N77-33067

COUNTDOWN TO SPACE EXPLORATION:
A MEMOIR OF THE JET PROPULSION LABORATORY, 1944-1958[+]

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I. INTRODUCTION

In the spring of 1944 I accepted the invitation of Theodore von Kármán, Director Caltech's Guggenheim Aeronautical Laboratory (GALCIT), to join a new wartime research d development project. It had been stimulated by the Allies' discovery of a large and igorous rocket-missile effort which the Germans soon launched upon the world under the me of V-2. Although Kármán and his associates in the GALCIT Project No. 1 had developed family of small rocket engines for aircraft use, another Caltech project had devised a ries of short-range rocket projectiles, and other U.S. technical groups had done impor- nt work in military rocketry, at the time no development or research in the field of ng-range rocket vehicles and missiles existed in this country to match the challenge of e V-2. Kármán proposed that such a program be started, and Army Ordnance offered to onsor the research at what was soon named Caltech's Jet Propulsion Laboratory.[1]

Many of the skills to be brought to bear on the long-range rocket projectile re already a part of the GALCIT Project, which had made major contributions to the chnology of rocket propulsion, notably in castable restricted-burning solid rockets and orable liquid-propellant engines.[2] But the new objective called for new technical ills. The brilliant applied mathematician Hsue-Shen Tsien, who had contributed with rmán and Frank Malina to the JPL-Ordnance proposal, organized a Research Analysis Sec- on; problems of air-breathing engines, aerodynamic testing, and structural design, would considered in other new sections; field testing and the acquisition of a test range re new problems. My own field, electronics and instrumentation, would also be heavily gaged in the Remote Control Section that I was to found.

[+] Presented at the Sixth History Symposium of the International Academy of tronautics, Vienna, Austria, October 1972.

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384
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At the time I spoke with von Kármán and agreed to join the new project, I was a member of Caltech's Electrical Engineering faculty engaged in a variety of teaching and research activities, mostly war-related. I had training programs underway for military electronics officers and civilian technicians; I had been associated in radar development, both at Caltech and at the MIT Radiation Laboratory; and I had worked actively in the 1930s and early 1940s with Victor Neher and Robert Millikan in cosmic-ray surveys using balloon-borne sensors. These interests fitted in rather well with the anticipated needs of the Jet Propulsion Laboratory, and it was very pleasing to be able to bring them together in this fashion. I am not certain whether I recognized the high-altitude rocket and its progeny the spacecraft as practical successors to the cosmic-ray balloon, but I feel certain that Kármán did see this far ahead.

Theodore von Kármán was many great men: a scientist and engineer, a teacher whose students may still be found among the leaders of aeronautics in many nations, a gracious gentleman and persuasive advocate, and a builder of institutions such as the International Academy of Astronautics.[3] But I think his greatest skill was as a mixer of intellectual disciplines and social forces. His personality drew me into the field of rocket technology, and created the Jet Propulsion Laboratory as a permanent link between ordnance and rocketry users and the scientists of Caltech.

This two-dimensional mixing process, between rocket technology and the applied sciences on the one hand and between Caltech and the government on the other, offers both a perspective for viewing the growth of the Laboratory from the challenge of the V-2 to the launch of Explorer 1, and a key for understanding the results. It is my purpose in this memoir to review the stages of this growth and to reflect on the mixing process as part of the preparation for the exploration of space.

II. A FOCUS FOR RESEARCH

The project to study the technical problems of a long-range rocket projectile, named ORDCIT after its Ordnance sponsor and Caltech as the research institution, came to life under contract in late June 1944. At that point it shared the research and test facilities with three other projects sponsored by the Army Air Forces. These were the continuing investigation of rocket propulsion (the original GALCIT Project No. 1), the study of an underwater rocket projectile under Louis Dunn's leadership, and research into the air-breathing ramjet engine. Cooperation among the sponsoring agencies did much to promote the joint and mixed research activities.

In part because of the broad spectrum of technical questions it raised and the new research it called for, and partly because of the strong appeal, both scientific and strategic, of ultimately being able to develop a high-altitude, long-range rocket vehicle, ORDCIT enjoyed an advantage over the three propulsion projects. A high-altitude sounding rocket would carry on the work of Malina and his pre-war colleagues, while the long-range missile answered the direct challenge of the V-2. Although all four of the projects continued to grow, this last one grew fastest and furthest. It grew geographically, expanding to temporary flight-test ranges in the Mojave desert and the Texas reaches of Fort Bliss, and to permanent launch facilities at White Sands, New Mexico; it grew technically, over the range of engineering disciplines mentioned above; and operationally, from the testing of research vehicles to the systematic integration of a new kind of weapon, and to new dimensions of scientific observation.[4]

My own efforts were concentrated upon the ORDCIT Project from the time I joined the Jet Propulsion Laboratory late that summer. My first task was to travel East to examine radar and optical tracking techniques at the MIT Radiation Laboratory and Aberdeen Proving Ground, look into the state of remote control equipment at Sperry Gyroscope and Gulf Industries, and see Theodore von Kármán, who was recuperating from surgery in New York. I concluded that we would develop the necessary ground-test instrumentation and flight-data information systems locally at JPL.

It is important to recall that the focus of the pre-war electronics industry was upon commercial broadcast and communications technology; television and feedback-controlled automation were on the bench, not on the shelf. High-frequency applications—such as radar was to be—were severely limited by the lack of an appropriate amplifying device. It was impossible to buy, and difficult to develop, equipment that would function reliably under the stresses of field operation or rocket flight. But wartime mobilization changed this completely.

During this period the state of electronics technology advanced rapidly, almost violently. Anglo-American collaboration made possible a large and growing family of radar equipment and widened fields of application. Components rugged enough to ride an artillery shell, exemplified by the proximity fuze, were in production. Aircraft autopilots, low-noise communications, and fire-control systems became widely available. Most of us realized how far the techniques had moved only when, in postwar surveys, we observed the extent to which Allied efforts had outstripped those of the Germans and Japanese. I found, for example, that although the V-2 development rounds carried a radio telemetry system, the Peenemunde engineers had to rely principally upon tracking and recovery of the wreckage for performance and diagnostic information.

By the time I returned from my first trip in the fall of 1944 and began activating JPL's Remote Control Section (also responsible for test instrumentation, flight performance "reporting" or telemetering, and tracking), two rocket-vehicle project efforts were underway. The first, called Private, was intended to provide early integration and launching experience and to yield whatever applied-research values were possible from so simple a design. It consisted essentially of a solid-propellant Aerojet JATO unit with aerodynamic nose and fin assembly added; it was launched from a rail by a cluster of four solid-propellant rockets. Stabilized by fins after burnout of the booster, Private required no guidance system; there was no attempt to equip it with radio telemetry. The flight trajectory was deduced from radar and motion-picture data. On the last two rockets of the first series, Private A, in December 1944, we installed armored motion-picture cameras in the nose, looking sideways, to give information on the roll rate. Though battered by launch and impact, this rudimentary flight instrumentation did give the necessary data (Figure 1).

Fig. 1
Private A Rocket Test Vehicle, Instrumented
With Motion-Picture Camera

This first ORDCIT vehicle was tested in the California desert north of Barstow, not far from the present Goldstone Tracking Station, in December 1944. It gave valuable experience not only to the JPL team, but also to the group from Aberdeen Proving Ground's Ballistic Research Laboratory, who provided radar tracking. The next Private series involved a winged version of the missile, called Private F; this was tested at the Hueco Range of Fort Bliss, Texas, near the White Sands site then under construction. Private F carried no flight telemetry or guidance, but the eye and the camera were enough to reveal the corkscrew instability of its flight path (Figure 2).

Fig. 2
Private F Flight Test, Hueco Range, Texas, April 1945
Showing Rolling Instability

Planning had begun for the "second type of long-range jet-propelled missile," named Corporal, before I had returned from the East Coast.[5] This was to be a guided vehicle, launched vertically, with a 20,000-lb-thrust rocket engine using aniline and red fuming nitric acid. It would be a large technical step up from the Private series and from prior art in rocket-engine design, aerodynamics and flight path, airframe, and most of all in telemetry and guidance. For several years this vehicle would be the focus of most of JPL's research—especially my own.

The emphasis in those years at JPL, in ORDCIT, and on these missile efforts was upon research. The Private and Corporal supported research and investigation, not vice versa, and although development of a military guided missile was the ultimate objective of our contractual work, the contract called for us rather to understand the problems of the system.[6] A summary of these research-support rockets is given in Table 1. A similar mandate prevailed in the propulsion studies: GALCIT Project No. 1 had studied the characteristics of rocket motors for aircraft propulsion and JATO, but the Aerojet Engineering Company (founded by Kármán, Malina, and associates) designed and produced the final hardware products. This applied-research impulse resulted from close institutional bonds between the scientists and government personnel, particularly Army Air Forces but including other armed services. These bonds had been built by Kármán in the field of Aeronautics

Table I.
JPL Rocket Research Vehicles of the 1940s

Dimensions	Private A 10-in. dia, 8 ft. long	Private F 10-in. dia, 8 ft. long, 3 ft. wings	Wac 12-in. dia, 12.5 ft. long	Corporal 30-in. dia, 40 ft. long	"Sergeant" [c] 15-in. diam.
Gross Weight	600 lb.	500 lb.	665 lb.	12,000 lb.	not applicable
Flight Profile	Ballistic from inclined launch, 10-mi range	Private A with lift for range increase	Vertical to 240,000 ft.	Ballistic from vertical launch, 60-mi range	Vertical (exceeding Wac)
Propulsion	Aerojet solid, 1000-lb thrust	Aerojet Solid, 1000-lb thrust	Aniline-RFNA engine, 1500-lb. thrust	Aniline-RFNA engine 20,000-lb. thrust	Polysulfide solid, approx. 6000-lb. thrust
Launch	From rail, with booster	32-ft. rail with booster [a]	102-ft. tower with booster [b]	ground platform no booster	no booster
Guidance	free-flight	free-flight	free-flight	Pneumatic autopilot, radar-command	electronic autopilot
Flight Test Operations	Leach Springs, Calif., Dec. 1944, 24 rounds total	Hueco Range, Ft. Bliss, Tex. Apr. 1945; 17 rounds	White Sands, N.M., Oct. 1945 (Wac A, 10 rounds) Dec. 1946-47 (Wac B)	White Sands, N.M., May 1947-1950 (Corporal E, 5 rounds launched)	Not flight tested; static firings at Camp Pendleton, Calif Feb.1949-50;12 motors

[a] Private booster: four Army 4.5-in. solid rockets total thrust 22,000 lb for 0.18 sec.

[b] Wac booster; NDRC Tiny Tim ballistite solid rocket, thrust 50,000 lb for 0.6 sec.

