

N77 - 33063

EARTH SATELLITES, A FIRST LOOK BY THE
UNITED STATES NAVY⁺

R. Cargill Hall (USA)⁺⁺

ORIGINS

Early in 1945 a special United States Naval Technical Mission in Europe accompanied Allied forces advancing through the low countries into Germany. Concerned with Axis technical and scientific matters, organized into Combined Advanced Field Teams composed of both British and American scientists, the mission members included the mathematician Anthony Biot, aerodynamicists Clark Millikan and Hsue-shen Tsien, and physicists Abraham Hyatt and George Ewald. These men conducted on-the-spot assessments of designated German scientific groups and installations of interest to Allied agencies.

On May 5, 1945, a few of the mission members interrogated the leaders of the Dornberger-von Braun rocket group who had surrendered to Allied troops a few days earlier at Reutte in the Tyrol. During the meeting in the small town of Kochel, Bavaria, Tsien¹ requested that von Braun prepare a summary of German rocket developments and his predictions for the future of rocketry and astronautics.² The resulting report, Survey of Development of Liquid Rockets in Germany and Their Future Prospects, suggested potential applications for earth satellites, manned space stations, and flights to neighboring celestial bodies including the moon, as suggested earlier by Tsiolkovsky, Goddard, Oberth, Noordung, and others.³ In July, that report accompanied Abe Hyatt when he returned to the Navy Bureau of Aeronautics (BuAer) in Washington, D.C. According to Hyatt, it stirred a good deal of interest among individuals at BuAer, especially among those in the Aviation Design Research Branch directed by Ivan H. Driggs.⁴ But the individual first and certainly most moved by the subject of earth satellites at BuAer was a young Navy lieutenant, Robert P. Haviland.

⁺Presented at the Fourth History Symposium of the International Academy of Astronautics, Constance, German Federal Republic, October 1970.

⁺⁺Jet Propulsion Laboratory, California Institute of Technology.

Haviland, attached to the Electronics Materiel Branch of the Engineering Division in the Navy Bureau of Aeronautics, examined Allied intelligence reports and other documents relating to aircraft identification and electronic countermeasures. With a decrease in work assignments near war's end, Haviland turned his attention to a favorite topic: the implications of space rocketry.⁵ In the late summer of 1945 he read a British report concerning the capabilities of the German V-2 rocket, and a NACA technical translation of some earlier work pursued by Eugen Sänger. Willy Ley's Rockets, the Future of Travel Beyond the Stratosphere (New York: Viking Press, 1944), which treated the energy requirements necessary for orbital flight and escape from the earth's gravitational attraction, also stimulated the young man.⁶

Aware of the discussions in the Aviation Design group and, apparently, the von Braun paper, Haviland set about considering potential space missions, and he spent several weeks exploring the technical feasibility of earth satellites based upon extensions of conventional V-2 rocket technology. On August 10, 1945, he combined the results of this study in a nine-page memo to the Head of the BuAer Special Weapons Section, recommending that an earth satellite project, "Project Rex," be authorized by the U.S. Navy. Although overlooking the problems of atmospheric reentry, Haviland calculated that by clustering and staging large rockets, manned artificial earth satellites were technically feasible, and he recommended a number of potential missions: as a platform for scientific research, as communications relay stations, and for use in mapping and meteorological surveillance.⁷

The President's announcement of the existence of the atomic bomb on August 6— which suggested a potential source of large amounts of energy—enhanced Navy interest in Haviland's proposal. It quickly won the support of his immediate superior, Commander J. A. Chambers,⁸ and from Captain Lloyd V. Berkner, himself destined to play a significant role in American astronautics. Captain Berkner, Head of the Electronics Materiel Branch, was much taken with the idea of a communications satellite employed as "an artificial ionosphere,"⁹ and he convinced his superiors of the desirability of investigating the prospect of earth satellites.¹⁰ With authorization to proceed, Berkner discussed the matter with Commander Harvey Hall,¹¹ Special Scientific Assistant to the Head of the Radar Section. Hall agreed to assist in a committee examination of the technical feasibility of earth satellites. On October 3, 1945, BuAer organized a Committee for Evaluating the Feasibility of Space Rocketry.

THEORETICAL VERIFICATION OF A SINGLE-STAGE SATELLITE ROCKET

Between mid-August 1945, when the Haviland memo was brought to the attention of Berkner, and the creation of the satellite committee on October 3, Harvey Hall determined that a truly practical and useful earth satellite could not be realized with existing

V-2 propellants and technology; a major advance in rocket technology, he reasoned, appeared necessary and desirable.¹² Assigned at this time to evaluate the application of jet propulsion to aircraft (which are "single-stage" vehicles), he also considered the avenues for advances in rocketry. Hall struck on the concept of a single-stage satellite rocket. With the satellite committee established, he successfully pressed this approach among associates. Accordingly, the committee was charged "to investigate presently available materials and techniques and arrive at some estimate of the possibility of attaining a velocity of libration from one stage of the operation."¹³

On October 29, 1945,¹⁴ the satellite committee concluded that the possibility of placing a single-stage space ship in orbit above the earth warranted establishing a project within BuAer to conduct a detailed study. A high mass-ratio, single-stage vehicle that would compensate for structural development problems by eliminating staging and reignition of engines at upper altitudes, and that burned high specific impulse liquid propellants such as hydrogen and oxygen, the members suggested, would provide a more powerful as well as reliable satellite rocket.

By the end of November 1945, considerable support had been generated within BuAer for an Earth Satellite Vehicle¹⁵ program, and functional-type project desks appeared in various sections as the satellite studies intensified.¹⁶ The satellite's proponents were now more numerous, and influential: Captain D. S. Fahrney, Head of the Special Design Branch which handled BuAer guided missile projects, Captain W. P. Cogswell¹⁷ of the BuAer Radio and Electrical Group, and shortly thereafter, Rear Admiral Leslie Stevens, Assistant Chief for Research and Development, BuAer. Stevens, though he accepted the satellite's usefulness for communications and as a relay station for guidance of surface-to-surface missiles, nonetheless remained very dubious about obtaining the money necessary to build one in view of the congressional cuts in the post-war Navy budget already taking place.¹⁸ But most of the supporters were optimistic. Captain Fahrney created a special desk in the Pilotless Aircraft Division "to handle all the engineering aspects of the Earth Satellite Program," and selected Lt. Commander R. P. Haviland, USNR¹⁹ to manage it.

Plans for this early Navy satellite project (not to be confused with the later Vanguard Program) called for three sequential phases leading to eventual flight testing: (1) the investigations and preliminary research recommended by the satellite committee, (2) a general engineering study by one or more contractors based upon the satisfactory completion of the preliminary research, and (3) award of a contract for construction and operation of a prototype vehicle.²⁰ Subsequent Navy work incorporated the satellite committee premise of a single-stage satellite rocket, and proceeded largely on the strength of a hydrogen-oxygen rocket motor development program conducted by the Aerojet Engineering Corporation,²² supervised by Lt. Commander Robert Truax. Late in 1947, Aerojet personnel succeeded in burning gaseous hydrogen and oxygen in a small rocket motor for the first time, and in the following year they placed the largest hydrogen

liquefier in the world in operation at Aerojet; liquid hydrogen was successfully stored, pumped, and burned in what became routine test operations.²³ Within a year the BuAer effort in large rocket propulsion systems involved serious "hardware" development contracts.[†] Additional contracts were modified or begun for the study of boro-hydride fuels and electronic components that could be employed in rockets.²⁴

But the Navy Bureau of Aeronautics first sought confirmation of the satellite committee's initial findings in a contract with the Jet Propulsion Laboratory (JPL) at the California Institute of Technology. This contract, executed on December 12, 1945, called for more detailed theoretical research on the relationships between aerodynamic drag during ascent and the desired orbit (altitudes), rocket motor and propellant performance, structural characteristics (mass ratio), payload, and suitable ascent trajectories.²⁵ JPL undertook these analyses predicated upon the prior satellite committee calculations and reports, and the Navy-stipulated assumptions that:

- a. The orbiting missile to be considered is a single-stage liquid propellant rocket missile.
- b. The rocket motor propellants are liquid oxygen and liquid hydrogen.
- c. The performance of this rocket motor is estimated from experimental data on hydrogen-oxygen propellants obtained by D. A. Young of the Aerojet Engineering Corp.²⁶

The study program quickly encountered problems. JPL personnel sought to configure ascent trajectories to achieve a desired circular orbit at an altitude of 240 kilometers (150 miles), a profile assumed to be above substantial interference from atmospheric drag. Both vertical and inclined ascent trajectories, given a specified engine burning period and the assumptions furnished by the Navy, yielded orbital altitudes only up to 80 kilometers (50 miles) where air resistance would not permit even one complete orbit of the earth with lightweight structures. This difficulty, already considered in BuAer, prompted an important innovative contribution to astronomical theory. In the words of JPL's Homer J. Stewart:

A method for attaining a higher orbiting altitude than it was feasible to attain in a single powered launching trajectory was proposed by Commander [Harvey] Hall. In this method the missile is projected, at the termination of its primary powered period, into an elliptic orbit of small eccentricity instead of a circular orbit (zero eccentricity). This can be done either by projecting the missile horizontally with a speed in excess of the circular orbital velocity or by projecting the missile at a small angle of climb. In either case, the missile climbs in an elliptic orbit to the aphelion [apogee] point. If a proper velocity increment is added at the aphelion point, the missile is then projected into a circular orbit at this increased altitude. This requires an additional start-stop control for the motor and an altitude [sic, read attitude] control for the missile.

