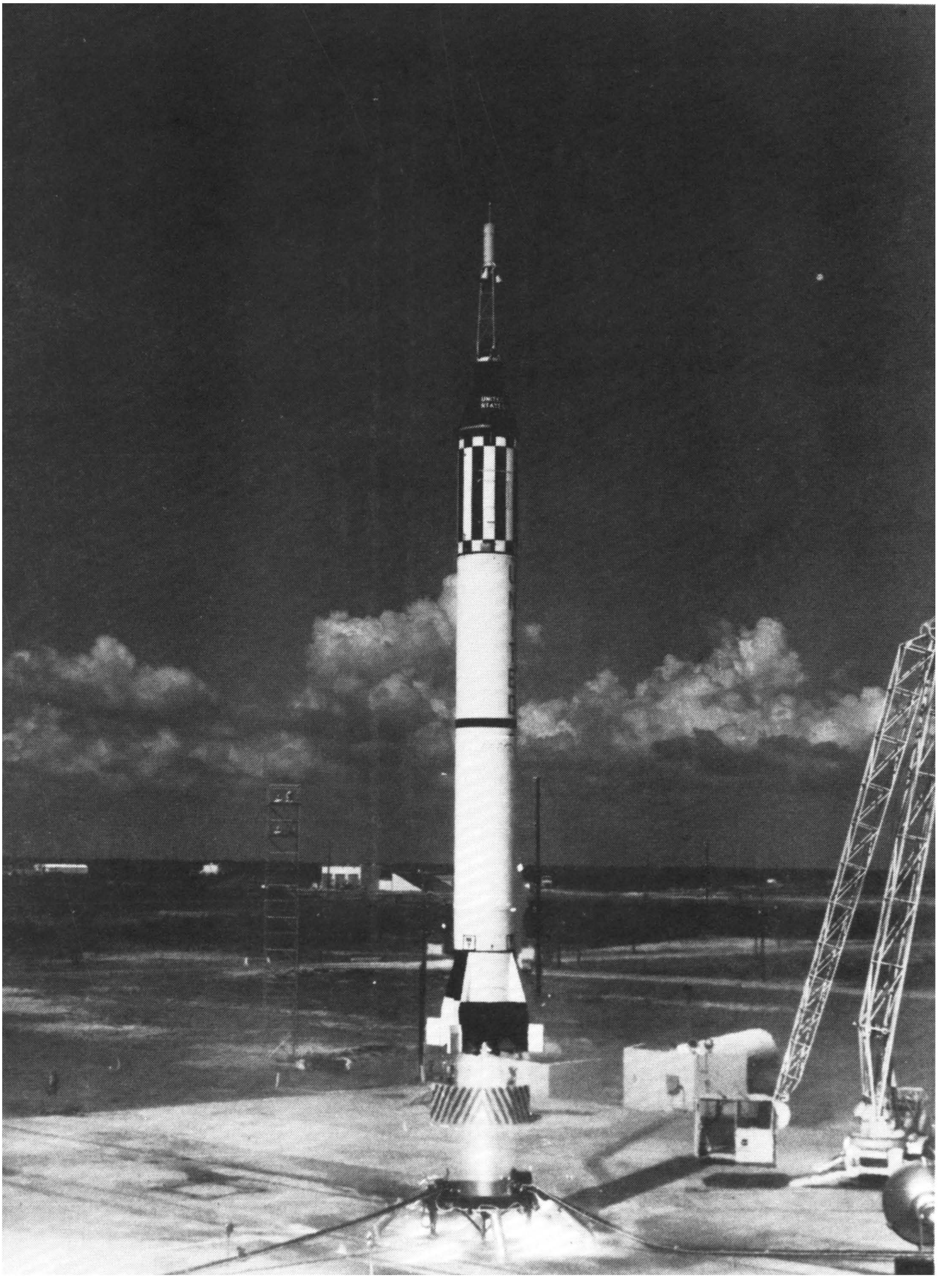

Figure 27 Launch of MR-3 at Cape Canaveral.