[c] This "Sergeant" research vehicle should not be confused with the Sergeant guided missile—See Table II.

during the previous decade, and reflected the science-in-society tradition established by Robert A. Millikan and George E. Hale a generation earlier in World War I.

When ORDCIT began, two complementary principles were in operation: that of cooperation and mutual understanding between the academic scientists of Caltech, the military officers, officials of the government, and the working engineers of industry; and that of the autonomy of the technical expert and investigator. The resulting balance was also worked out on a grand scale in the nationwide wartime research mobilization led by Vannevar Bush. The autonomy principle was formalized and strengthened by Louis Dunn soon after he took over direction of the Laboratory in 1947: the broad Air Forces contract was modified slightly to recognize the right of the Institute, as well as the government, to approve the technical tasks proposed.[7] This independence was seldom exercised in fact, but it assured the integrity of the Laboratory as an impartial technical advisor.

In 1945 I prepared a preliminary analysis of guidance and telemetry problems for Corporal.[8] After reiterating the research mission of Corporal, I divided the flight profile into (1) vertical ascent, (2) declining-angle thrust phase, and (3) parabolic free flight, each with its particular control requirements. (We might note that the smaller test vehicles evaded such requirements by the nature of their launch modes and flight profiles.) Stabilization during the vertical ascent, by a gyro-controlled autopilot, and the programmed pitch turn were required by Corporal's mode of flight, and control of the burnout velocity and flight-path angle to provide the required target accuracy. I selected the radar-command mode for this guidance, whose elements are illustrated in Figur

While the Corporal research vehicle was maturing on paper, Frank Malina conceived an interim scaled-down test vehicle which could also be used as a vertical sounding rocket—the climactic goal of the original Caltech student group. It was soon named Wac Corporal. Designed to carry a 25-lb instrument payload to 100,000 ft, it was to be unguided, boosted out of a 100-ft tower by a "Tiny Tim" solid rocket and propelled by a 1500-lb-thrust acid-aniline rocket engine (Figure 4). The first version, tested in the fall of 1945 at White Sands (and inaugurating that facility) carried a Signal Corps radiosonic package, but no missile telemetry; a later version, tested in December 1946 and the following Spring, carried a five-channel JPL-developed FM/FM telemetry system as well as a parachute recovery scheme which could return the instruments or even the whole missile undamaged for re-use (Figure 5).

The Wac Corporal was a triumphant program in many respects.[9] Outgrowing its R&D test-vehicle function, it offered for the first time the realistic role of scientific instrument carrier in a simple, relatively cheap form. It outperformed specifications, exceeding 200,000 ft altitude (a world record at the time). It brought forth a new design cycle for rocket engine and airframe. But most important here, its launch operations, involving the cooperation of JPL crews, the Aberdeen tracking team under L.A. Delsasso (which had also supported prior flight tests), and the White Sands range, were a valuable preparation for Corporal testing.

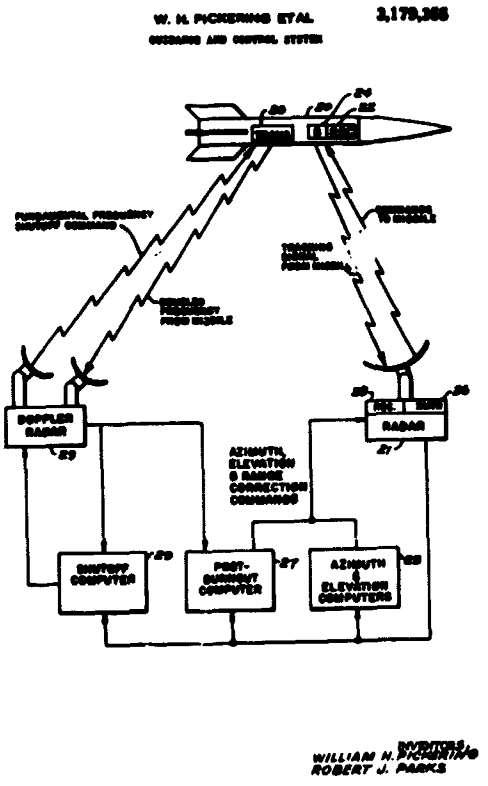

Fig. 3
Guidance and Control System for Corporal
(From U.S. Patent 3,179,355)

I was out of the country during the first series of Wac tests in 1945; in company with Kármán, I was looking into the test instrumentation and electronics developments of Germany and Japan, where we found very little that could add to what the Laboratory was already doing. I participated in Wac B operations, however, and began an interesting association with the system problems of test-range operations and flight instrumentation. In the meantime, the Corporal vehicle moved deliberately but surely towards its first flight.

On May 22, 1947, Corporal E No. 1 rose from White Sands. Weighing almost six tons and stabilized by a pneumatic Sperry autopilot, the slim white rocket lifted off its flat stand, gradually pitched forward toward the target, and flew a ballistic curve to within two miles of its 62-mile target range (Figure 6). No precision guidance had been employed, though an experimental radio command was exercised successfully. A ten-channel FM/FM telemetry set (actually two of the Wac telemetry sets) returned measurements of

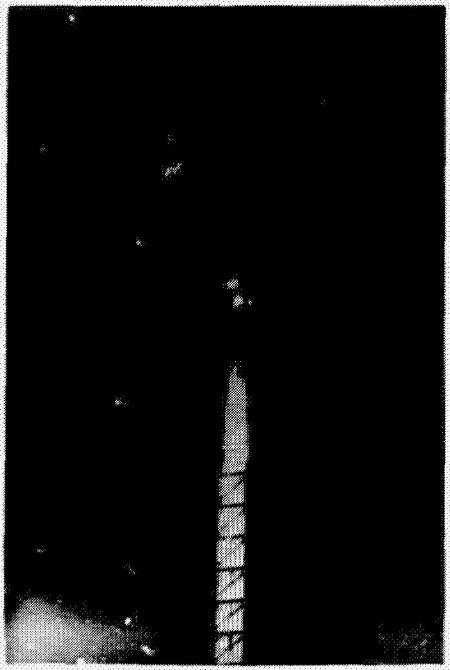

Fig. 4
WAC Corporal Launch, Just
At Booster Separation

guidance and propulsion-system parameters, and the trajectory was plotted from radar position and velocity measurements acquired by an active (flight transponder) tracking system (Figure 7).

Buoyed by this success, we prepared the next bird for launching eight weeks later. The second Corporal flight test, however, was a fiasco. Apparently the air-pressure regulator, which controlled the flow of propellants to the rocket engine, malfunctioned; the engine ignited, but with insufficient thrust, and burned on the stand for 90 seconds before the rocket was light enough to get off the ground. Then the missile rose, tipped over, headed for the sand, and proceeded to skitter through the desert underbrush under power until it blew up (Figure 8). A wag at the scene named it "the rabbit killer." The next two flight tests were better than this, but not so good as the first. The following two years were filled with bench experiments, redesigns, and ground testing. Certain essential features of the system remained to be flown, in particular the complete guidance system.[10]

In addition to the Corporal and its antecedents, which engaged elements of nearly every Laboratory section, there were several specialized rocket projects in this period which gathered a few—usually about two—research strands into a flight-test focus.

Fig. 5
WAC Nose Section After Recovery
(Author in Foreground)

The first of these jointly interested my telemetry group and some of H. J. Stewart's research analysts beginning in 1944; it was called RAFT, the rocket airfoil tester.

As the name implies, RAFT was designed to obtain aerodynamic information. At this time, supersonic wind tunnels were few and far between, and the transonic region was and still is difficult to simulate in a tunnel because of wall effects. The alternative is a free-flight vehicle, mounting the test airfoil and necessary instrumentation. The RAFT vehicle was simply a five-inch Navy ordnance rocket, with test section and instruments replacing the warhead (Figure 9). The need for telemetering the measurements gave my group the challenge of putting together a small, rugged, flight telemetry set and associated ground equipment; the test operation, conducted first in the Mojave desert site in early 1945, gave us valuable early experience in field work and data acquisition. These three-and five-channel sets were the first working rocket telemetry units in the United States. They operated on the FM/FM scheme, with the measured forces varying the frequency of a subcarrier oscillator, and several separate subcarrier signals frequency-modulating the RF carrier.[11] This scheme was subsequently carried over to Wac and Corporal.

Fig. 6
First Corporal Launch, White Sands Missile
Range, New Mexico, May 22, 1947

Other special-purpose rocket vehicles supported research in solid propellants and high-acceleration, high-speed dynamics. A small vehicle unofficially called "Thunderbird," demonstrated the polysulfide composite-propellant, internal-burning star-grain solid motor in 1947. With an acceleration over 100g, it led to the Wac-scale solid-propellant research vehicle called Sergeant in 1948.

But the Sergeant sounding rocket, unrelated to the tactical missile of the same name, proved to be ahead of its time. It was inspired by calculations that indicated a solid-propellant rocket of the internal-burning-star design could deliver several times the payload of a liquid-propelled V-2 type of similar weight. The motor chamber walls were to be very thin because the propellant, burning from within, would help contain heat and pressure. An autopilot design effort was begun, and static tests of the motor,