[†]See G. H. Osborn, R. Gordon, and H. L. Coplen, with G. S. James, "Liquid Hydrogen Rocket Engine Development at Aerojet, 1944-1950," in this volume - Ed.

BuAer and JPL-Caltech adopted this ascent technique as a correlative axiom, and used it in all subsequent engineering studies for the high altitude test vehicle (HATV). It has since become standard procedure in all space programs for configuring ascent trajectories, for altering orbital altitudes and eccentricity, and, with later modifications for stored vehicles, for improving payload capacity for a given mass ratio. Unknown to those at work on the Navy satellite studies, the same innovation had been advanced many years before by the Russian astronautical pioneer K. E. Tsiolkovsky.

JPL conducted these studies between December 1945 and July 1946 under the direction of Homer J. Stewart and Frank J. Malina. Using the stipulations and ascent technique suggested by the Navy, JPL calculations²⁸ confirmed the technical feasibility of a single-stage liquid hydrogen-oxygen satellite rocket attaining a minimum circular earth orbit at 240 km (150 miles) altitude provided: the fuel and engine combination would perform according to theory, and that a projected propellant-gross structure weight (mass) ratio of 0.885 to 0.895:1 could actually be realized. At the same time, in a final report, JPL participants felt obliged to remind the Navy that "the required propellant-gross weight ratio could be greatly reduced if a step rocket [staging] were used. For example, a two-step rocket would require, for each step, a propellant-gross weight ratio of about 0.7."²⁹

Encouraged by the Caltech work, on July 1, 1946, the Navy awarded a second contract to Aerojet Engineering. BuAer wanted Aerojet to determine whether a test stand value of the specific impulse of liquid hydrogen-oxygen was sufficiently near the theoretical value to justify the JPL conclusions of satellite feasibility, perform a design study of a liquid hydrogen-oxygen rocket engine producing 136,000 kg (300,000 pounds) thrust, and fabricate a larger hydrogen-oxygen test engine rated at 454 kg (1000 pounds) thrust.³⁰ These propulsion system contracts led to the construction of the large hydrogen liquefier mentioned previously, and actual test stand operation of the liquid hydrogen-oxygen rocket engines that did confirm theoretical performance specifications.³¹ Another contract was awarded to North American Phillips Company to design a lightweight solar engine with a 50 watt electrical output to power satellite electronic equipment, and work commenced in BuAer on the guidance and attitude control equipment required for the period of unpowered coast along an elliptical trajectory prior to insertion in a circular orbit, and for orbit operations.³² Verification of the structure mass ratio for the single-stage vehicle, the second condition stipulated by JPL, also began in mid-1946 as the Navy moved into the engineering design phase of the earth satellite project.

Meantime, before most of these early investigations had been completed, support for the satellite project was solicited from many individuals and at many levels in the Navy outside of BuAer. It soon became apparent that full Navy support for an actual flight test vehicle program--as Admiral Stevens suspected--would be difficult to achieve. In November 1945, costs for the engineering and preliminary design phase of the project

had been estimated at \$5 million to \$8 million.³³ The postwar demobilization and cutback in Navy appropriations in early 1946 clearly indicated that whatever progress the service might attain would have to be managed on a great deal less than \$5 million.³⁴

SATELLITE INTEREST IN THE ARMY AIR FORCES

Faced with this unpromising fiscal situation, members of the Navy satellite committee approached the Army Air Forces in the hope of establishing a joint earth satellite project. A joint project, they believed, might be able to command financial support sufficient for flight tests. The first meeting between representatives of the two services took place in Washington, D.C. on March 7, 1946, in the office of the Air Force Major General H. M. McClelland. Navy personnel presented the objectives and status of their rocket satellite project, together with a suggested plan for the proposed Army Air Forces-Navy experimental program to evaluate, justify, and, if warranted, construct and launch a prototype vehicle. Reception of the Navy proposal by the Army Air Forces representatives seemed most favorable; furthermore:

It was agreed at the conference that the general advantages to be derived from pursuing the satellite development appear to be sufficient to justify a major program, in spite of the fact that the obvious military, or purely naval applications in themselves, may not appear at this time to warrant the expenditure.

On this basis, the Army representatives agreed to investigate the extent of Army interest by discussions with General LeMay and others, after which a future joint conference is planned.³⁵

For several days in March 1946 it appeared that a joint satellite project leading to flight tests might possibly commence in the United States.

After carefully reviewing the Navy proposal, General Carl Spaatz, Army Air Forces Chief of Staff, designated Major General Curtis E. LeMay, recently appointed Deputy Chief of Air Staff for Research and Development, to represent the Army Air Forces in negotiations with the Navy satellite proposal team. In mid-March the General informed a dismayed Commander Hall that the Army Air Forces had decided not to support the proposed joint satellite project, although he left open the possibility of further discussions of earth satellites.³⁶ Army Air Forces representatives confirmed the Spaatz-LeMay decision at a second meeting in the Research and Development Committee of the Aeronautical Board on April 9, 1946. Air Force Brigadier General Laurence Craigie declared two separate programs preferable to one.³⁷ If earth satellites were to be constructed, Craigie implied, the Army Air Forces intended to be the service to do it, especially since the Army Air Forces had already staked a claim to future military missions in outer space.³⁸

Personnel at the Navy Bureau of Aeronautics returned to their single-stage satellite rocket investigations with the groups at JPL and Aerojet. Though the encounter

with the Army Air Forces had been a disappointment, it had one positive ramification. It prompted another extensive satellite study. The Army Air Forces Research and Development organization turned to the Project RAND research group and, as a first task, instructed this newly formed consultant organization to perform a separate earth satellite feasibility study.³⁹ Attempts by the Navy Bureau of Aeronautics to arrange another conference met with repeated delays while the Air Force satellite study progressed.

On May 15 the respective service representatives met again in the Research and Development Committee of the Aeronautical Board. This Board, formed during World War I and composed of ranking members from the Army and Navy air arms,⁴⁰ normally met at monthly intervals to review new developments and to reconcile "the viewpoints of the two services for the mutual benefit of aviation."⁴¹ At this third meeting AAF General Craigie introduced the Project RAND satellite study "on which the ink was hardly dry, as the basis of a bargaining position that the AAF was on an equal or similar development position with the Navy," Harvey Hall reflected. "From this point on, no further progress was made towards a joint project."⁴² But the meeting, admittedly convened for the purpose of coordinating "the initial phases of a [satellite] project . . . and to define service responsibility, if desirable at this time," bespoke the serious contemporary interest in an artificial earth satellite:

- a. It is the most promising means that has been suggested for providing guidance for guided missiles and pilotless aircraft at ranges in excess of about 250 miles.
- b. It would provide means for freeing world-wide communications of periodic lack of reliability attributed to outer atmospheric effects.
- c. It might be of much value in extending the understanding of meteorology, with consequent improvement in meteorological predictions.
- d. It would provide an initial step toward the eventual construction of inhabited satellites and interplanetary travel, with far-reaching implications.⁴³

Lacking agreement on which service should be responsible for actual development of prototype satellite vehicles, however, the members referred the question of jurisdiction back to the full Aeronautical Board for a decision. The Navy members maintained steadfastly "that the unknowns involved in this project, and its implications for the possibility of space travel, render premature any attempts to define Service responsibility at this time . . . [but actual development of a satellite should] be undertaken jointly by the Army, the Navy, and civilian science. The Army members consider that because intercontinental warfare is of paramount interest to the Army Air Forces, future plans involving actual construction of an earth satellite should be under the control of that organization . . ."⁴⁴ In the face of these service positions, the Research and Development Committee could only recommend that the Army Air Forces and the Navy continue

separate preliminary investigations. Meantime, the committee established a formal subcommittee on earth satellites to further examine its potential applications, ensure coordination, and prevent duplication of efforts between the services.⁴⁵

SATELLITE ENGINEERING DESIGNS

Without agreement on joint responsibility, a well-defined use for earth satellites, or project approval from the Aeronautical Board, the Navy satellite study project by itself could not command broad internal support and the necessary funding. Navy participants now realized that construction and launch of a prototype satellite—calculated to cost between \$50 and \$150 million—was at least temporarily precluded. But further "preliminary investigations" were assured on May 8, 1946, when the Chief of Naval Operations formally approved the BuAer satellite study project,⁴⁶ and the second phase of work began: vehicle engineering design. In June and July the Navy Bureau of Aeronautics contracted for two major structural design studies, the first with North American Aviation, and the second with an old Navy stalwart, the Glenn L. Martin Company of Baltimore, Maryland. Both firms teamed with Aerojet Engineering Corporation on the engine and propellants.⁴⁷

On September 26, 1946, North American Aviation submitted its report to BuAer. The design study, directed by William A. Bollay, had been carried out in the firm's newly established Aerophysics Laboratory. R. G. Wilson served as Project Engineer, with individual technical sections prepared by L. A. Gore, responsible for propellants, surface heating, and power plant; Bruno W. Augenstein, aerodynamics; R. G. Wilson, weight, balance, structural and general design; and R. G. Knutson, guidance and control. Each of the contributors based his work on the Navy stipulated single-stage satellite rocket burning liquid hydrogen-oxygen, and the JPL specified mass ratio of 0.895:1 maximum. North American recommended a pressure stabilized ogive structure 26 meters (86 feet) long and with a maximum diameter of 4.9 meters (16 feet). "It is constructed of stainless steel and has nine clustered individual thrust motors. The vehicle is capable of attaining a maximum velocity of 6,820 meters per second (25,400 feet per second) at an altitude of about 225 kilometers (140 miles)"⁴⁸ (Figure 1).

