THE JET PROPULSION LABORATORY AND THE BEGINNING OF AMERICAN EXPLORATION OF SPACE

C. R. KOPPES
Department of History, Oberlin College, Oberlin, Ohio 44074, USA.

The Jet Propulsion Laboratory (JPL) in Pasadena, California, has played a leading role in space exploration. JPL's series of scientific space ventures – Mariner, Viking and Voyager – have helped to revolutionise our understanding of the cosmos. The Laboratory's embattled but ultimately successful Rangers and Surveyors in the 1960's began the exploration of the Moon and provided indispensable support for the Apollo manned landings. The forerunners of these undertakings could be found in the Laboratory's role in the Explorers and Pioneers of the late 1950's – the first successful United States space flights. Despite the extensive writing on Explorer I, however, JPL's role has remained obscure. The purpose of this article is to examine the Laboratory's part in the beginnings of American space exploration from 1954 to 1960.

EARTH-ORBITING SATELLITES, WHOSE principles had been known since Isaac Newton, had approached technical feasibility with the development of rocketry during World War II. The first requirement for orbiting a satellite was attaining the proper speed. Intercontinental missiles attained speeds of about 6.4 km/s (4 mi/s) and went out into space about 1280 km (800 mi) before falling back to Earth. Satellites required a speed of 8 km/s (5 mi/s). Some scientists at the RAND Corporation and the Navy had proposed building satellites in the late 1940's. By 1954, as the United States initiated a crash programme to develop intercontinental ballistic missiles and the scientific and military uses of satellites became apparent, satellite proposals neared the hardware stage [1].

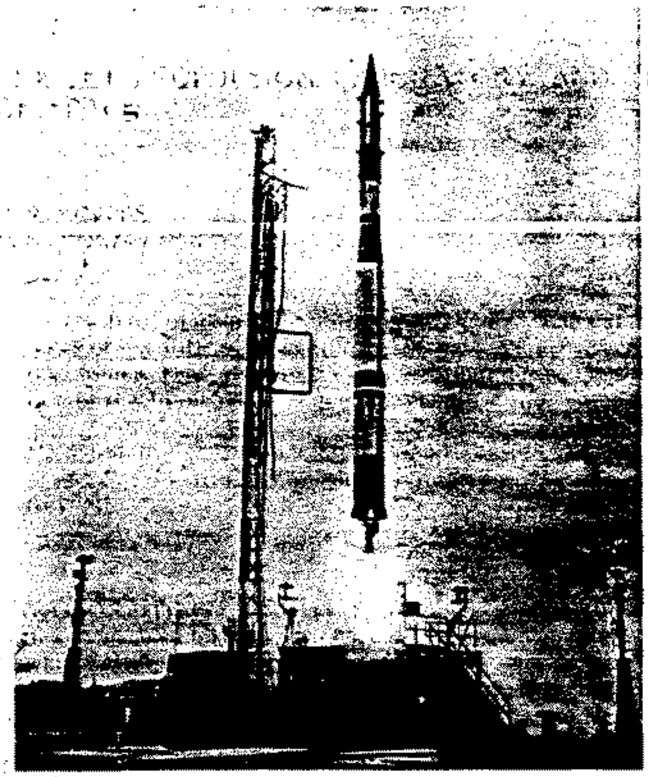
Although JPL was to play a major role in early space ventures, it had concentrated on basic research and hardware development in the missile field during the 1940's and early 1950's. This emphasis reflected the major source of the Laboratory's funding, the U.S. Army Ordnance Corps. Nominally managed by the California Institute of Technology (CIT), JPL operated out of its own facilities several miles from the campus and had little connection with its parent. The Laboratory had gotten its start in 1936 under the aegis of the great aerodynamicist Dr. Theodore von Kármán when several graduate students and rocket enthusiasts, headed by Dr. Frank J. Malina, began xeperimenting with rockets. The project laid the foundation for American rocketry during World War II with its successful development of solid-propellant rocket motors and its building of the first sounding rocket, the WAC Corporal (a liquid-propellant rocket vehicle with a solid-propellant booster stage) in 1945. After several years of basic research in the context of weapons systems, JPL began development of the Corporal tactical nuclear missile in 1950. A hastily modified test vehicle, Corporal was supplanted by the solid-propellant, much more sophisticated Sergeant weapon system, which the Laboratory began to develop in 1954 [2].