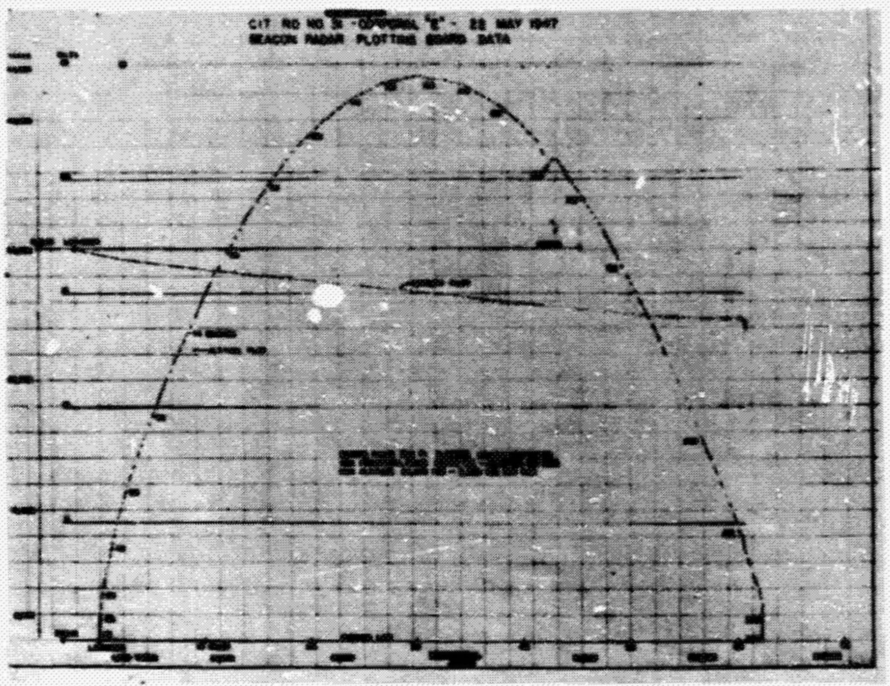

Fig. 7
Corporal E-1 Trajectory From Radar Data

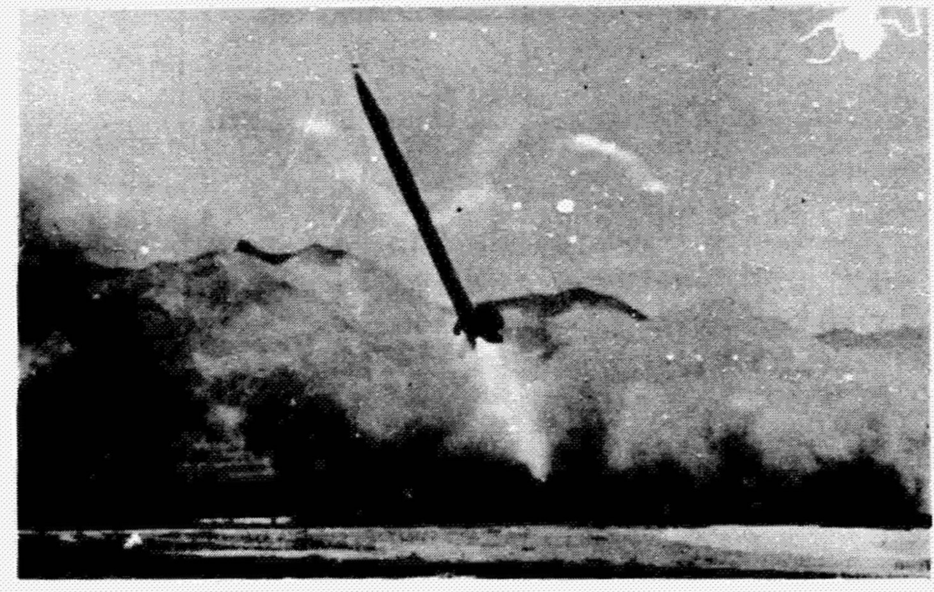

Fig. 8
Corporal E-2 Launch

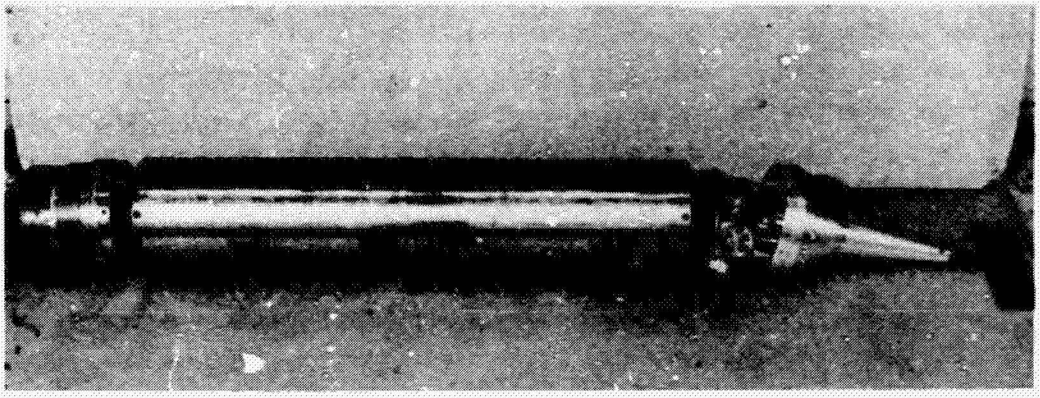

Fig. 9
Rocket Airfoil Tester (Without Rocket Motor) Showing Mounted
Airfoil, Instrumentation, Telemetry Compartment

weighing 1300 lbs and delivering about 6000 lbs thrust for more than 30 seconds, were conducted (Figure 10). Difficulties with solid rocket, manifested in the rupture of the thin-wall case, coincided with a change in the JPL mission and an acceleration and

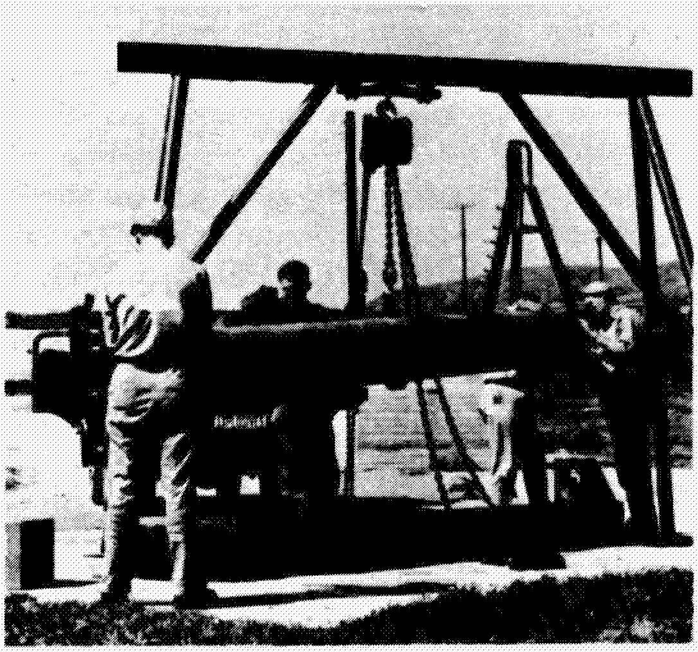

Fig. 10
Experimental Solid-Rocket Motor, "Sergeant," Preparing
For Static Test, Camp Pendleton, Calif., 1949

expansion of Corporal development; the Sergeant project was suspended. The electronic autopilot was adopted for the Corporal missile while the solid-propellant engineers took their problems back to the laboratory and test stand for more investigation. Further development was undertaken by the Thiokol Chemical Corporation. The ultimate heritage of this early "Sergeant" powerplant was the reliable solid rocket, used in large scale in the Sergeant and other military missiles, and in clustered miniatures to launch the first Explorer satellites.[12]

Other projects of an interagency character also focussed JPL efforts in this period. They did not center upon rocket vehicles but rather upon large-scale test facilities. The first was the Supersonic Wind Tunnel, which grew in part from the ram jet propulsion project but mostly from the needs of the designers of the long-range rocket for supersonic test data. The wide range and high value of Mach numbers under which the rocket models would need to be tested went beyond the capability of any available facility. A general need for such facilities could be foreseen, and the talents of Caltach—in particular the brilliant aeronautical engineer Allen Puckett—were ready and willing to fill this gap. Accordingly, the Army and Air Force authorized JPL to proceed. A flexible-throat wind-tunnel of 12-in test section was completed in 1947, and a 20-in tunnel in 1950. This enterprise supported not only JPL rocket design and research programs, but also a large group of rocket and supersonic aircraft developers and research laboratories under the aegis of the two armed service sponsors. At one time the wind tunnel took up about one-quarter of the Laboratory's effort, and it remains in operation to this day.[13]

The second interagency effort was more directly concerned with the rocket projects—ours and others—and involved my own efforts as well as the Laboratory in its consultative role. The primary external need posed by the long-range rocket projectile was a well-instrumented flight-test facility. We began to use and improve the White Sands range in 1945, inaugurating it with the first Wac Corporal in the fall of that year. We learned a great deal about the instrumentation and operational requirements of rocket testing in those early years, and, when the Navy developed their Point Mugu test range (beginning in late 1946), I performed a number of studies to help them set up their instrumentation system.[14] We shared what we had learned more informally with the other users of White Sands, which included the V-2 scientific and engineering program, the Nike antiaircraft development, and the Navy's Project Viking.[+]

This interchange of information, and the standardization of practice which followed, was coordinated by the Research and Development Board of the Department of Defense. One of the committees operated by this board, chaired in succession by Edmond C. Buckley and myself, was concerned with test range instrumentation: tracking, telemetry, and command control. We wrote standards for an FM/FM telemetry system, expecting this to be an

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[+] See Milton Rosen, "The Viking Rocket: A Memoir," in this volume—Ed.

interim stage pending the adoption of pulse telemetry systems. To the surprise of a good many people, FM/FM proved quite durable, and remained in good use much longer than expected. The successor to our committee, the Inter-Range Instrumentation Group, maintained our standards in terms of subcarrier channels, but in later years the field of telemetry modulation gradually opened up to a great variety of schemes.

By mid-1949, then, the rocket- and missile-related research of the Laboratory was focused principally in the Corporal as a test vehicle for the technology of the liquid-propellant guided missile, with smaller solid-propellant efforts gathered around the Sergeant research vehicle, and aerodynamic research and testing in the wind-tunnel. The still-growing electronics activity was engaged in guidance, telemetry, and tracking for the missiles, and in instrumentation systems for the wind tunnel and the rocket firing ranges. My own interest was primarily engaged by Corporal's problems, though I was concerned with ground instrumentation systems and the distant potential of the rocket for upper-atmosphere research.

III. THE GUIDED MISSILE SYSTEM

Nothing in nature remains fixed, and the swinging pendulum of research and development under which we had worked on Corporal swung rapidly forward in the fall of 1949. The experimental rocket vehicle which we used as a device to study guidance, missile aerodynamics, and the like, was transformed into a guided missile under development.

Under the pressure of the changing world situation, and with the guided-missile program now five years old, Army Ordnance reviewed the prospect of obtaining an accurate and usable weapons system from our ongoing study effort. This was, after all, their objective. Their program had moved forward on two fronts: ORDCIT on an applied-research basis, and Project Hermes building from the captured remains of the V-2 development as an industrially-based technological program at the General Electric Company. With four flight tests accomplished, one of them highly successful, Corporal was evidently making good progress towards Ordnance's goal, and Colonel (later Major General) Holger Toftoy of the Ordnance Missiles and Rockets Branch, asked Louis Dunn, JPL's Director, to determine whether it could be converted to a weapons system.

Louis Dunn, who had been generally responsible for the Corporal program since 1945, reasoned that the major technical step was the provision of an accurate guidance system. He accordingly brought me into the inquiry, and we gave the matter much thought before deciding in effect, "let's give it a go." In September 1949 we travelled East to confer with the Colonel Toftoy at the Pentagon. He talked to us about the need for a demonstrably field-worthy guided missile, the limited prospect for achieving this soon, and the Ordnance Department's wish that JPL move Corporal rapidly in this direction. I was much impressed by the faith of this professional soldier in the industrial-development capability of our Laboratory, considering that we were so largely research-oriented and had no experience of this kind. I believed we could solve the technical problems of the guidance system, however, and Louis was confident that we could handle the industrial-engineering transition. Thus began the Corporal guided-missile development project, for which Louis asked me to take responsibility. JPL began to change from a research organization to a duel-purpose, research and hardware-development team. It really was as simple as that: we said we could do it, and Toftoy told us to go ahead.