North American designed the High Altitude Test Vehicle to weigh 41,130 kg (101,400 lbs), broken down into major components: Propellants, 40,000 kg (89,000 lbs); payload, 450 kg (1,000 lbs); motor and accessories, 2,250 kg (5,000 lbs); and structure, 2,900 kg (6,400 lbs). The starting weight required an initial thrust of 105,700 kg (233,000 lbs) varying to about 139,700 kg (308,000 lbs) thrust at altitude.⁴⁹ The firm recommended an eventual longitudinal scaling of the vehicle to about 59,000 kg (130,000 lbs) gross weight with no increase in the vehicle's maximum diameter in a final configuration, and an extension in the burning time of the engines from 126 to 165 seconds.

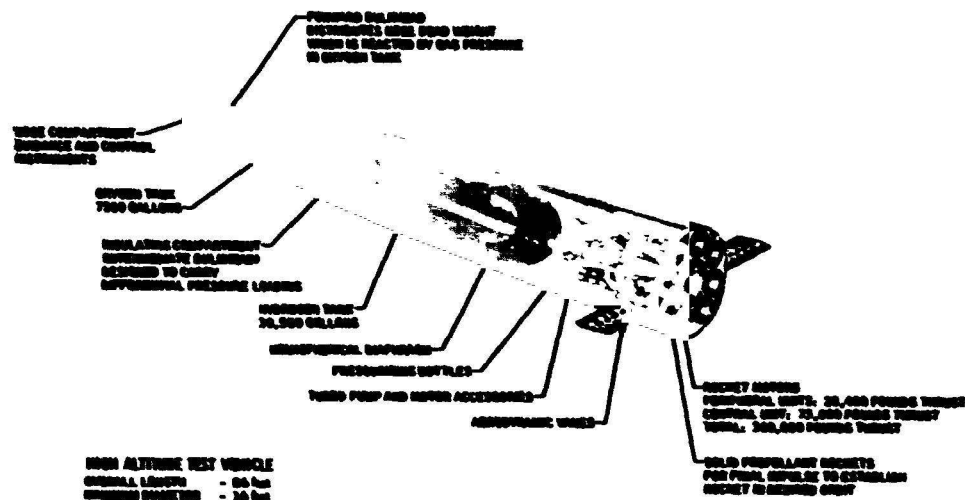


Fig. 1

Since the structures portion of this projected single-stage vehicle could not weigh much more than five percent of the total weight of the satellite rocket, the specifications called for a propellant-to-structure (content-to-shell) ratio approaching that of an egg. This task, at once an engineer's aspiration and nightmare, eventually would be realized.⁵⁰

The Glenn L. Martin Company and Aerojet studies continued for a complete fiscal year, ending in June 1947. In its first progress report, Martin proposed the use of a standard honeycomb shell construction if the strength requirements could be maintained within the temperature and pressure ranges encountered during flight into earth orbit.⁵¹ Under subsequent testing, engineers found this material inadequate to meet the necessary regime, and they dropped it in favor of the North American thin-skin, stainless steel, pressure-stabilized "blimp" structural scheme. Martin's extensive final report, which incorporated the Aerojet findings on a 136,000 kg (300,000 lb)-thrust liquid hydrogen-oxygen engine, described a truly remarkable single-stage satellite rocket embodying virtually all of the subsystem features presently found in separable booster rockets and spacecraft. This report was prepared by Pedro C. Medina and William B. Bergen, with support from Charles H. Harry, who handled vehicle temperatures and trajectories, and Albert J. Devaud, responsible for devising the novel ascent guidance and control and orbital attitude control systems[†] (Figure 2).

[†]See R. E. Roberson, "Evolution of Spacecraft Attitude Control Concepts Before 1952," in this volume - Ed.

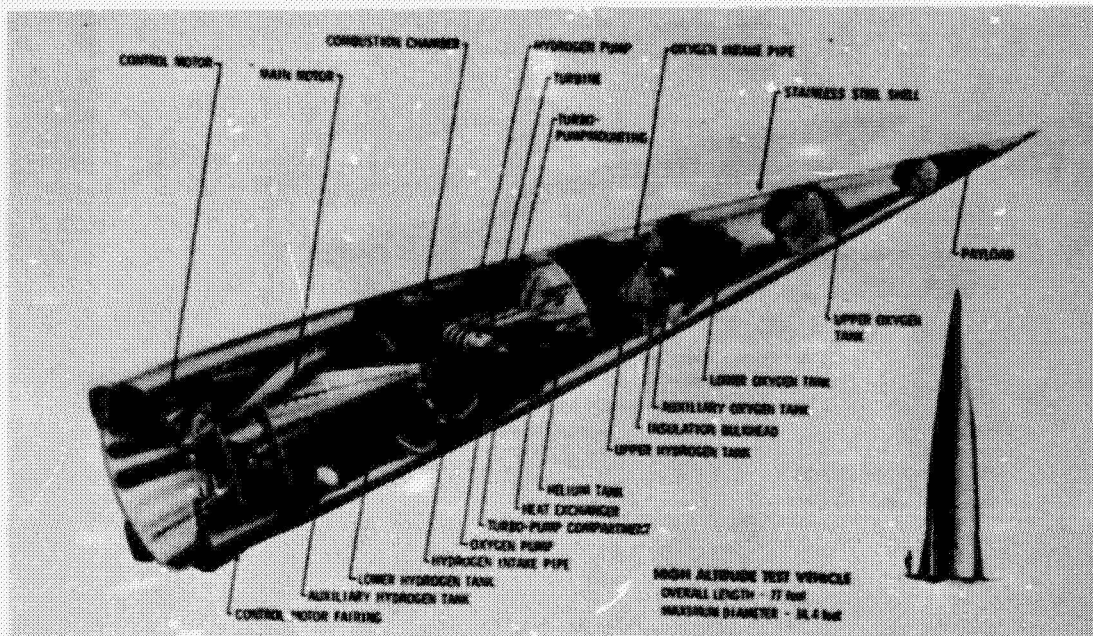


Fig. 2

The basic Martin rocket was an ogive body 23.5 meters (77 feet) long and 4.4 meters (14.4 feet) in maximum diameter. The gross weight at launch was 46,550 kg (104,648 lbs), with a mass ratio of 0.895:1, including a 653 kg (1,450 lb) payload. These engineers projected the weight of the structural shell and bulkheads at 16,138 kg (3,628 lbs), about 3.5 percent of the gross weight!⁵² Medina assumed a west-to-east launching at equatorial latitudes to take advantage of the earth's peripheral velocity of rotation, together with a suitable number of ground stations located around the earth for tracking and data acquisition.

Unlike the North American prototype, the Martin vehicle employed no aerodynamic surfaces, and although the main stage Aerojet engine remained fixed, dynamic stability was to be provided by four auxiliary control engines which would damp oscillations in pitch, yaw, and roll. The pump-fed, transpiration cooled, liquid hydrogen-oxygen rocket engine, designed by David A. Young and Robert Gordon at Aerojet, had an exit diameter of 4.1 meters (13 and one-half feet) and an overall length of 6.9 meters (22 and one-half feet) tapering to 0.6 meters (2 feet) diameter at the chamber injection plate. The engine would provide 90,400 kg (203,600 lbs) thrust at sea level varying to 136,000 kg (300,000 lbs) at altitude, with a specific impulse of 425 seconds. Its designers allotted 1,674 kg (3,683 lbs) to the engine, turbopumps, valves and plumbing.⁵³

Though aware at this time that a small satellite could be made by multi-staging conventional (V-2) rockets, such as the Bumper WAC, the engineers at North American and

Martin responded to the Navy's requirements to see if a larger, single-stage satellite rocket could be devised. With the exception of the extensive work on the propulsion subsystem and some electronic devices, these studies were not hardware contracts. Rather, they involved preliminary feasibility and vehicle design studies for the purpose of evaluating the upper limit to which a single-stage liquid hydrogen-oxygen satellite rocket design could be carried. The answers were positive and encouraging: with appropriate extension of rocket engine burning times and with small improvements in metallurgy and electronics, a single-stage vehicle appeared definitely feasible.⁵⁴

TERMINAL EVENTS

With the engineering designs completed in mid-1947, the BuAer satellite studies had progressed about as far as they could possibly go on paper. The prospect of a hiatus, or worse—complete cessation—of the work, caused individuals associated with the Navy proposal to seek again authorization of third phase hardware development and construction of a prototype vehicle. But the renewed search for institutional support would be made all the more difficult by the unresolved questions of satellite utility, the continued interest of the Army Air Forces in a separate satellite project of its own, and by the postwar reorganization of the armed services.