Table 6

MERCURY-REDSTONE 4 (MR-4) CHARACTERISTICS[57]

Date of launch (ETR pad No.)	21 July 1961 (5)
Spacecraft designation	Mercury capsule 11
Unofficial spacecraft designation	Liberty Bell 7
Launch vehicle designation	Mercury-Redstone 8
Spacecraft weight (kg)	1824.4
Spacecraft shape, dimensions (m)	Conical Width at base, 2.1 Length, 3.4
Crew	Virgil I. Grissom
Backup crew	Glenn
Cap com	Shepard (Mercury Control Center)
Max. alt. (km)	190.76
Range (km)	487.08
No. of orbits	Suborbital
Length of mission	00:15:37
Mission events (date, time, ground elapsed time)	
Launch	21 July, 7:20 a.m., EST
Main engine shutoff	7:22:22 00:02:22
Capsule separation	7:22:32.4 00:02:32.4
Initiation of retrofire	7:24:45.8 00:04:45.8
Splashdown	7:35:37 00:15:37
Distance traveled (km)	1014
Time in weightlessness	00:04:54
Landing point	27°32'N, 75°44'W (9.3 km from target)
Recovery ship:	*U.S.S. Randolf* (crew on-board in 20 min)
Mission objectives	Evaluate pilot's reaction to spaceflight and his performance as an integral part of the flight system
Results:	The only event that marred the flight was the loss of the capsule during recovery operations when the explosive side egress hatch activated prematurely while Grissom was waiting for the recovery helicopter. The spacecraft sank after Grissom left it. He was recovered after being in the water 3 or 4 min. Two attempts to launch the mission on 18 and 19 July were scrubbed due to inclement weather

Conclusions

After the MR-4 flight, attention in STG turned to the question of whether additional Mercury-Redstone missions were necessary or desirable. Paul E. Purser, special assistant to the director of STG, on 14 August 1961 drafted a termination recommendation for Director Robert R. Gilruth to submit to Dr. Abe Silverstein, director for Space Flight Development for NASA. In it, Purser pointed out that the Mercury-Redstone had qualified the spacecraft and its astronauts, as well as many of the critical aspects of the launch operations. The launch vehicle had also proven various astronaut training devices. Furthermore, the Mercury-Redstone had uncovered many technical problems, none of which were considered insoluble before committing man to orbital flight.[58]

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[57] Ezell, *op. cit.*, p. 144.

[58] Swenson, *et. al.*, *op. cit.*, p. 377.

Figure 28 Astronaut Grissom poses before his MR-4 (*Liberty Bell 7*) spacecraft.

At MSFC, the Mercury-Redstone team was disappointed to learn on 18 August, that the remainder of the flights had been canceled. However, they accepted the logic of the decision and evaluated their efforts in the program.

After reviewing data and experience gathered during the Mercury-Redstone project, the MSFC group considered the results in four categories: man-rating, design, testing, and operations.

Man-Rating the Vehicle

The process of man-rating became narrowly defined as the project progressed. It included a more thorough understanding of failure effects through ground testing and analytical studies. From these studies grew the recognition of a need for a flight-safety (abort) system to counter failures and detailed quality assurance programs.

The most important single component added to the Mercury-Redstone vehicle, to enhance astronaut safety and survival, was the automatic, in-flight, abort sensing system. This system measured as few parameters as possible to reduce the possibility of a false abort and to produce a system with high, intrinsic reliability. The selection of those parameters, and the setting of their limits, was a major contribution to the design of the future of such systems, as used on the Mercury-Atlas and Saturn vehicles. Another important design feature of the abort system was its use of sensors with positive and negative redundancy, i.e., the system had to assure an abort when required and greatly lessen probability of a false abort.