Things began to move. In April 1950 the Army Ordnance Guided Missile Center was activated at Redstone Arsenal, Huntsville, Alabama. Although at first the Department of Defense disapproved the Army's request to list Corporal as a weapons system development, in October 1950 they established the Office of Director of Guided Missiles at a high department level. In the same month JPL was issued a contract for the new Corporal program.[15]

This shift in the Laboratory's objective was accompanied by a more gradual change in the organization, in part to reflect the recognition of a dichotomy between research and development engineering. In the early years there had been a relatively free mixing of researchers and rocket-builders, and it had often been possible and appropriate for one man to follow his work through research to hardware development. By late 1944, however, we had separate guidance and electronics-research activities. In 1946, the many technical sections were clustered into four divisions; in Dunn's reorganization of 1950 two of these emerged as research oriented, contrasted with my division, now called Guided Missile Electronics, and the one headed by Paul Meeks, Guided Missile Engineering.

I was not altogether in agreement with this dichotomy, partly because my own interests and the technical discipline of electronics are strongly rooted on both sides of the fence. The electronics activity at JPL had a dual role from the start: the immediate development of test instrumentation systems with long-term guidance research, or, in the later period, missile and test-range electronics together with communications theory. Thus, my inclination was more toward organizing on the basis of technical disciplines, and lowering the barriers between research and practical operational development. In 1954, after I was named Director of the Laboratory, additional growth in form and function called for another reorganization of the Laboratory, and we moved toward somewhat greater integration of research and engineering, with three departments divided essentially upon discipline lines. By the time of Explorer 1, the three Department Chiefs (respectively Frank Goddard, Jack Froehlich, and Bob Parks) had additional responsibilities in the areas of research (including the wind tunnel operations), the space project, and the missile project, respectively, though these three activities each drew on the technical resources of all three departments.

But in 1950 when it formally became a candidate guided-missile system, Corporal was still evolving slowly as a research vehicle. The propulsion system, mature in principle, was still developing in terms of hardware as the designers probed the dimensions of weight, material, and configuration. The autopilot was at a similar stage, having progressed from the hydraulic design used in aircraft to a pneumatic one, whose vulnerability to the heat and vibration environment of the missile was demonstrated in the fourth flight test. Long-range guidance to provide accuracy at the target was still maturing in principle; test instrumentation, radio telemetry, and radar tracking were essentially ready to meet the needs of the development program.[16]

The most critical technical problem was long-range accuracy. Corporal had to reach a target only a few hundred meters across, about 110 kilometers from its launch site, after flying a course which left the atmosphere and re-entered it. The broad principles of radar-command guidance were those I had worked out in 1945, and have mentioned above; the practical realization of equipment which would perform correctly and could be mass-produced was a distinct challange.

This was complicated, in turn, by two "strategic" conditions. First, none of us knew quite how accurate or reliable such a guidance system ought or needed to be; and second, the Army wanted one quickly. As a consequence of the first condition, the requirements for Corporal tended to evolve with the system, as the theoreticians, the engineers, and the military planners worked along and learned their way, and also as the Corporal test program fed information back to them. The second condition made it desirable that we work toward an interim solution rather than ultimate perfection. The Corporal system thus emerged as a hybrid, or lash-up, based on existing equipment or designs: A modified Corporal E rocket (Figure 11), an all-electronic autopilot derived from the Sergeant test-vehicle project, modified Signal Corps 584 radar, and a doppler link for velocity measurement. For ground handling vehicles, we modified the designs of construction and agricultural machines, among others. It was implicit in this approach that Corporal would be succeeded by a new and better system, probably in the 1960s.

As ultimately developed, the Corporal guidance system conformed essentially to my plan of 1945: the inertial autopilot stabilized it through launch and continued in operation, but it was augmented in later phases of flight by overriding commands from the more precise ground computer, operating from radar and telemetered missile gyro data. Range control was maintained by shutting off the rocket engine when the proper velocity had been attained; this was sensed by the separate doppler link, and executed by a very precise valve system actuated on radio command from the ground computer.[17] A measure of the accuracy of this early radio guidance is that within a few years we were able to find errors in the survey maps of White Sands.

In the Corporal E flight tests, we had early discovered guidance and control equipment problems arising from the rugged environment of a rocket in flight: the early autopilot was placed next to the rocket engine, surrounded by heat and vibration. Mountings and structures often would amplify the vibration by resonance, and we learned a great

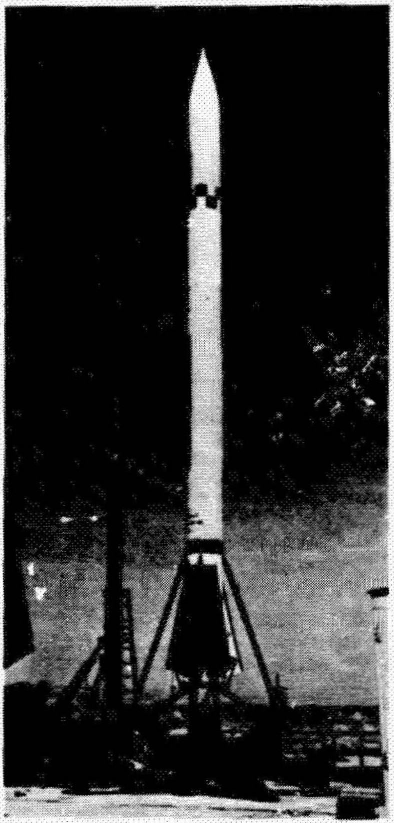

Fig. 11
Early Weapons System Version of Corporal, With Handling
Equipment, White Sands Missile Range

deal about environmental testing and the design of sturdy and reliable equipment, not only for the missile itself but for the complex ground equipment which must operate in the field as well. This special technology was to have important implications for space exploration, of course.

By 1953 the Corporal system was ready to be tested in tactical conditions. A sketch of the launch area in the field is given in Figure 12, and a natural view is shown in Figure 13. Two industrial firms, the Firestone Tire and Rubber Company for the missile, and Gilfillan Brothers, Inc., for the guidance system, had begun limited production. We had already launched some forty missiles at White Sands in the course of experimental and development testing. Accordingly, the Army began a long series of field test firings, while we continued development flights at a rate which reached one a week over an extended period. A small JPL contingent had taken up permanent residence at White Sands by this time, and a much larger group spent a great deal of time there. Although JPL involvement

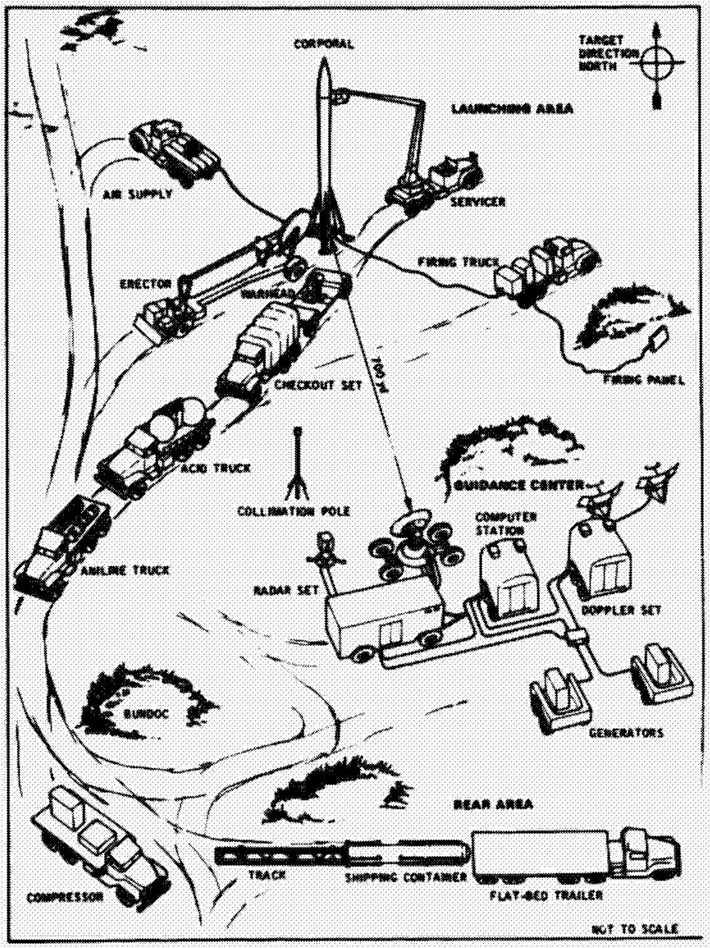

Fig. 12
Corporal Tactical Field-Test Diagram

in Corporal continued at a vigorous pace, from the point of view of statistical testing, technical advice and training for the military, cooperation with the industrial production engineers, and advanced development, the development was essentially completed.

At about this time, Corporal's successor entered the picture. In January 1953, Army Ordnance asked us to investigate the feasibility of an improved solid-propellant missile capable of taking over the Corporal mission. Our study revealed that considerable improvement in accuracy, reliability, and ease of handling was possible with such a vehicle, provided an improved radio-inertial guidance system was employed. The benefits of replacing the complex liquid-propellant powerplant with a one-piece solid motor were

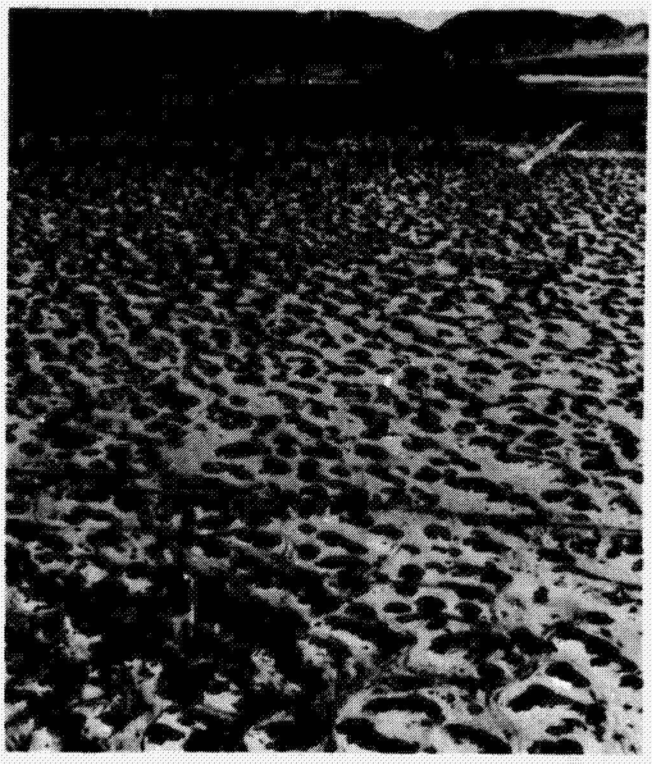

Fig. 13
Corporal Tactical Field-Test Arrangement at White Sands

obvious, especially now that the motor evolved from the Sergeant test vehicle of 1948-49 via the Hermes RV-A-10, had been perfected. But this simple and easily-handled propulsion system offered one large problem to the guidance designer--it could not be simply shut off with the closing of a valve. In addition, it provided a challenge to the electronics packagers in the form of a new and stronger vibration environment. Still another problem faced the guidance engineers: the missile had to be immune, or nearly so, to radio interference and jamming. The obvious solution to this was to remove the ground link and program the missile to control itself internally, using inertial data. In 1953 this solution appeared unsatisfactory from the point of view of costs, reliability and accuracy. As a result, we worked on an essentially noise-free and jam-proof communications link for the radio guidance system.