On January 24, 1947, Rear Admiral Leslie Stevens, Assistant Chief for Research and Development, BuAer, sent a letter to the Joint Research and Development Board (JRDB). Coordination of interservice requirements for earth satellites, he declared, was "beyond the scope of action" of the Aeronautical Board, particularly when one considered the possibility of mutual cooperation between civilian scientific and military groups.⁵⁵ The satellite held great potential for extending basic knowledge through cooperation with university scientists, Admiral Stevens continued, and he proposed that "the Joint Research and Development Board establish an agency for the coordination, evaluation, justification, and allocation of all phases of the Earth Satellite Vehicle program . . ." by means of a new ad hoc JRDB panel composed of civilian scientists as well as military representatives.⁵⁶

The War Department's Joint Research and Development Board took Admiral Stevens' proposal under advisement. Shortly thereafter, upon request of the Army Air Forces and in keeping with military comity extended in such situations, it was remanded to the Aeronautical Board for review before final action. Meantime, however, the American military services underwent the most profound reorganization in their collective history. On July 26, 1947, President Truman signed the National Military Act. A National Military Establishment, under a Secretary of Defense, replaced the historic Departments of War and Navy, and the Army, Navy and Air Force received equal service status. The Act also replaced the JRDB with a Research and Development Board (RDB).⁵⁷

Speaking for the Aeronautical Board a few weeks before the Military reorganization, Air Force Lieutenant General Hoyt S. Vandenberg and Navy Vice Admiral D. B. Duncan informed the JRDB that, notwithstanding Admiral Steven's contentions concerning the interests of civilian scientists, the Aeronautical Board remained competent to decide matters of earth satellites. The JRDB, they said, would be apprised of any decisions made on the satellite program.⁵⁸

Thus, throughout the latter half of 1947 the subject of earth satellites remained suspended in both governmental bureaus: in the satellite subcommittee of the Research and Development Committee of the Aeronautical Board, and in the JRDB-RDB. In the first group, progress on the Air Force and Navy satellite programs was reported and discussed, and other proposals on the disposition of responsibility for earth satellites considered. For example, late in the year the satellite subcommittee of the Aero Board "noted with interest" a second Navy proposal that offered the Office of Naval Research as a potential satellite coordinating agency in the view of the scientific aspects of the program. The subcommittee referred the issue to the full R&D Committee of the Aero Board "for action."⁵⁹

Since the implications for basic scientific research in outer space rather obviously transcended military interests alone, the RDB likewise sought to decide where to place government responsibility for coordinating earth satellite activity.⁶⁰ At its initial meeting on December 19, 1947, the reconstituted Research and Development Board addressed this question and the Aeronautical Board's June response. Though the members judged a separate *ad hoc* coordinating committee originally urged by Admiral Stevens unnecessary,⁶¹ they removed responsibility for satellite developments from the Aeronautical Board and vested it in the RDB Committee on Guided Missiles.⁶² The Guided Missile Committee, in turn, assigned an evaluation of all the satellite work to one of its subpanels, the Technical Evaluation Group. The Committee instructed this civilian-staffed Technical Evaluation Group, chaired by Walter A. MacNair,⁶³ to provide an "opinion as to the desirability of such a [satellite] program, whether a single jointly supported program or separate competitive developments should be sponsored, and an estimate of the time scales and expenditures required for completion of the recommended program. . . ." by the end of March 1948.⁶⁴ With the log-jam over a coordinating agency broken at last, the way appeared open for Research and Development Board approval of continued Navy satellite work--or perhaps a joint program, if not with the Air Force, then possibly with scientific groups.

On March 29, 1948, the Technical Evaluation Group reported on its evaluation of the Navy and Air Force satellite programs. In a three-point opinion, the civilian group held the technical feasibility of building an earth satellite vehicle to be clearly established; however, neither the Navy nor the Air Force, the members declared, had as yet offered a military or scientific utility commensurate with the expected cost of such a vehicle. Consequently, the group recommended that at present, a satellite not be

constructed. Because severe development problems could be anticipated in building a single-stage satellite rocket, the group further recommended that studies of the utility of earth satellites be the only serious activity to continue at Project RAND. Though the group encouraged the Navy to participate with the Air Force in the RAND studies and pursue limited development of liquid hydrogen-oxygen engines and lightweight tanks and structures,⁶⁵ the findings clearly spelled a deferral of satellite work in general, and, in particular, an end to the Navy's single-stage satellite rocket.

A month later in April, Harvey Hall and his associates in BuAer made a last desperate attempt to continue the Navy satellite program in modified form. This die-hard group of space scientists now urged construction of liquid hydrogen-oxygen "Interim Test Vehicle, M07," reconfigured to a super performance sounding rocket that would rise to an altitude of 320-640 km (200-to-400 miles) (Figure 3). They submitted this proposal⁶⁶ to an ad hoc subcommittee of the National Advisory Committee for Aeronautics (NACA) that had been recently established to explore and organize methods for extending the tables of the standard atmosphere at altitudes above 6,100 meters (20,000 feet).⁶⁷ If approved and built, the Navy satellite proponents hoped the sounding rocket might rally eventual financial support for the construction and launch of an earth satellite vehicle.

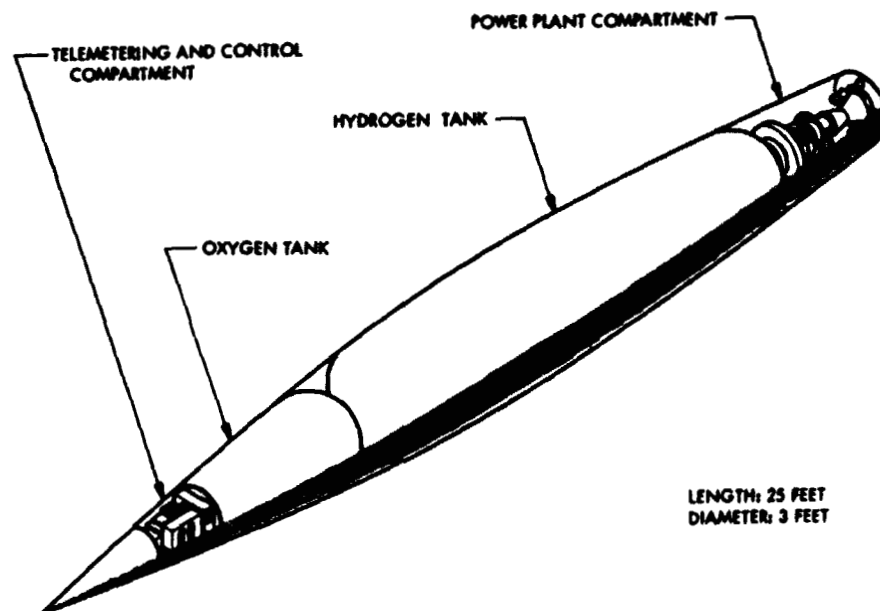


Fig. 3

In addition to the NACA Subcommittee on the Upper Atmosphere, Navy proponents also sought formal acceptance and endorsement of the new rocket from the RDB's Geophysical Sciences Committee. By this time, however, the BuAer proposal confronted severe obstacles—not only in the form of the Technical Evaluation Group findings of the previous month, but in direct competition from a companion at arms: the Office of Naval Research had already received Navy approval to construct and launch a sounding rocket for upper atmosphere research.⁶⁸ According to Hall, the response to this penultimate proposal ended all Navy satellite studies at this time. The RDB Geophysical Sciences Committee took no action whatever; the NACA Subcommittee on the Upper Atmosphere favorably endorsed the project but had no funds to commit to the work. Whatever interest in earth satellites that existed at higher command levels in the Navy had now all but disappeared.⁶⁹

In March 1948, in response to a Presidential ceiling on expenditures for fiscal year 1949, the Navy Bureau of Aeronautics began transferring the remaining funds earmarked for satellites to other projects of more immediate interest. The Navy satellite effort terminated for all practical purposes on June 22, 1948, when the Pilotless Aircraft Division notified Admiral Stevens that "the Earth Satellite Project has been discontinued as such and work is now proceeding with emphasis on the development of a liquid-oxygen, liquid-hydrogen rocket engine. When this power plant appears feasible, flight test vehicles will be designed and constructed."⁷⁰

At Aerojet, work on this last remaining satellite component did continue for one more year, but suffered from technical problems associated with engine heat exchange and chamber cooling processes. That effort concluded in 1949,⁷¹ ringing down the curtain on Navy satellite efforts in the 1940s. The total cost to the Navy of all satellite-related work conducted between 1945 and 1949 has been estimated at approximately \$1.5 million.⁷² Ironically, when the satellite program expired in the BuAer Pilotless Aircraft Division, the Navy reprogrammed the remaining funds (around \$170,000) to the Office of Naval Research for development of the Viking sounding rocket, also under contract at the Glenn L. Martin Company.⁷³ In time, Viking became the first stage booster for America's International Geophysical Year satellite in the mid-1950s.⁺