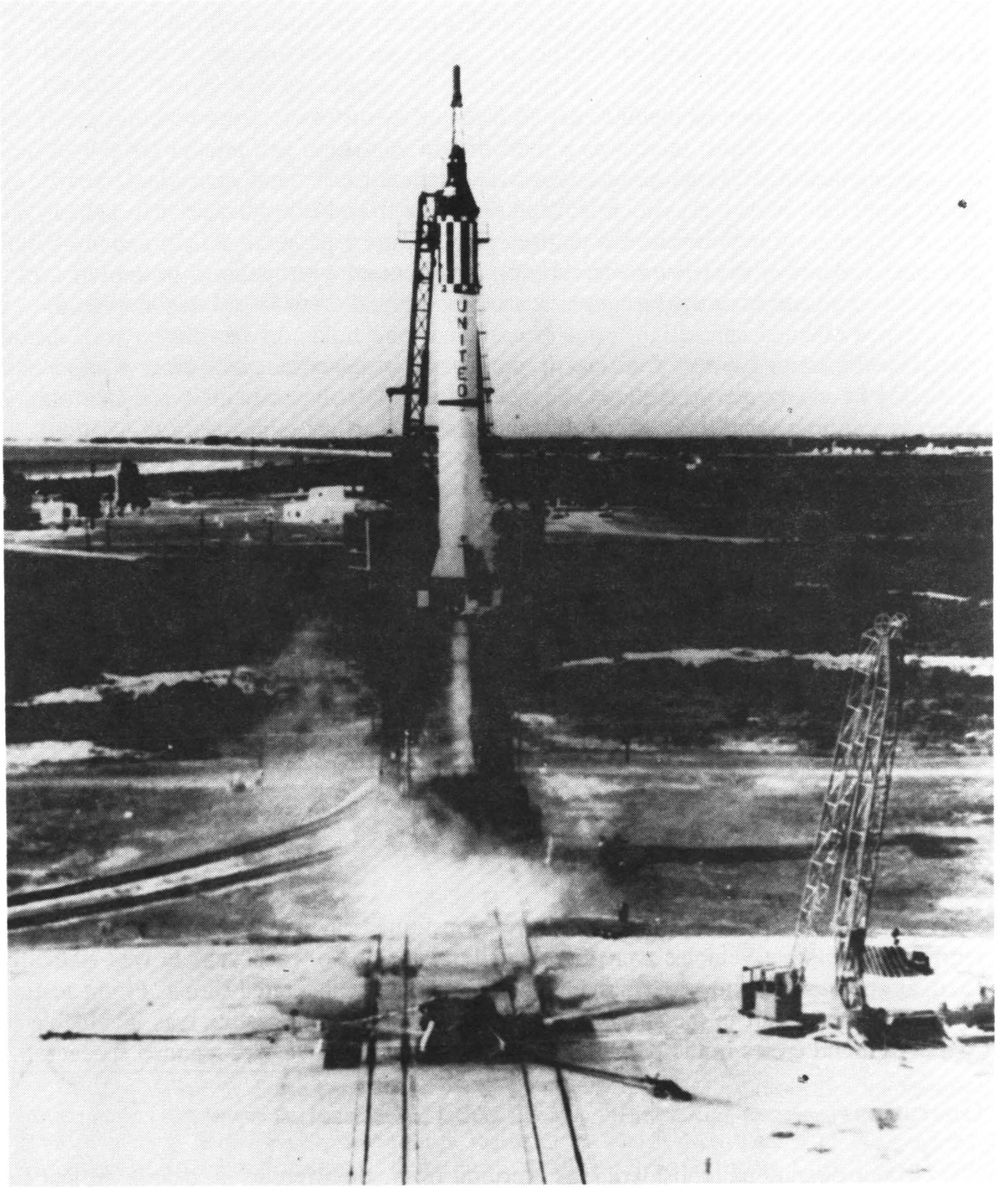

Figure 29 Launch of MR-4 at Cape Canaveral.

While the abort system was a major contribution to astronaut safety, equally important was the role played by the Mercury Awareness Program. Achieving high-quality components and human performance were the product of highly motivated workers in every field of endeavor of the Mercury-Redstone project. The program was later successfully adopted for future manned spaceflight projects, as well as some unmanned ones.

Design

A major decision in the Mercury-Redstone project was to freeze the design of the propulsion system. Thus, there was a reduction in confusion and human error by eliminating engineering change orders, hardware substitutions, and procedural revisions. Also, propellant prevalves, which isolated the tanks from the engine prior to launch, but which served no function once the engine ignited, were a potential failure and were thus eliminated. Another decision made early on was to employ propellants of known explosive properties and toxicity. Hence, astronaut and ground crew safety was increased.

Since manned spaceflight often occasioned long holds on the launch pad, means were developed to prevent freezing of propellant lines, valves, and other components produced by cryogenic propellants. Engine and engine compartments were also purged of explosive fumes and toxic vapors by compressed, inert gases just prior to ignition.

Structures

A rule was established at the outset of the Mercury-Redstone project: the structure would be self-supporting under all expected loads without internal pressurization stabilization. The redesigned aft unit of the instrument compartment was constructed with this rule in mind. To obtain maximum performance with safety, the tank walls of the center section varied in thickness to conform to the established 1.35 safety factor (and yield factor of 1.1) and anticipated loads. The incorporation of a modified range-safety fuel dispersion (destruct) system also enhanced astronaut survival by having a destruct delay feature. It insured that the spacecraft would be a safe distance away from the launch vehicle before destruction was initiated.

Testing

A "pyramidal" testing philosophy was instituted, in which components, subsystems, and complete vehicles were functionally tested. Also, each vehicle was statically fired to check satisfactory performance and reliability under rated thrust. Flight testing proved the spacecraft in the space environment itself. All such testing was invaluable in training ground crews in the preparation, launching, and recovery of manned spacecraft.