The benefits of all we had learned in the Corporal development were freely available to the new Sergeant missile program, partly through a continuity of people between the projects. Principal among these was Robert J. Parks, a long-time associate and former student of mine, who had succeeded me as chief of the Guidance and Control Section and of the Guidance Research Division, and became Sergeant Project Manager. The communications links were simplified to one up and one down from the missile, with command, telemetry, and doppler tracking all gathered into one looped circuit. Transistorized electronics were a part of the Sergeant design from the start, while Corporal telemetry had had, for example, to be "updated" with such circuits. New equipment packaging, in which the subsystem units took the form of nearly solid blocks, in which the chassis were hollowed-out shells rather than flimsy internal skeletons, reduced our worries about vibration. Automatic checkout equipment rapidly verified the readiness of all circuits for launch.

The major guidance problem, velocity control, was solved when the JPL system design group developed a set of aerodynamic drag brakes (Figure 14). Operating rather

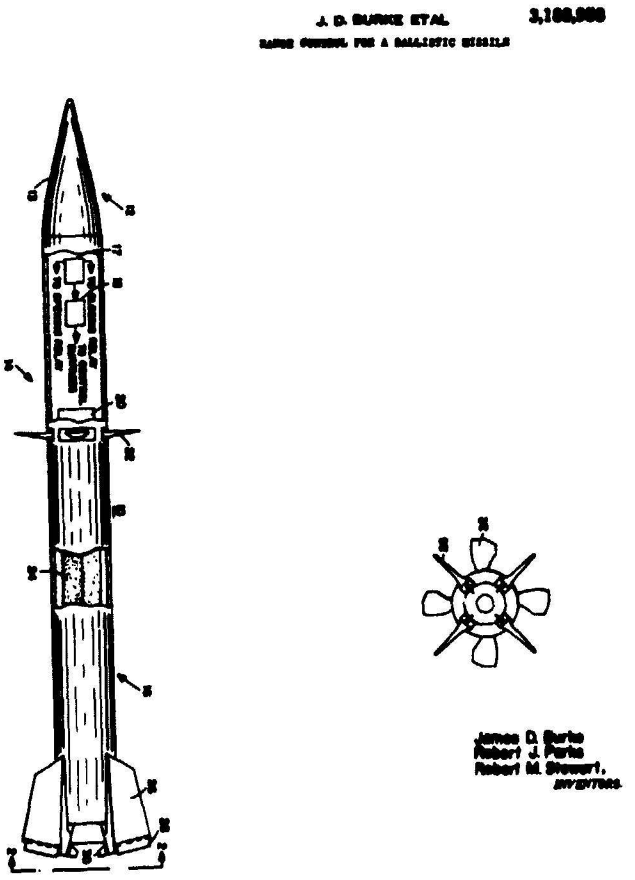

Fig. 14
Sergeant Range-Control System
(From U.S. Patent 3,188,958)

like the blades of a camera shutter, the brakes reduced the velocity to the required value. Flight-tested, the design proved as simple and precise as the shutoff valves which performed the corresponding function on the liquid propellant Corporal.[18]

Yet a fundamental debate still remained on the central issue of second-generation missile guidance. Those of us with Corporal experience advocated continuing the principle of keeping the major computing function on the ground, and using the missile-ground link as the accurate reference-measuring system. We felt that all-inertial guidance schemes, then being developed for early ICBM programs, would be too massive and expensive for Sergeant. But Army Ordnance and the field forces favored the invulnerability and simplicity of this mode, and authorized parallel developments, with support from industrial contractors, of all-inertial and radio-inertial guidance systems for Sergeant. In a relatively short time, Bob Parks, with John Scull and other JPL Colleagues, came up with a highly acceptable small stable platform for the Sergeant. Although the advanced ground-based guidance derived from Corporal was somewhat more accurate, it could not match the inertial design for field simplicity and freedom from radio interference. In 1955, the inertial system was formally selected.

The Sergeant missile system development went forward at a more rapid pace than Corporal, partly because of the simplicity and excellent performance of its powerplant, but mostly because both the engineers and soldiers were building upon the Corporal experience. Less than three dozen Sergeants were test flown at White Sands (Figure 15), compared with over one hundred Corporals; both JPL and the Army had learned how to handle guided missiles and test firings smoothly, and had flown certain crucial Sergeant experiments as passengers aboard earlier Corporals. Finally, Corporal had taught us how best to use industrial collaboration. The engineering firm which would build Sergeant, a new division of the old Sperry Gyroscope Company I had visited on my first trip out of JPL a decade before, joined as co-contractor during Sergeant's development.

One minor missile-system project of the early 1950s deserves mention at this point, for it served as a solid-propellant research focus and a case study in missile development. Project Loki began as an attempt to adapt the World War II German Taifun antiaircraft rocket technology. This rather small unguided projectile was developed for some time using the liquid-propellant design of the original before the Army asked us to study it in the solid-propellant mode early in 1951. The rocket booster was about six feet long, three inches in diameter, and joined to a ballistic dart about the size of the handle of a broom. It was spin-stabilized. For R&D purposes, the dart contained a tracking beacon and telemetry set. Designed for targets at 40,000 ft. altitude, the missile reached an acceleration of over 100g' after being launched from a long tube (Figure 16). Although we could build individual rounds precisely enough to achieve the necessary accuracy, the mass-produced version fell somewhat outside the target circle. About this time a military analysis showed that a different approach—guided ascent, exemplified by

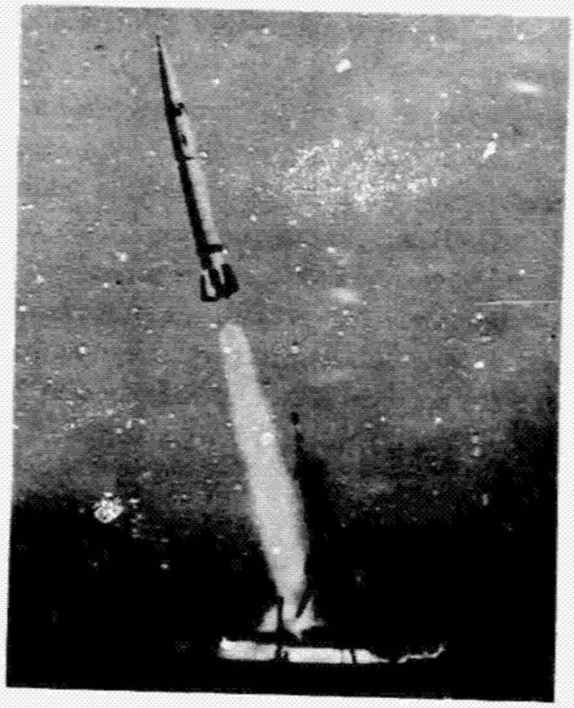

Fig. 15
Sergeant Launch, White Sands

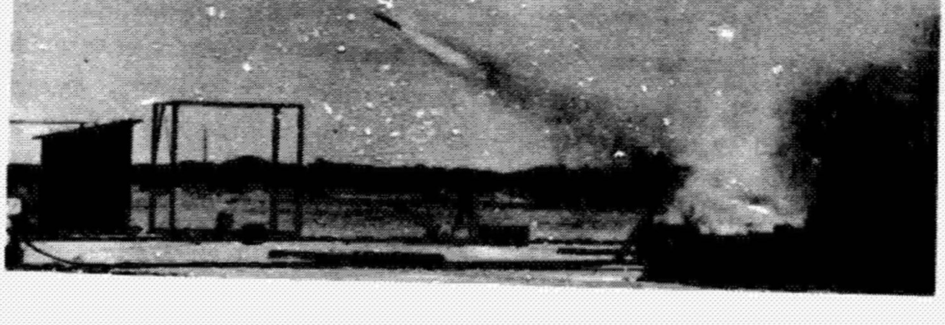

Fig. 16
Loki Rocket in Test at White Sands, [illegible]t 1952

Nike—was strategically superior to the Loki unguided-volley mode, and the project was terminated. However, many of the manufactured rockets were later used as small-scale sounding rockets and test-vehicle stages, a role in which they served with distinction.

While the laboratory appeared to enjoy a greater freedom of research in the earlier research-dominated period of rocket and guided-missile experimentation than in the Corporal-Sergeant missile engineering phase of the 1950s (see Table 2), the difference is partly illusory. For one thing, JPL was growing at a rapid rate throughout this period, and the expansion of missile development was not at the expense of reserach activity; in fact the two components grew together. For another, missile development produced new classes of research problems, of which elastic properties and telecommunications are two important examples. The ultimate positive effect of missile development on applied science was almost a case of serendipity rather than technological determinism, and represents the major theme of my memoir: the missile contributed much of the technology for, as well as the impulse towards, the practical science of astronautics.

It is only with hindsight that we can see the embryo of the spacecraft within the body of guided-missile developments in the early 1950s. At the time, in a project sense, we were oriented toward the practical problems at hand, even though the advances in technology had far-ranging implications, some of them as obvious as rocket propulsion and others as subtle as ground-based guidance. In addition, the practice in system integration and environmental testing that the missile projects afforded us would simplify the development of space systems. But throughout this period, from the inception of the Corporal to the termination of the Loki, the seeds of space exploration were germinating; in the middle of the 1950s they began to grow. We at JPL became involved in the proposal, and then in the development, of a space vehicle.