CONCLUSION

The earth satellite studies undertaken by the Navy Bureau of Aeronautics in the late phases of World War II responded to (1) rapid wartime advances in rocket technology at home and abroad, (2) an encounter between members of an Allied technical intelligence team and German rocket specialists from the Peenemunde rocket base, and (3) accounts of the V-2 ballistic missile and its potential applications published in open literature

⁺See M. W. Rosen, "The Viking Rocket: A Memoir," in this volume - Ed.

and in contemporary intelligence reports. These investigations took place before the invention of the transistor, the development of solid-state circuitry,⁷⁴ and the spread of digital computers; they were complicated further by questions of satellite utility, military jurisdiction, the technical difficulties involved in a single-stage, hydrogen-oxygen satellite rocket, and the projected costs and economies of the moment. It is reasonable to assume that one or a combination of all these conditions would have deterred the endeavor in the years that immediately followed. The participant's inability to secure Navy support outside BuAer, added to these factors, prefigured the denouement.⁷⁵

Before March 1948, a Navy decision to proceed to third-phase construction of a prototype hydrogen-oxygen single-stage satellite vehicle was, ultimately, Rear Admiral Stevens' to make. The Admiral, a man of strong convictions, surmised that a third-phase hardware program in 1947-1948 would involve a technical undertaking of colossal proportions, with little prospect for any early return on the investment. Without broad internal interest or joint service sponsorship for a satellite program, he elected not to proceed.⁷⁶ If keen enthusiasm remained evident throughout this period among individuals in its research bureaus, influential members of the operating arm of the Navy remained generally unaware of—or at least not much taken with—these studies or the satellite's potential applications.⁷⁷ The demise of Navy-BuAer satellite studies in the late 1940s appear to devolve from these two interrelated causes: reserved institutional support (which is normally reflected in priorities), and contemporary exigencies associated with technology, cost, and vehicle utility.

On the other hand, the Air Force—a relatively new service primarily concerned with flight in and beyond the atmosphere—moved actively into satellite research. Prompted by the Navy work, the Air Force soon issued orders for active institutional support of an earth satellite program at the highest levels of command.⁷⁸ This interest was sustained, waited on or advanced the required technology, and culminated in the Thor-Agena and Atlas-Agena satellite flights that began eleven years later, in 1959.

Though the aspirations of Haviland, Hall, and their Navy colleagues would not be fulfilled as rapidly as they wished, an historic milestone had passed for astronautics in the late 1940s. The technical feasibility of space flight—as opposed to the theoretical feasibility of this activity developed by Goddard, Tsiolkovsky, Oberth and others during the early years of this century—had been firmly established and officially acknowledged.⁷⁹ Questions asked and answered would no longer remain focused on astronautical theory,⁸⁰ but on practicalities of when and how, and on satellite utility. Answers to these questions would come in the decade to follow.

ACKNOWLEDGMENTS

The author is indebted to a number of individuals who took time to read and critique early drafts of this work, or who kindly assisted in the task of research. Most especially he is indebted to those whose assistance made this paper possible:

Robert P. Haviland and Harvey Hall; Myra Grenier, Corporate Librarian, Aerojet General Corporation; Eugene M. Erme, NASA Historian; Lee M. Pearson, Historian, Naval Air Systems Command; D. C. Allard, Operational Archives Branch, Office of the Chief of Naval Operations; Max Rosenberg, Deputy Chief Historian, Office of the Air Force Chief of Staff; R. A. Wirnaker, Historian, Office of the Secretary of Defense; and Herman G. Goldbeck and Thomas E. Hohmann of the General Services Administration, National Archives and Records Service.

REFERENCES

1. Military ranks were assigned civilians functioning in military zones. Commissioned an Army Lieutenant, Dr. Hsue-shen Tsien was a protege of Theodore von Kármán at the California Institute of Technology and, as a student, a member of the GALCIT Rocket Research Project during 1937-1939.
2. Events as reconstructed in a telephone interview, Abraham Hyatt with the author, January 22, 1970. While not present at this meeting Hyatt related that Tsien informed him of the proceedings during subsequent discussions. Von Braun's paper was published in F. Zwicky, Report on Certain Phases of War Research in Germany, Vol. 1, Aerojet Engineering Corporation, October 1, 1945, 66-72; republished by the Air Materiel Command, Wright Field, Dayton, Ohio, in January 1947.
3. Cf., Hermann Oberth, Die Rakete zu den Planetenraumen, Verlag von R. Oldenbourg, Munich and Berlin, 1923, NASA TT F-9227, pp. 94-96; and H. Noordung, Das Problem der Befahrung des Weltraum, Berlin, 1929; on German wartime planning, see Theodore von Kármán, Where We Stand, a report prepared for the AAF Scientific Advisory Group, August 1945, [published May 1946 by Headquarters, Air Materiel Command] 13; also, "The Station in Space," Journal of the American Rocket Society, #63, September 1945, 8; and Zwicky, loc. cit.
4. Hyatt Interview, loc. cit.
5. Haviland, who demonstrated a youthful interest in electronics, graduated from the Missouri School of Mines in electrical engineering in the late 1930s together with a fellow classmate in the same field, George Mueller, who would later serve as NASA Associate Administrator for Manned Space Flight. (R. P. Haviland, "Personal Profile," Journal of Space Flight, March, 1970, 106 ff.), Capt. W. P. Cogswell, an associate at BuAer, recalled the Lieutenant's unrestrained enthusiasm for astronautics years later: "More than once Haviland told me: 'Captain, you've got to get space-minded!'" (Letter, Captain W. P. Cogswell, USN (Ret.) to the author, February 9, 1970.)
6. The material reviewed by Haviland at this time is referenced in his satellite memo cited at note 7. Much later Haviland recalled that he had also seen a letter to the editor from RAF radarman Arthur C. Clarke which appeared in the British journal Wireless World. The Clarke letter proposed the postwar use of V-2 rockets for (1) exploring the upper atmosphere as rocket sondes, and (2), with upper stages, placing unmanned satellites

in orbit about the earth to conduct scientific experiments and to act as communications relay stations. If accurate, this letter and the work by Willy Ley apparently started Haviland thinking seriously about astronautics several months earlier. Telephone interview with Robert P. Haviland, January 28 and June 19, 1969. (See also, Clarke, "V-2 for Ionosphere Research?" in Letters to Editor, Wireless World, February 1945, p. 58.)

7. Memo Aer-E-313-RPH, F.41 (1), from R. P. Haviland, Beacon Desk, Identification Section, Elect. Materiel Branch, Subject: Comments Concerning Use and Development of Rockets, August 16, 1945, 8. Knowledge of the contemporary German suggestions is indicated when he ". . . noted that the German Command was actually planning such a [satellite] program with the added feature of an impractical 'Sun Gun.'"

8. Chambers agreed that "space-ships, as proposed [by Haviland] will afford a world-wide navigation and communication system on high frequencies, and free from horizon limitations and sky-wave errors." Memo, Aer-E-315-JAC, F41 (1), from Head, Special Weapons Section, to Head, Experiments and Developments Branch, Subject: "First Enclosure" on Beacon Desk . . . Memo Aer-E-313-RPH F41 (1) Written 10 August 1945, August 25, 1945.

9. Letter, Captain W. P. Cogswell, loc. cit. Dr. Berkner apparently was first attracted to the ionosphere as an area of research in 1937; satellites no doubt appeared as a practical means to extended investigations in this region. In the early 1950s Dr. Berkner was instrumental in the creation of the U.S. IGY satellite program. Years later he intimated that a still earlier satellite technology survey may have been conducted at BuAer: "During the war our early studies in the Navy showed the orbiting Earth satellite was within the range of our technology. But in 1943 it was clear that space technology, aside from short-range rockets, would not be a factor in that war, so the matter was laid aside. . . ." (Italics added, Lloyd V. Berkner "Science, the Scientist and Space," Proceedings of the Conference on Space Science and Space Law, June 18, 1963, ed. by Mortimer D. Schwartz, New Jersey: Fred B. Rothman & Co., 1964, 1.) Dr. Harvey Hall, science advisor to Dr. Berkner between 1941 and 1944 has indicated, however, that these earlier wartime studies concerned rockets, not satellites. Letter, Harvey Hall to the author, December 4, 1969.

10. D. S. Fahrney, "The History of Pilotless Aircraft and Guided Missiles," BuAer, 1958, unpublished, p. 1132.

11. Dr. Hall, a theoretical physicist, had just returned from an assignment with the U.S. Naval Technical Mission in Europe during August 1945, and had been persuaded to remain in the Navy by Rear Admiral Leslie Stevens to assist in evaluating the future of jet propulsion primarily with respect to its potential value for naval aviation. Admiral Stevens was concerned that with the sharply reduced budget, the Navy might "find itself irreparably frozen in an absolute pattern in aviation." (Hall letter, December 4, 1969, loc. cit.) While Lt. Robert Haviland provided the initial spark setting earth satellite events in motion, Dr. Harvey Hall, the theoretician, largely determined the technological course these events were to take at BuAer in succeeding months.