Operations

Major operational considerations accruing from the Mercury-Redstone project for future manned spaceflight were:

1. Facility requirements must be comprehensively planned at the very inception of a program. Facilities and ground support equipment (GSE) require as much, and sometimes more, lead time as the development period of the first vehicle.
2. On-the-pad emergency egress procedures are mandatory in manned space vehicle operations, and they must be considered in the earliest design phase of the complex and the space vehicle to provide an optimum system. Figure 30 shows the gantry crane used to effect astronaut removal from spacecraft on launch pad.
3. Integration of launch operations under one control point is essential to assure that a feasible, coordinated countdown of reasonable duration will result. Experience indicated that some degree of automation will help to reduce the countdown period to an acceptable length.
4. Serious consideration should be given to improving the reliability of obtaining, presenting, and digesting inflight information.
5. Design of the space vehicle should consider test and launch operation requirements at the launch site. Design compatibility should be emphasized in the area of GSE, communications systems, ordnance requirements, emergency conditions, and interface considerations.
6. Realistic scheduling is essential throughout a program, but it should be especially emphasized at the launch site, where numerous supporting organizations must participate. Test schedules at the launch site should be coordinated at one central point, to assure that precedence, priority, conflicting checkout functions, and other AMR programs are properly coordinated and controlled.
7. The complexity of manned launch vehicles, and the launch operations, dictates that a single point of entry for range support is necessary. This procedure will assure that all NASA problems are coordinated within NASA to prevent conflicting or confusing information from reaching range or contractor personnel.
8. Weather restrictions on launch operations must be reduced, if critical schedules, such as launch windows, are to be met on an operational basis. Vehicle design should consider this factor in terms of allowable ground and upper air winds. A study should be initiated to provide a method of optical coverage through the maximum dynamic pressure region, which is independent of ground weather conditions.[59]

[59] "The Mercury-Redstone Project," pp. 9-8 to 9-9. For more detailed information on the Mercury-Redstone project see: Jerome B. Hammack and Jack C. Hebering, "The Mercury-Redstone Program," Paper 2238-61, American Rocket Society Space Flight Report to the Nation, New York, 9-15 October 1961. "Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight," Washington, D.C.: National Aeronautics and Space Administration, 6 June 1961. "Results of the Second U.S. Manned Suborbital Space Flight," Washington, D.C.: National Aeronautical and Space Administration, 21 July 1961.

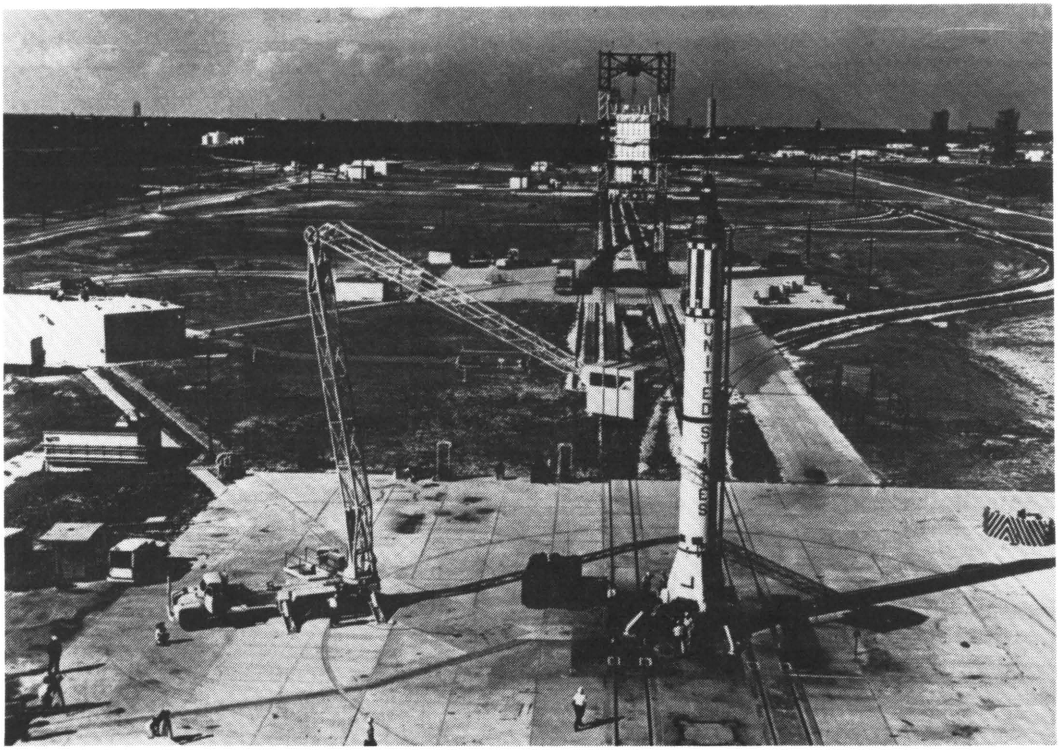

Figure 30 In case of an emergency on the launch pad, a nearby gantry crane could quickly remove the astronaut from the Mercury spacecraft.

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