IV. TOWARD SPACE

JPL's formal activities directed toward space exploration began almost immediately following World War II. Frank Malina has described the origin and early success of Wac Corporal as a sounding rocket,[20] and I have alluded to its role in the Corporal technology. At about the time the first Wac vehicles were reaching toward "extreme altitude," JPL received a U.S. Navy contract to study the problem of orbiting a satellite. This activity had its origins in the Navy Bureau of Aeronautics in mid-1945, where the satellite mission, inspired by review of the V-2 development, was studied and considered for scientific, communications, and cartographic roles. The launch mode in this study was a single-stage rocket using hydrogen and oxygen; Robert Haviland and Harvey Hall were its most enthusiastic Champions.[21] JPL's involvement took the form of a technical review and confirmation of the Navy's calculations, and was conducted by the Research Analysis Section under Homer J. Stewart's direction. Stewart and his colleagues concluded that the

Table II
JPL Guided-Missile Project Activities

Name and Function	JPL Responsibility	Test Flights	Remarks
Corporal: radio-guided, surface-to-surface liquid-propellant ballistic missile	Complete missile system, incl. ground equipment and tech. training	Corporal E, 1947-50 (sec. Table I) flight 10, October 1951 Flight 20, May 1952 " 40, Dec. 1952 " 70, Jan. 1954 " 100, Spring 1955	Four flights in 1954-55 supported Sergeant guidance research; some flights in 1954 carried atmospheric research instruments for Ballistic Research Laboratory. In service, U.S. Army, from 1954; JPL development ceased, 1956.
Sergeant, inertially-guided surface-to-surface solid-propelled ballistic missile	Guided missile system.	Flight 1, Jan. 1956 Flight 10, Mar. 1958 Flight 20, Mar. 1959 Flight 29, Mar. 1960	Sperry served as co-contractor from March 1956. In service, U.S. Army, from 1963. JPL development ceased, 1960.
Loki, unguided solid-propellant antiaircraft missile	Rocket booster development and analysis only	1757 tests, White Sands, 1951-1955	Statistical data acquired, probes instrumented for tracking, spin rate, and temperature or pressure. Adapted as sounding and test vehicle.
Jupiter Project Support	Backup radio guidance	Three tests in 1957 on Corporal missiles.	"Codorac" system, noise-modulated, 1956-1957.
	Re-entry Test Vehicle support.	RTV-1, Sept. 1956 RTV-2, May 1957 RTV-3, Aug. 1957, at Cape Canaveral	High-speed stages (scale model Sergeant motors) and Microlock communications. Modified for satellite launch, Explorer 1

single-stage mode was feasible but marginal for a successful satellite mission, while multiple rocket stages would be preferable.[22] With a somewhat adverse technical judgement, and the difficulty of finding a proper military mission for the project, these early satellite studies gradually faded away, but the potential of military rocketry in the service of experimental science did not.

About sixty V-2 rockets had been brought from Europe to the U.S., and test-firings of these missiles began at White Sands in 1946. The opportunity to fly scientific payloads in these big birds was quickly seized, and an interagency group, which soon became the Upper Atmosphere Rocket Research Panel under James Van Allen's leadership, began to coordinate this work. I served on this panel, which eventually became the Rocket and Satellite Research Panel during the IGY. The Jet Propulsion Laboratory also took an early hand in the promotion and diffusion of upper-atmosphere and "space" science. In mid-March 1946 we organized a symposium on Guided Missiles and The Upper Atmosphere at Caltech, gathering scientists and engineers from university, industrial, and government laboratories to discuss high-speed aerodynamics, missile launching, the physics of the upper atmosphere, and problems in combustion and gas dynamics.[23]

This symposium, which heard thirty-six papers plus a supplementary discussion on upper-air experiments, was a prime example of the mixing process I have outlined. First of all it was an opportunity for many of those engaged in rocket development and its applied sciences, internal and external, to compare notes across a technical field from smokeless powder to super-aerodynamics—probably for the first time on such a scale. Second, and perhaps more important, it brought this broad population of rocket technologists into contact with an equally broad spectrum of potential scientific users, from the astronomer to the meteorologist. As an institutional mixer, the symposium was equally effective: JPL, Caltech, the University of California, and the R&D groups of Southern California's aircraft industry were strongly represented, while the eastern universities, various armed-service research groups, and at least one eastern industrial laboratory were also in evidence. The lines of communication represented and reinforced at this meeting, and maintained by the Upper Atmosphere panel, continued to be effective in the next decade of aerospace growth in the United States.

The value of the rocket to the kinds of experimenters present at this symposium, and the degree of organizing and planning work remaining to be done, are indicated in a publication of mine written in 1947. I wrote: ". . . it would appear that the design of the rockets is not adequately coordinated with the physical research programs to which they are intended to apply." The same conclusion was expressed in action with the development of the Wac-based Aerobee by the Applied Physics Laboratory of Johns Hopkins, 1946-1949 (under Navy sponsorship), and of the Naval Research Laboratory's Viking (1947-1955). My analysis matched desirable research programs and their necessary observational conditions against two representative available rockets, Wac and V-2, the research conditions they could provide, and the techniques they represented—especially in telemetry, instrument recovery, and the like. I suggested that extensive cosmic-radiation studies be deferred "until a satellite rocket can be produced," but I did not venture to predict that a period of ten years and seven months would be enough.

The difficulty with the sounding rocket for most atmospheric and space science, was the short life of the mission. For meteorlogical investigations, balloon-borne instrumentation was superior. The Wac, for example, flashed through the strata of interest too rapidly for sensors to respond; for upper-atmosphere physics and astrophysics, the duration at trajectory's peak, and our ability then to control the vehicle's attitude for instrument pointing, was marginal. Parachute recovery of the scientific payloads was considered rather as a means of supporting the use of spectral and photographic instruments than of remaining at altitudes of interest, for the latter were too high for a parachute to have helped. Finally, I considered the question of payload weight distribution, and it is interesting that my weight estimates for flight electronics equipment were approximately those used in Ranger and Mariner spacecraft in the early 1960s, though of course the development of microcircuits and the great increase in complexity and power have balanced each other in this case. The entire payload weight of Explorer 1 totalled less than the 20-lb figure I had allocated for telemetering alone for the research rocket.

Meantime, in the late 1940s, the two "available" high-altitude rockets came together for the next step towards space exploration. During the early Wac launchings, Holger Toftoy, Frank Malina, and others discussed combining V-2 and Wac as a two-stage test vehicle. This became the Bumper project in which JPL joined the General Electric Hermes activity, providing Wac B rockets modified for spin-stabilized launch at the peak of the V-2's trajectory (Figure 17). The high-altitude Bumper-Wac flights, which achieved a record altitude of 250 miles on February 24, 1949, did not return data from a scientific instrument payload. However they demonstrated the feasibility of rocket staging, and in particular that of joining two existing vehicles to produce a third. The later Bumper-Wac launches were devoted to the study of another technical problem, aerodynamics at high speed, and thus did not relate to space science.

Project Orbiter, which grew into a competitive proposal for a U.S. Satellite launch during the International Geophysical Year, resembled the Bumper vehicle in some system respects. That is, existing hardware was to be brought together for a new mission, supported by a multiple-agency team growing from roots set in Peenemunde and Pasadena, with a first emphasis on flight demonstration and such simplifying compromises as spin stabilization for the upper stages.

The Orbiter idea originated in mid-1954 at meeting of satellite advocates from the Office of Naval Research, the American Rocket Society, the astrophysics community, and (in the person of Wernher von Braun) the Army Ordnance rocket program. Those in attendance

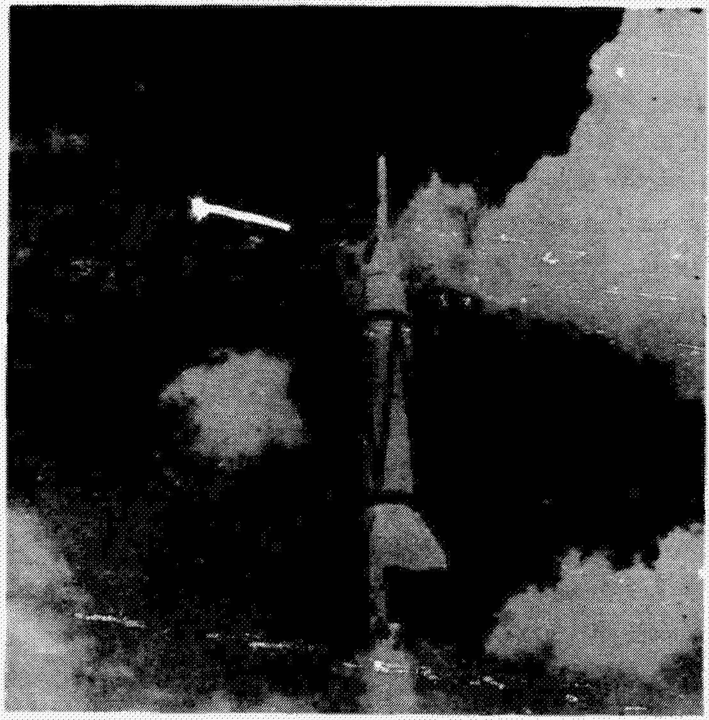

Fig. 17
Bumper-WAC Launch

proposed to use a Redstone missile (descendant of V-2) as first stage, clusters of JPL-developed Loki solid rockets as upper stages, and a lightweight, inactive satellite payload. During the next year, this proposed fusion of V-2 technology, JPL rocket technology, and what was still designated as upper-atmosphere experimental science went through many stages of study and debate, in which JPL participated, until in 1955 it was finally rejected by the Defense Department in favor of the Naval Research Laboratory's Vanguard Program.[25]

We were asked to comment on von Braun's Redstone-Loki Orbiter proposal in November 1954. Homer J. Stewart's review, completed the following April, suggested replacing the Loki rockets in the upper-stage clusters with sub-scale Sergeant motors, which we made and used for a variety of tests in the Sergeant missile project. A typical cluster of this type is shown in Figure 18. A more elaborate study of this alternative was completed and released in July 1955.[26]

Up to this point, like the consideration of the long-range rocket projectile a decade before, the satellite proposal had been dominated by the rocket-propulsion function, by mechanical-engineering considerations, and was essentially devoid of instrumentation