12. "Not that orbiting payloads was impossible without it [the advance], but the rockets would be large, complex, expensive, with small payloads, and the missiles that had been proposed . . . hardly appeared to justify the effort." Harvey Hall, letter of December 4, 1969, loc. cit.

13. Memo, Aer-E-203-KWM, from Captain R. S. Hatcher, Deputy Director of Engineering, Experiments and Developments, to Distribution, Subject: Establishment of a Committee for Evaluating the Feasibility of Space Rocketry, October 3, 1945.

14. "Minutes of the Fourth Meeting of the Space Rocket Committee," October 29, 1945, Lt. (jg) Max, Secretary. Members of the satellite committee were:

Comdr. C. D. Case - E&D	Lt. F. A. Parker	- Sh. Instal.
Lt. (jg) K. W. Max - E&D	Lt. L. A. Hanson	- Sh. Instal.
Comdr. H. Hall - R&E	Lt. Comdr. O. E. Lancaster	- ADR
Lt. R. P. Haviland - R&E	Mr. J. R. Moore	- ADR
	Mr. I. Driggs	- ADR

(Driggs attended meetings but was not a formal member of the committee.)

15. During the next three years participants in the BuAer satellite project referred to their work variously as the Earth Satellite Vehicle (ESV), Project Orbit, as well as by an eminently respectable term, High Altitude Test Vehicle (HATV). All of these Navy studies, beginning with the satellite committee, considered only unmanned satellites, in contrast to the original Haviland proposal.

16. O. E. Lancaster, J. R. Moore, P. B. Olmsted, and M. M. Taylor, Investigation on the Possibility of Establishing a Space Ship in an Orbit Above the Surface of the Earth, ADR Report R-48, November 1945. This document is pessimistic about the possibility of realizing a single-stage vehicle, and Harvey Hall appears to have remained the champion of this particular approach. (Cf., Hall's proposal for a single-stage vehicle; an enclosure to the Minutes of the Third Meeting of the CEFSR, October 22, 1945.)

17. Captain Cogswell recalls tempering support for the satellite vehicle, which he considered a deserving project, with skepticism concerning the mass-ratio involved in a single-stage satellite rocket burning a propellant combination that "was of course only a dream at the time." (Cogswell letter, loc. cit.)

18. D. S. Fahrney, op. cit., 1132; also telephone interview with R. P. Haviland June 19, 1969. (See also note 34 below.) The duties of the BuAer Office of Engineering for Experiments and Developments, headed by Captains T. C. Lonnquest and R. S. Hatcher, were expanded and divided by Rear Admiral Stevens when he arrived at BuAer in February 1946. Captain C. A. Nicholson became Assistant Chief for Design and Engineering, BuAer, while Rear Admiral Stevens became Assistant Chief for Research and Development, BuAer. "In this reshuffle Rear Admiral Stevens took a much more active interest in R&D affairs than had been possible for Captain Lonnquest. . . ." (Rear Admiral R. S. Hatcher, USN (Ret.), letter to the author, July 3, 1970.)

19. Fahrney, op. cit., 1134. During the next few years there were no more than ten-to-fifteen BuAer personnel actively involved in the satellite project. For the most part these individuals guided and monitored the activities of the various participating contractors, where many more people were involved.

20. R. P. Haviland, "Notes on the Earth Satellite Vehicle," The Guided Missile, July 1946. (The Guided Missile was an in-house publication of the Guided Missiles Committee, Joint Committee on New Weapons and Equipment, Joint Chief of Staff.) In concluding this article, Haviland observed: "The full effect of this [satellite] development on military operations and indeed on world conditions in general, can hardly be forecast. Its possibilities as a peacetime aid to rocket travel and communications is unlimited. The writer is of the opinion that interplanetary travel will become possible, perhaps even commonplace, within twenty-five years." He was not far wrong.

21. This work, authorized in December 1945 as a task under Contract NOa(s) 5350, began investigations of the use of hydrogen as a fuel in jet engines. Memo Aer-PA-52 P41(1) from Rear Admiral L. C. Stevens, for Chief, Bureau of Aeronautics, to Joint Research and Development Board, Subject: Agency Coordination of Earth Satellite Vehicle, January 24, 1947, 1, 2.

22. Aerojet Engineering Corporation was a rocket production firm founded during World War II by members of the GALCIT Rocket Research Project at the California Institute of Technology to fabricate rocket motors for the armed services. Although Caltech actively sponsored rocket research in the United States during the 1930s, it held no interest in large-scale manufacturing operations. The GALCIT Rocket Research Project eventually expanded to become the Jet Propulsion Laboratory in 1944, a non-profit research and development facility operated by the California Institute of Technology under contract to the government. See F. J. Malina, "On the GALCIT Rocket Research Project, 1936-1938," in the Proceedings of the First and Second History Symposia of the International Academy of Astronautics, Smithsonian Annals of Flight, No. 10, 1974, pp. 113ff; also, Malina, "Origins and First Decade of the Jet Propulsion Laboratory," in Buse, ed., The History of Rocket Technology (Detroit: Wayne State University Press, 1964).

23. The availability of this hydrogen liquefier was later to fill an important requirement in the AEC's hydrogen bomb development program, after the Navy Bureau of Aeronautics's hydrogen rocket program had been terminated.

24. Interview with Harvey Hall on Early Navy Satellite Studies, March 31, 1963. Lithalloys Corporation had earlier begun work on means of producing experimental quantities of lithium-borohydride for another project.

25. Memo, Aer-PA-52 P41(1), to Joint Research and Development Board, January 24, 1947, op. cit., 1; also, BuAer Contract NOa(s)7913 with the California Institute of Technology, dated December 12, 1945. Dr. Hall had already examined the effect of aerodynamic drag during ascent to earth orbit because, even though it was only a correction factor, it was an important consideration for the proposed lightweight structure in terms of potential deformation of shape and extra propellant required to overcome the drag. Since no test work had been done at such high aerodynamic speeds, and the theory of supersonic flight was not yet developed, "I again turned to basic theory and found that, even assuming the worst aerodynamic shape possible, the effect of drag would amount at most to a few percent." (Harvey Hall letter, December 4, 1969, loc. cit.) Hall's major contribution at this time was in devising a method of approximate analysis for ascent trajectories which greatly reduced tedious step by step mathematical integration in arriving at orbit computations--necessary in an era before electronic computers. (Telephone interview with R. P. Kiviland, May 25, 1970; theory in Harvey Hall, "Estimation of Mass Ratio for Rocket Ascent," October 1945.

26. Cited in H. J. Stewart, A Summary of Performance Studies for a High Altitude Orbiting Missile, JPL Report No. 8-5, July 10, 1946, 1. See also Aerojet Engineering Corporation, Calculated Performance of Hydrogen and Oxygen as Jet Motor Propellants, Report No. RIM-24, February 28, 1946; and, D. A. Young, C. C. Stittier, and H. Coplen, Research and Development of High Performance Rocket Motors Using Gaseous Hydrogen and Oxygen as Propellants, Project Final report, Aerojet Report R-64, August 26, 1946.

27. JPL Report No. 8-5, op. cit., 11. This idea first appears in Hall, "Estimation of Mass Ratio for Rocket Ascent," and forms a premise for figuring ascent trajectory calculations in Lancaster, et. al., ADR Report R-48, November 1945, op. cit., 14. Considering this development many years later, Hall remembered using the concept in configuring single-stage trajectories, but "it may well have been originated by others also," he concluded. "In fact, I did not regard it as anything especially clever at the time, except that it supported the single-stage concept. . . . Anyone studying these problems would surely be led before long to this scheme." Harvey Hall letter, December 4, 1969, loc. cit.

28. They are W. Z. Chien, Preliminary Calculations on the Performance of a High Altitude Test Vehicle, JPL Memorandum No. 8-1, January 3, 1946; Chien, Studies on the Performance of a High Altitude Test Vehicle with Uniform Burning Rate Based on Vertical Trajectories as the First Approximation, JPL Report No. 8-1, March 18, 1946; E. C. Sledge and G. G. Halvorson, Investigation of the Launching Trajectories of a High Altitude Test Vehicle with Uniform Burning Rate, JPL Report No. 8-2, June 18, 1946; Joseph V. Charyk, Studies of the Effects of Nonuniform Burning Rates on the Performance of a High Altitude Test Vehicle, JPL Report No. 8-3, July 3, 1946; W. Z. Chien, Studies of a High Altitude Test Vehicle in a Dissipating Elliptic Orbit, JPL Report No. 8-4, July 9, 1946; and H. J. Stewart, JPL Report No. 8-5, at op. cit.

29. JPL Report No. 8-5, op. cit., 3. According to Dr. Malina, first director of JPL, at about the same time as the BuAer project began, the study of sounding rockets (first initiated by the GALCIT Rocket Research Project in the late 1930s) was resumed and extended to include step rockets and satellites. (Letter, F. J. Malina to the author, December 8, 1969.) See also F. J. Malina and A. M. O. Smith, "Flight Analysis of the Sounding Rocket," Journal of the Aeronautical Sciences, No. 6, 50 (1938); F. J. Malina, "Is the Sky the Limit? Ordnance Rockets Demolish the Barriers of Space," Army Ordnance, July 1946 (a recommendation for staging the JPL WAC Corporal sounding rocket atop German V-2 missiles for upper atmosphere research); and, F. J. Malina and Martin Summerfield, "The Problem of Escape from the Earth by Rocket," JPL Publication No. 5, August 23, 1946 (theoretical analysis of requirements involved in projecting a rocket to escape velocity).

30. Contract NOa(s)8496 discussed in Fahrney, History of Pilotless Aircraft and Guided Missiles, op. cit., 1133-1134, and letter from L. M. Pearson, Naval Historian, to the author, AIR-06B-LMP, July 29, 1969. Subsequently, on June 27, 1947 as design of the full-scale engine was completed—and under an amendment to the same contract—BuAer authorized Aerojet to develop and fabricate a liquid hydrogen-oxygen rocket engine of 2,000 to 3,000 pounds thrust, essentially a small scale experimental model of the anticipated, final version.

31. See D. A. Young, Progress Report, Aerojet R-70, January 1947, NOa(s)8496; and, Robert Gordon, Final Report on 300,000 Pound Thrust Liquid Rocket Power Plant, Aerojet R-74, March 1947; also, Robert Gordon, The Relative Importance of Propellant Density and Specific Impulse on Satellite Vehicle Performance, Aerojet R-92, May 1948.

32. The power unit, with an estimated weight of about 13 pounds, was to employ hydrogen as a working medium and use a liquid such as methanol as a heat exchanger. See Harvey Hall, "Early History and Background on Earth Satellites," ONR memo, ONR:405:HH:dr, November 29, 1957, 3; and, letter from L. M. Pearson, AIR06B:LMP, December 30, 1969. Hall indicates that mass ratio constraints favored a "small but useful power output of about 30 watts . . . [over] a higher power but heavier nuclear energy or nuclear isotope power source," which would require a more extensive development period.

33. BuAer Memo Aer-E-31T-HH, CX-281360, November 27, 1945, cited in Harvey Hall memo, "Early History and Background on Earth Satellites," loc. cit.

34. As one observer recalled: "After V-J day . . . scientists, as at the Radiation Lab., could not be interested in guided missile projects (of which the communications satellite [ESV] was only one) and wanted only to wind up their affairs and go back to their former pursuits, or better. Likewise the BuAer admirals were unenchanted by guided missile projects—as one remarked: 'We want equipment that we know works'" (Letter, Capt. W. P. Cogswell, loc. cit.); and, Albion and Connery point out that "Fiscal 1946, drawn up in anticipation of a huge invasion of Japan, quickly began to be whittled away before it could be spent. Altogether, more than \$20 billion of Navy funds were cut back." Fiscal 1947 was finally approved at \$4.1 billion (as opposed to a Navy request for \$6.3 billion) and Fiscal 1948 and 1949 followed at \$3.6 and \$3.7 billion respectively. See R. G. Albion and R. H. Connery, Forrestal and the Navy (New York: Columbia University Press, 1962) 154.

35. BuAer letter to Commanding General, Army Air Forces, Aer-EL-1-HH, F 41(1), Ser. C02262, March 15, 1946; cited in Harvey Hall memo, "Early History," 1957, loc cit. Members attending the conference of March 7 were: Major General H. J. Knerr, AAF; Major General H. M. McClelland, AAF; Brigadier General W. L. Richardson, AAF; Captain W. P. Cogswell, USN; Commander H. Hall, USNR.

36. Interview with Harvey Hall, March 21, 1963, loc. cit.

37. BuAer memo Aer-PA-52 F41(1), to Joint Research and Development Board, January 24, 1947, op. cit., p. 2.

38. In his Third Report to the Secretary of War the preceding year, General H. H. Arnold forecast that, as antiaircraft weapons were perfected, strategic bombers eventually would be replaced by long-range V-2 type ballistic rockets. He continued: "If defenses which can cope even with a 3,000 mile-per-hour projectile are developed, we must be ready to launch such projectiles near the target, to give them a shorter time of flight and make them harder to detect. We must be ready to launch them from unexpected directions. This can be done from true space ships, capable of operating outside the Earth's atmosphere. The design of such a ship is all but practicable today; research will unquestionably bring it into being within the foreseeable future." Arnold, Third Report of the Commanding General of the Army Air Forces to the Secretary of War, November 12, 1945, "New Concepts," p. 68. Moreover, in the Foreword to its report on a Proposed Air Engineering Development Center (eventually the Arnold Engineering Development Center in Tennessee), released on December 10, 1945, the AAF had asserted that planning for the new experimental facility must include "the expeditious and continuous development of all materiel contributing to air power in its broadest sense." This involved "1. Supersonic aircraft, piloted and pilotless; and winged missiles having velocities approaching meteoric velocities," and "3. Flight and survival equipment for use above the atmosphere, including space vehicles, space bases, and persuasive devices for use therein." Engineering Division, Air Technical Service Command, report, Proposed Air Engineering Development Center, December 10, 1945, p. iv.

39. Project RAND was chartered by the Army Air Forces in March 1946, to pursue a program of study and research devoted to the broad subject of intercontinental strategy and warfare. Contract W-33-038ac 14105 formalized this effort in May 1946. Initially, Project RAND operated as a semi-autonomous branch of the Douglas Aircraft Corporation, responsible directly to the Vice President, Engineering. Qualified physicists, engineers, and mathematical analysts were drawn from Douglas and other nearby aircraft firms as well as universities, and settled at Santa Monica, California, in separate quarters. In November 1948, the RAND Corporation was created and became a completely autonomous, non-profit research institution.

40. Formal members of the Aeroboard Research and Development Committee at this time were Brigadier General Laurence C. Craigie, Army Air Forces, Colonel H. G. Bunker, A. C.; Rear Admiral Leslie C. Stevens, U.S.N., Chairman; and Captain R. S. Hatcher, U.S.N. Also present at Research and Development meetings were additional invited personnel.

41. Adrian O. Van Wyen, The Aeronautical Board, 1916-1947 (Washington, D.C.: Deputy Chief of Naval Operations (Air), History Unit, GPO, 1947), 1. Later, in June 1946, this organization was partially supplanted by the Joint Research and Development Board [JRDB] of the War Department chaired by Vannevar Bush, which expanded and formalized many of the functions performed by the Aeronautical Board over a wider spectrum of activities. (The Aeronautical Board passed away completely in 1948.)

The chief responsibility of the JRDB involved preparation of an integrated program of research and development, in the light of which individual projects of the Army, Navy, and Air Force could be evaluated. The Board decided who developed what weapons. It made sure that there was no unnecessary duplication in the activities of the services although it could permit competition which promised to produce better results. JRDB in turn was

superseded by the RDB in 1947. Because service assignment of responsibility for different range rocket weapons could not be agreed upon until years later, by the late 1940s the principle of preventing duplication of effort among the services had been seriously eroded.

42. Harvey Hall memo, "Early History and Background on Earth Satellites," op. cit., 4.

43. Research and Development Committee, Aeronautical Board, Case No. 244, Report No. 1, May 15, 1946, pp. 1-2.

44. Ibid., p. 4.

45. In subsequent meetings of this ESV subcommittee in 1946-1947 a firm, but unwritten, understanding was reached between Navy and Army Air Forces representatives which divided the field between the two technical approaches: single-stage to the Navy, and multi-stage to the Army Air Forces. (Rear Admiral R. S. Hatcher, letter to the author, op. cit., p. 4.) p. 4.)

46. The CNO affirmed that, "inasmuch as an earth satellite vehicle will probably contribute importantly to the advancement of knowledge in the fields of guided missiles, communications, meteorology, and other technical fields with military applications, the program as set forth is approved." Letter CNO to BuAer, Ser. 037P517, May 8, 1946, cited in "Status Report, Earth Satellite Vehicle," Committee on Guided Missiles, Research and Development Board, GM 13/5, 15 January 1948, 4.

47. Initial discussions were conducted with several airframe manufacturers in early March 1946; and contracts were awarded after the Chief of Naval Operations approved the design studies on May 8. (Cf., Douglas Aircraft Co., Inc., Report No. E.S. 20515, "Considerations of a High Altitude Space Vehicle (Hall Project)," March 28, 1946; and, Glenn L. Martin Co., Report No. 2373, same subject, May 1946. North American Aviation prepared an informal summary of its ESV considerations. Douglas later withdrew from participation in the Navy ESV design study because of its close affiliation with Project RAND satellite studies being conducted for the Army Air Forces at that time.

48. G. Wilson, Structural Design Study, High Altitude Test Vehicle, Contract NOa(s) 8349, North American Aviation, Inc., Report No. NA 46-758, September 26, 1946, p. 1-1.

49. Ibid., pp. 2-1 and 3-1.

50. Ultimately the United States Air Force approximated just what BuAer had proposed when an entire Atlas ICBM was guided into orbit in late 1958 in "Project Score." As finally developed, the "stage and a half" Atlas ICBM was also a thin-skin, stainless steel, pressure-stabilized structure; moreover, the Atlas employed conventional propellants (kerosene and liquid oxygen) which do not approach the higher specific impulse delivered by liquid hydrogen-oxygen, in some ways making that vehicle a more difficult engineering achievement than the original Navy Bureau of Aeronautics single-stage HATV satellite rocket proposal.