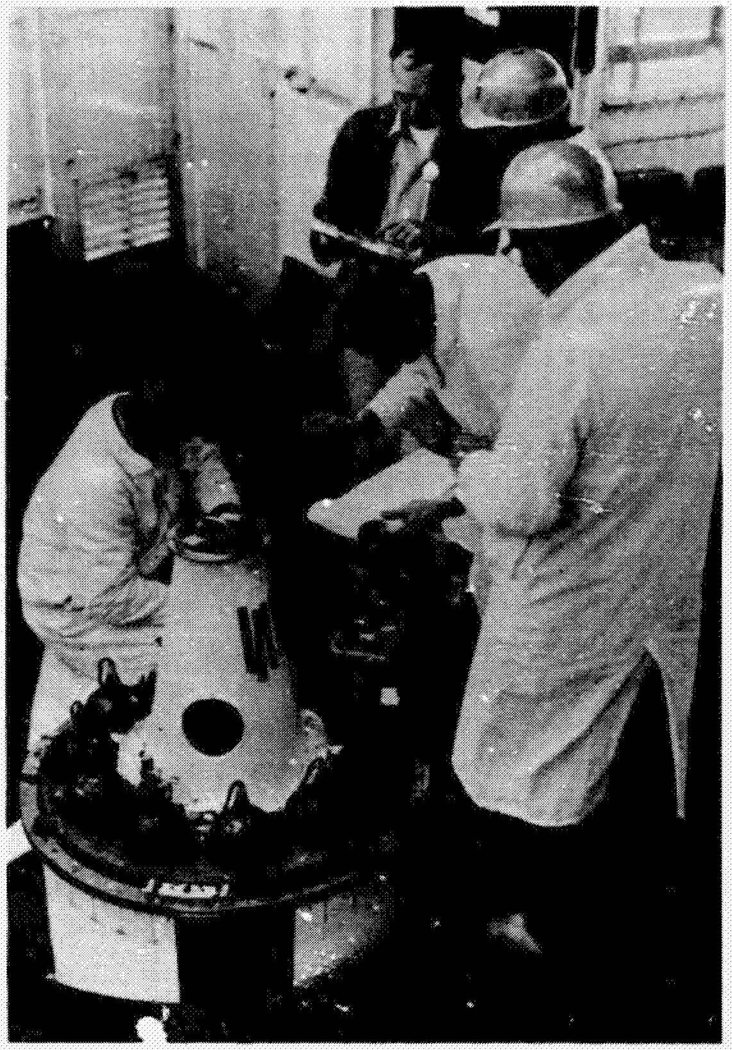

Fig. 18
Cluster of 6/31 Scale Sergeant Rockets Used as Upper Stages in
Re-entry Test Vehicle and Explorer Satellite Launching Vehicle

planning. Indeed, the original scientific plan had called for optical tracking of an inert satellite, a technique which offered some useful experiments and remained a supplementary method in the Vanguard project. Further, Orbiter's lack of stress on instrumentation, compared with the Naval Research Laboratory's thorough study of instrumenting the Vanguard satellite, was very influential in the ultimate decision in favor of the latter project.[27]

Before that decision became final, however, we set to work to redress the balance. Instrumenting the Ordnance-proposed satellite was not impossible, or even technically difficult. Rather, as in the case of radio telemetry for the Private rocket vehicles, or guidance for the early Corporal, it had been a second-order problem, and its consideration had been deferred. But it proved quite feasible to adapt tracking and communication techniques from practice and research in missile guidance to the satellite. The initial study was part of the revised Orbiter proposal offered when the Vanguard decision was reconsidered in August and September 1955; a more extensive report, introducing the name "Microlock," appeared in April 1956.[28]

These satellite studies were able to draw upon our applied research in guidance systems and our guided-missile development work in distinct and valuable ways. First, the technical basis of the Microlock system lay in information-theory and radio-frequency research originally related to jamming and radio-noise problems in missile guidance. Such research related equally to the need for tracking and communicating with a small, low-power space probe. Second, the vibration and acceleration environments expected for satellite equipment were comparable to those observed in missile testing, especially in the Loki missile development. Third, many of the problems to be considered in the satellite study were interdisciplinary and intersystem in the same way that problems of guided-missile development cross these boundaries. It should be noted that Microlock was a one-way tracking and communications system, having, unlike missile guidance, no up-link to send commands to the flight vehicle. The system design is given in Figure 19, and the portable ground site, with interferometric antenna array for satellite use, appears in Figure 20.

The original Microlock study and development had been oriented entirely toward the Army Ordnance proposal for an earth satellite. However, notwithstanding the improvements and continued arguments by Army representatives on its merits, the proposal was still not accepted by the U.S. Government, and Project Vanguard continued as our IGY satellite effort.

My interest and activity in upper-atmosphere research and instrumentation had led to my serving on Joseph Kaplan's "Long Playing Rocket" subcommittee of the Rocketry Panel in the National Academy's IGY committee; John Townsend, Milton Rosen and I had reported on the usefulness of a satellite in the IGY program without advocating any specific project. When the Technical Panel for the Earth Satellite Program was organized by the United States IGY committee in October 1955, I was a member, and proceeded to chair the Panel's Working Group on tracking and computation throughout the term of the IGY. Thus, though involved in JPL's support of a competing technical proposal, I was engaged in organizing operational support for the Vanguard mission. It was part of our task to encourage and coordinate various efforts, including international activities, in connection with observation and tracking stations for Vanguard.

The Microlock satellite communications, though now without a satellite mission, had further potential. The Jupiter missile project had to solve the problem of

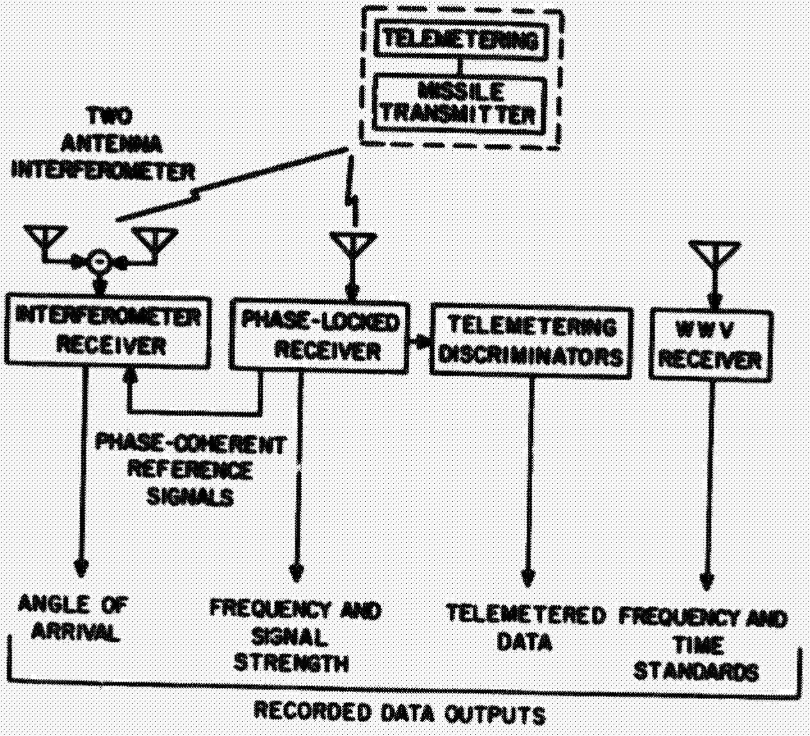

Fig. 19
Microlock System

Fig. 20
Microlock Receiving Antennas

atmospheric re-entry at high velocity, and a heat dissipating nose cone of the ablation type was designed for this purpose. This design had to be tested under flight conditions—that is, actual reentry in a long-range ballistic trajectory—as soon as possible. The test cone would have to be instrumented so that its performance could be telemetered and its flight could be tracked for recovery of the probe. The April 1956 Microlock study report referred to this alternative possibility for the communications system. In fact, the test-vehicle program was already underway.

When Project Orbiter was terminated in late 1955, it was a fairly mature satellite system design based partly upon the use and adaptation of existing materials from missile projects. The long-range test mission required by Jupiter appeared to be very similar to the satellite launch, differing mainly in the lesser energy demand, and of course in the payload. The transformation of the Orbiter launch vehicle and telemetry into a Re-Entry Test Vehicle (RTV) would save time and money for the latter and provide at least a partial test demonstration of the former. It was a natural evolution.

First authorization of the RTV came in September 1955, after the Orbiter satellite proposal had been rejected. Flight design, laboratory and ground tests, and assembly of the system proceeded on schedule, and one year later the proof-test model was launched. The improved sub-scale Sergeant spinning clustered solid-rocket upper stages, and Microlock tracking and telemetry performed well, but only an inert payload was flown over the 3000-mile trajectory. The second test, the following May, carried a 1/10 scale Jupiter nose cone, but a guidance malfunction precluded its recovery. On the third test in August 1957, all systems performed excellently and the nose cone was recovered, validating its design for Jupiter and concluding the RTV program with several sets of flight hardware left over.

The successful orbiting of Sputnik 1 two months later created unprecedented excitement worldwide, and corresponding tension within the United States. Nowhere, I think, were feelings so strong as in the beleaguered Vanguard project, where the normal ups and downs of rocket and instrument development were now transformed by the press and public into gains and losses (mostly the latter) in a global competition. Among the former proponents of Project Orbiter, in Washington, Huntsville, and Pasadena, feelings of frustration also ran high in view of the recent RTV demonstration, and on occasion tempers wore thin. It was an enormous relief when the Army was authorized to proceed with its oft-proposed satellite development as a backup for Vanguard; I served as coordinator for this project with the Technical Panel for the Earth Satellite Program.

At the conclusion of the re-entry test program, General Medaris and Wernher von Braun had placed all the improved Redstone hardware in carefully controlled storage just in case they should be needed. Jack Froehlich, the JPL project manager, had reassigned all the one-fifth-scale Sergeant motors from the project to long-term life test, a device which had the same result. Enough Microlock ground sets had been constructed for extensive field testing as well as installation at the Cape for RTV tracking. But one critical element—the satellite itself—had to be created from scratch. Jack Froehlich, Homer Stewart, and I felt strongly that this task was logically the responsibility of the Laboratory, as it was so intimately involved with our communications system, our spectrum of skills, and our prior work in the Orbiter studies. The von Braun team, as a part of their strong motivation which had carried this cause unflaggingly for three years, and in view of their undeniable skill, felt that they should be responsible for the whole effort. The point was settled in favor of the Laboratory's participation, in a vigorous meeting before General Medaris,[29] and I think none of the team has since had cause to regret this resolution.

As coordinator for the Technical Panel for the Earth Satellite Program, I proposed that the Army satellite carry James Van Allen's cosmic-ray instrument (also flown in Vanguard), which I knew we could readily accommodate, and Maurice Dubin's micrometeorite sensors; four temperature measurements from inside and outside the payload package completed the list of telemetry sources. We expected the micrometeorite information and the temperature data to be of duel value, helping the immediate future design of satellite equipment as well as adding to scientific knowledge. The Van Allen experiment had been considered one of the high-priority IGY upper-atmosphere or space investigations, a judgement happily confirmed by its bountiful results in several missions.

We decided to fly two battery-powered radio transmitters, each carrying four standard channels of telemetry, dividing up the temperature sensor outputs and those of the two micrometeorite detectors, and carrying Van Allen's Geiger-tube measurements redundantly (Figure 21). Because of limited battery capacity, one transmitter operated at high power—fifty milliwatts—for a short time, and the other at only ten milliwatts for an expected two months. The high-power signal, which was amplitude-modulated, was intended to be recoverable by Project Vanguard's Minitrack ground stations and the like, but only our few Microlock sites were expected to be able to track the long-life, low-power signal.

When we were given the go-ahead, we had promised to be ready in 90 days, or by early February 1958; but scheduling at the Cape Canaveral test range allowed us only a few days at the end of January. This was indeed a hectic and busy time: not only had we to prepare the satellite, but the Sergeant missile and Jupiter radio-guidance programs were also coming to a head.