51. Pedro C. Medina, Progress Report No. 1, Orbit Project, Contract NOa(s) 8376, The Glenn L. Martin Company, Report No. 2454, September 15, 1946, p. 5.

52. Pedro C. Medina, HATV Summary Report, Contract NOa(s) 8376, The Glenn L. Martin Company, Report No. 2666, June 1947, pp. A and B.

53. R. Gordon, D. A. Young, G. Bosco, and A. Pelton, Final Report on a 300,000 Pound Thrust Liquid Rocket Power Plant, Contract NOa(s) 8496, Aerojet Engineering Corporation, Report No. R-74, March 31, 1947, pp. 2 and 4.

54. In addition to the foregoing design studies, the Navy also found confirmation of this concept in two more limited separate studies, the first—already mentioned, ADR Report No. 48—prepared by the BuAer Aviation Design Research group under the technical direction of I. H. Driggs, and the second by W. F. Ballhaus at the Douglas Aircraft Company. Letter, O. E. Lancaster to the author, February 6, 1970; and W. F. Ballhaus, Preliminary Design of a Satellite, Douglas Aircraft Company, Report No. ES 20606, August 7, 1946.

55. The Aeronautical Board, comprised of military personnel, did not contain civilian representatives.

56. Memo Aer-PA-52 F41(1), Stevens to Joint Research and Development Board, January 24, 1947, op. cit., 3.

57. As provided for in the legislation, the Research and Development Board (RDB) was established effective September 30, 1947, to assist the Secretary of Defense in coordinating the R&D activities of the armed services. Vannevar Bush also chaired the new RDB, which absorbed and superseded the older JRDB (formed in June 1946). RDB responsibilities were defined to include determination of availability and approval of equipment developed for use by the military. (Responsibility for procurement, production, and supply of approved equipment continued to reside in the Munitions Board, while the Joint Chiefs of Staff remained in charge of operations.)

58. Memo for the JRDB from Hoyt S. Vandenberg, Lt. Gen. USAF, Subject: Agency for the Coordination of Earth Satellite Vehicle, June 13, 1947; also, Report No. 2, Case No. 244, The Aeronautical Board Research and Development Committee, Memo for the Aeronautical Board, June 13, 1947, 2.

59. Cited in Fahrney, op. cit., 1140. Since the predisposition of the services in the full committee was already known, this referral amounted to tabling the motion.

60. In April 1947, as impediments to further satellite progress grew (i.e., questions of jurisdiction, satellite utility, and limited funding and support) Lt. Commander R. P. Haviland requested orders to inactive duty, and subsequently joined the General Electric Corporation's Hermes rocket development project. He has remained with G.E., involved in work on various space programs since that time.

61. Fahrney, op. cit., 1140-1141.

62. Memo to the Committee on Guided Missiles, from L. R. Hafstad, Executive Secretary of the RDB, Subject: Earth Satellite Vehicle, GM 13/4, January 7, 1948; and, Fahrney, loc. cit.

63. Dr. Walter A. MacNair of the Bell Telephone Laboratories, served as chairman of this six-man civilian panel in the late 1940s. The other members were Dr. Francis Clauser, RAND Corporation; Dr. Richard Porter, General Electric Company; Mr. Robert L. Gilruth, NACA; Dr. H. Guyford Stever, Massachusetts Institute of Technology; and Dr. Clark Millikan, California Institute of Technology.

64. Letter from Frederick L. Hovde, Chairman of the Committee on Guided Missiles, RDB, to W. A. MacNair, Bell Telephone Laboratories, February 6, 1948.

65. "Satellite Vehicle Program," Technical Evaluation Group, Committee on Guided Missiles, Research and Development Board, GM 13/7, MEG 24/1, March 29, 1948. The first public announcement of contemporary U.S. earth satellite programs, contained in the First Annual Report of the Secretary of Defense, 1948, evoked some controversy in this country as well as in the Soviet Union. (R. Cargill Hall, "Early U.S. Satellite Proposals," Technology and Culture, Vol. IV, No. 4, 1963, 427-428.)

66. The Glenn L. Martin Company, Engineering Report No. 2854, Model M07, Proposed Interim Test Vehicle, March 1948.

67. The data was needed to provide aircraft firms information on pressures, atmospheric drag and heating effects at these high altitudes for use in the design of advanced jet aircraft. Subcommittee members included Captain W. S. Diehl, USN; Dr. Homer E. Newell, Naval Research Laboratory; Dr. Fred Whipple, Smithsonian Observatory; Harry Wechsler, U.S. Weather Bureau; and Dr. Harvey Hall, USNR; among others.

68. The Office of Naval Research smaller Neptune rocket, burning conventional propellants and carrying the same name as a contemporary airplane then under design for the Navy, was rechristened "Viking" to avoid anticipated confusion. Evolution noted in M. W. Rosen, The Viking Rocket Story (New York: Harper & Brothers, Publishers, 1955).

69. Harvey Hall, "Early History and Background on Earth Satellites," op. cit., p. 4.

70. BuAer PAD Memo, Aer-PA-5, June 22, 1948, cited in Fahrney, op. cit., 1141-1142. Dr. Harvey Hall left the Navy a few months later, worked for a time on earth satellites with the RAND Corporation in Santa Monica, California, and then resumed a teaching career at the University of Southern California. He joined the United States space program in 1960, after the creation of the National Aeronautics and Space Administration, serving NASA as Chief Scientist, Advanced Manned Missions Programs.

71. Aerojet Engineering Corporation, Research Technical Memo No. 54, Development of a 300-lb. Thrust Liquid-Hydrogen - Liquid-Oxygen Rocket Motor, August 29, 1949, 1.

72. Letter, AIR-06B-LMP, from Lee Pearson, Naval Historian, to the author, July 29, 1969; and Hall, "Early History . . ." loc. cit.

73. Fahrney, op. cit., 1142. (See also note 68, above.)

74. These technical circumstances account for the large 1000-lb. payload that was stipulated for the ESV in the Navy design studies in 1946-1947.

75. Perhaps the lack of interest may be attributed to the Navy's historic preoccupation with surface vessels and life that surrounds this singular activity. See Elting E. Morison, Men, Machines, and Modern Times (Cambridge, Mass.: MIT Press, 1966) especially Chapters 2 and 6.

76. It should be noted that, as the budget tightened after World War II, the Navy curtailed a number of surface-oriented R&D projects in aircraft and submarines, to the point of eliminating anti-ship missiles and light gun barrels and mounts, for example. Admiral Stevens thus had to justify major funding for a space effort at a time when it would mean cutting back still further on projects directly involved "with fulfillment of the Navy's responsibilities on, over, and under the sea." Early cost estimates for construction and launch of a Navy prototype vehicle were set at \$150 million (not including launch facilities), a figure, considering the LOX-hydrogen applications, that was probably underestimated considerably. In short, it just was not a salable proposition in the 1940s. (See also note 34, above.) R. P. Haviland, telephone interview with the author, July 2, 1970. A similar observation concerning Admiral Stevens' view of the expected cost and technical difficulties is contained in Rear Admiral R. S. Hatcher, letter to the author, loc. cit.

77. The single notable exception to this observation was CNO approval of BuAer satellite design on May 8, 1946. (See note 46, above.) One of the ESV participants, Grayson Merrill, observed: "As it turned out space flight was of very limited appeal compared to other government agencies and, I think, the Navy." Capt. Grayson Merrill, USN (Ret.) letter to the author,

78. On January 15, 1948 the USAF issued an earth satellite policy which declared that, because of the strategic implications, logical responsibility for satellite developments belonged to the Air Force. The policy "states, 'research and development will be pursued as rapidly as progress in the guided missiles art justifies and requirements dictate. To this end the problem will be continually studied with a view to keeping an optimum design abreast of the art, to determine the military worth of the vehicle, considering its utility and probable cost--to insure development in critical components, if indicated-- and to recommend initiation of the development phases of the project at the proper time.'" (Statement of Policy for a Satellite Vehicle, General Hoyt S. Vandenberg, USAF Vice Chief of Staff, cited in "Status Report, Earth Satellite Vehicle," Committee on Guided Missiles, Research and Development Board, GM 13/15, January 15, 1948, 7.) No known equivalent satellite policy was offered by the Navy.

79. A Soviet historian has suggested that the decision not to proceed with construction of earth satellites at this time was due to "the vacillation and doubt regarding the feasibility of large-scale rockets in the U.S.A." (See I. N. Bubnov, "The Development of Large-Scale Rocket Designing in the USA, 1944-1948," Transactions of the Ninth Scientific Conference of Graduate Students and Junior Scientific Associates of the Institute for the History of Natural Science and Technology, Moscow, 1966, NASA TT F-540, August 1968, p. 19.) This contention is amply refuted by the record.

80. Modern aeronautical theory (that is, as distinct from rocketry alone), quite noticeably preceded determined attempts to design and construct space vehicles, in contrast to development of the steam engine, for example, where much theory developed concurrently or followed empirical experimentation.