High winds forced postponement of the scheduled launch on January 29, 1958, and again the next day. But conditions improved on January 31 and the countdown carried to zero. I monitored the events from Washington, D.C., in the company with Wernher von Braun, James Van Allen, and many friends and colleagues of the IGY committee and the Department of Defense. Liftoff came at 10:48 p.m. EST (Figure 22). About five minutes later, Wernher turned to me and said, "It's yours now"—the first stage had been separated and the high-speed cluster ignited. From this point, of course, active guidance and Redstone telemetry

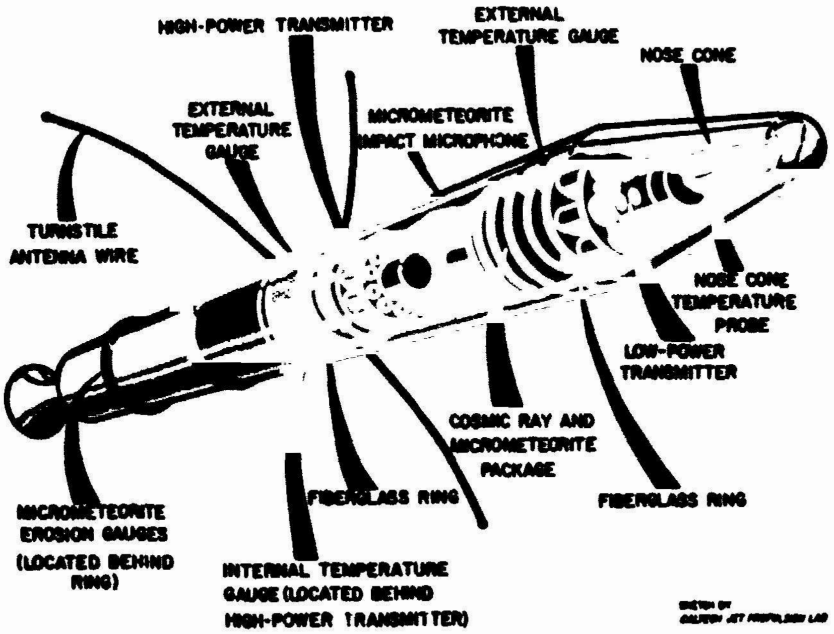

Fig. 21
Explorer 1 Satellite Instrumentation

were out out of the system, there was no command link any more, and after the antenna at Antigua Island lost the signal we would not hear from the space probe again until it passed over California, an hour and three-quarters afterward, if indeed it was in orbit. Several of us tried rough calculations of the flight path, unaware, as it turned out, that the still-strong jet stream above the Cape had boosted the bird to a high velocity and apogee, and hence a longer period. Finally, eight minutes late by our reckoning, the San Gabriel Valley Radio Club near Pasadena, and the Earthquake Valley Microlock site near San Diego, California, picked up the signal and called us. We were in orbit.

A few hours later at a press conference in the main hall of the National Academy of Sciences, I joined Wernher von Braun and James Van Allen, answering questions about the United States satellite. It was a turning point for each of us and the organizations we represented, perhaps most of all for the Laboratory and myself. The event was also symbolic of the mixing process between engineering and science, between the world and the research laboratory, which I have sought to trace through the dozen postwar years of growth of the Jet Propulsion Laboratory. Now the process had gone a step further, as I am sure Theodore von Kármán had expected, both through the Russian efforts and our own: it had mixed rocket technology with the universe, and reduced astronautics to practice at last.

Fig. 22
Explorer 1 Launch

REFERENCES

1. Memorandum on the Possibilities of Long-Range Rocket Projectiles, by Th. von Kármán, and a Review and Preliminary Analysis of Long-Range Rocket Projectiles, by H.S. Tsien and F.J. Malina, Memo 1, Jet Propulsion Laboratory, California Institute of Technology, November 20, 1943 (Unpublished).

2. Frank Malina, Chief Engineer of GALCIT No. 1 and Acting Director of JPL, has well described this activity in "Origins and First Decade of the Jet Propulsion Laboratory," in The History of Rocket Technology, ed. by E.M. Emme, Wayne State University Press, 1964, and a series of memoir papers given at IAA History Symposia.

3. Hugh Dryden's éloge of Kármán in the NAS Biographical Memoirs Vol. 38, 1965, and those of Frank Malina in Technology and Culture, No. 2, Spring 1964, and Frank Wattendorf and Malina in Astronautica Acta X, Fasc. 2, 1964, give essential and close views of his character; his autobiography, The Wind and Beyond, written with Lee Edson, Little, Brown and Co., 1967, gives his own outlook.

4. Frank Malina, "America's First Long Range Missile and Space Exploration Program: the ORDCIT Project of the Jet Propulsion Laboratory, 1943-1946 A Memoir," in this volume.

5. ORDCIT Memorandum No. 2, Research Program for the Second Type of Long-Range Jet Propelled Missile, Jet Propulsion Laboratory, California Institute of Technology, August 20, 1944 (unpublished). This study was directed by H.S. Tsien, who presented it orally to the staff on August 17.

6. Specifically, "The Contractor shall undertake research, developmental, experimental and engineering work and investigation on long-range rocket missiles...," Contract No. W-04-200-ORD-455, Definitive Contract (Supplement No. 9), January 16, 1945. An official account of the effort notes that the Corporal control system "... was not selected primarily to meet service requirements in the field or for its accuracy in finding the target, but rather for its usefulness as a means of studying control problems in such a missile." (Capt. R.C. Miles, The History of the ORDCIT Project Up To 30 June 1946, Ordnance R&D Service Suboffice (Rocket), California Institute of Technology, Pasadena, California (unpublished).

7. The issue was raised in mid-1947 in connection with modifying the contract for the rocket-engine project. It had been suggested that the sponsor have the right to assign specific problems for immediate solution on a priority basis. Arguing that this conceivably could saddle JPL with a problem outside its field, Dunn obtained a "mutual consent" clause which appeared in Supplemental Agreement No. 24 to that Contract (W 535-ac-20262) on March 15, 1948.

8. W.H. Pickering, Control and Telemetering for "Corporal [illegible]," Progress Report No. 4-15, Jet Propulsion Laboratory, California Institute of Technology, [illegible] 1945 (unpublished).

9. Development and Flight Performance of A High-Altitude Sounding Rockets, the WAC Corporal, by F.J. Malina, Report No. 4-18, Jet Propulsion Laboratory, California Institute of Technology, January 24, 1946 (unpublished). Design, Development, and Field Tests of the WAC B Sounding Rocket, by P.J. Meeks, F.G. Denison Jr., and R.F. Rose, Report No. 4-41, Jet Propulsion Laboratory, California Institute of Technology, December 15, 1947 (unpublished). WAC, by the way, symbolized "without attitude control."

10. JPL Report No. 20-100, The Corporal: A Surface-to-Surface Guided Ballistic Missile, Jet Propulsion Laboratory, California Institute of Technology, March 17, 1958, and J.W. Bragg, Development of the Corporal: The Embryo of the Army Missile Program, Historical Monograph No. 4, Army Ballistic Missile Agency, Redstone Arsenal, April 1961, both describe the antecedents and progress of this research vehicle and missile system.

11. J.R. David, Progress of the RAFT Project up to January 1, 1946, Progress Report No. 4-27, Jet Propulsion Laboratory, California Institute of Technology, July 15, 1946.

12. The context of development of this solid-propellant material and design is given in P.T. Carroll, Historical Origins of the Sergeant Missile Powerplant, JPL/HR-3, Jet Propulsion Laboratory, California Institute of Technology, August 1972 (unpublished).

13. Allen Puckett's Performance of the 12-inch Wind Tunnel, JPL Memorandum No. 4-52, June 1, 1949, gives a description and prospectus of the first JPL wind tunnel at its completion; Wind-Tunnel Testing at the Jet Propulsion Laboratory (no author), JPL Report No. 20-83, January 1, 1957, describes the entire facility, including the then-building 21-in hypersonic tunnel, as of a later, high-usage period.

14. W.H. Pickering and J.A. Young, External Instrumentation for NAMTC, JPL Progress Reports NA 10-1 through 10-9, 1946-47, and W.H. Pickering and P.H. Reedy, JPL Progress Reports No. 18-1 through 18-8, 1949-50.

15. Contract No. DA-04-495-Ord 18, Letter Order October 5, 1950, Definitive Contract January 2, 1951, described at JPL as the JPL-20 Contract.

16. See JPL Report 20-100, The Corporal, and J.W. Bragg, Development of the Corporal, cited above (Note 10), describe the Corporal's evolution in detail.

17. William H. Pickering and Robert J. Parks, Guidance and Control System, United States Patent No. 3,179,355, granted April 20, 1965.

18. James D. Burke, Robert J. Parks, and Robert M. Stewart, Range Control for a Ballistic Missile, United States Patent No. 3,188,958, granted June 15, 1965.

19. J.C. Porter, Jr., Loki Ballistic-Test Program, JPL Progress Report No. 20-295, Jet Propulsion Laboratory, California Institute of Technology, March 30, 1956.

20. F.J. Malina, "America's First Long Range Missile and Space Exploration Project," see Note 4.

21. R. Cargill Hall, "Earth Satellites, A First Look by the United States Navy," in this volume.

22. H.J. Stewart, A Summary of Performance Studies for a High Altitude Orbiting Missile, JPL Report No. 8-5, Jet Propulsion Laboratory, California Institute of Technology, July 10, 1946 (unpublished).

23. JPL Publication No. 3, Abstracts of Papers Presented at the Guided Missiles and Upper Atmosphere Symposium (held March 13-16, 1946), Jet Propulsion Laboratory, California Institute of Technology (unpublished).

24. W.H. Pickering, Study of the Upper Atmosphere by Means of Rockets, JPL Publication No. 15, Jet Propulsion Laboratory, California Institute of Technology, June 20, 1947 (unpublished).

25. Constance McLaughlin Green and Milton Lomask, Vanguard: A History, Smithsonian Press, 1971; Chapters 1-3, discuss this complex evolution and competition of proposals and projects.

26. JPL Publication No. 47, A Feasibility Study of the High Velocity Stages of a Minimum Orbiting Missile, Jet Propulsion Laboratory, California Institute of Technology, July 15, 1955 (unpublished). This development is summarized in W.H. Pickering, "History of the Cluster System," in From Peenemünde to Outer Space, NASA Marshall Space Flight Center, March 23, 1962.

27. Green and Lomask, Vanguard (see Note 25) cite Clifford C. Furnas of the Defense Department's review committee to the effect that somehow combining Orbiter's launch vehicle and Vanguard's satellite was briefly considered.

28. H.L. Richter, Jr., W.F. Sampson, and R. Stevens, "Microlock: A Minimum Weight Instrumentation System for a Satellite," Jet Propulsion 28: 532-540 (August 1958), reprints the content of the study, which was JPL Publication No. 63.

29. Alluded to in J.B. Medaris, Countdown for Decision, G.P. Putnam's Sons, 1960, Chapter XIV.