Yet space exploration had never been far from the minds of some of the Laboratory's scientists and engineers. Frank Malina and JPL engineer Dr. Martin Summerfield had calculated in 1945 that it was possible to build a rocket that would "escape Earth's atmosphere." In 1949, the Bumper WAC, a WAC Corporal mounted on a V-2, became the first man-made object to reach extraterrestrial space by ascending 400 km (250 mi); it had also proved the feasibility of multistaged rockets. Passing the time between test flights at White Sands, New Mexico, in 1950, some JPL engineers scribbled back-of-the-envelope calculations that showed it was possible to cluster some Loki rockets on a Corporal missile and land an empty beer tin on the Moon. More seriously and certainly more formally, JPL Director Dr. William Pickering was active throughout the 1940's and 50's on the Upper Atmosphere Research Panel, which sponsored research using high-altitude sounding rockets [3].

Scientists won approval for a satellite as a United States contribution to the International Geophysical Year scheduled for 1957-58. JPL became involved in the venture when the Army Ballistic Missile Agency (ABMA) and the Office of Naval Research (ONR) sent their proposals for the joint effort, Project Orbiter, to Pasadena for review in late 1954. Orbiter's first stage would be an uprated Redstone missile. The remaining stages would consist of Lokis, the small solid-propellant antiaircraft rockets developed at JPL; the second stage would use 24 Lokis; the third, six; and the fourth, one Loki and the five-pound payload. JPL reviewers recommended against the use of Lokis because the failure of one of the 31 rocket units could prevent the satellite from attaining orbit. Dr. Homer J. Stewart, the CIT aerodynamics professor, who also supervised systems analysis at JPL, recommended instead that Orbiter use a smaller number of the more powerful and more reliable Sergeant rocket motors, scaled down from 31 inches in diameter to six inches in diameter. Revised in accordance with Stewart's ideas, the Orbiter proposal appeared to be headed for smooth sailing in early 1955 [4].

But Stewart, ironically, had to preside over the demise of the ABMA-ONR-JPL proposal. He chaired the Ad Hoc Committee on Special Capabilities, a sub-group of the Department of Defense Guided Missiles Committee, which was formed to referee the competition between the Orbiter and Vanguard, a dark-horse entry from the Naval Research Laboratory (NRL). Orbiter's strength lay in its powerful rocket motors and proven technology, which made possible a launch by August 1955, to make Vanguard the first American satellite programme. When the Soviet Sputnik upstaged Vanguard while Orbiter waited in the wings, the decision became one of the most controversial of the space age [5].

JPL and the other Orbiter backers chafed under the decision and tried repeatedly to get it reversed. The Laboratory contributed several more sophisticated electronics studies, but Orbiter remained moribund. Yet through



Orbiter/Explorer's competitor: Vanguard. In the end Vanguard had to take a back seat because of its spectacular failure in December 1957.

personal and institutional connections in the communications aspects of missilery, JPL remained near the centre of action. Pickering was a member of the Technical Panel for the Earth Satellite Program that was organised by the United States IGY committee in October 1955; and he chaired the working group on tracking and computation. The JPL director was in the anomalous position of promoting a competing technical proposal but organising operational support for Vanguard [8].

JPL and ABMA found an institutional outlet for their Orbiter studies in the Re-entry Test Vehicle, which, by a circuitous course, eventually produced the first American space triumph. ABMA, led by Wernher von Braun and Brigadier General John B. Medaris, was developing the Jupiter, a medium-range ballistic missile that was engaged in a competition with the Air Force's Thor. To counteract the great heat the Jupiter encountered as it reentered the atmosphere at high velocity, ABMA planned to use an ablation-type nosecone in which the various layers burned away during reentry. JPL's Orbiter electronics proposals therefore proved readily adaptable to the Jupiter's programme's nosecone testing. The Laboratory's telemetry could send data back to ground control on the heating effects of the missile during flight and its tracking mechanism made it possible to recover the nosecone at the end of the flight [7].

The main JPL contribution was Microlock, a phase-locked loop tracking system. The innovation in Microlock was its ability to lock to a very low-level signal; under ideal conditions it could lock on a signal as low as a milliwatt nearly 9600 km (6000 mi) away. The origins of Microlock could be traced to some of the early guidance and information theory research for the Corporal. Researching the high-frequency properties of transistors, JPL engineers discovered they operated well but could put out only 50 mW Such low power at first seemed to be useless but calculations followed by experiments demonstrated that, if an appropriate phase-locked receiver were used, the signal might be received from as far as 1600 km (1000 mi) in free space transmission. As adapted for the RTV, Microlock would also extract information from five minimum-weight telemetry channels. Microlock was an interesting example of how advances in technology sometimes lead to a string of conceptual innovations [8].

The RTV also incorporated JPL's skills with solid-propellant motors in the delicate positioning of the upper stages. The 11 motors of the second stage were mounted in an annular ring inside a tub, the 3 motors of the third stage were inside the second stage, and the fourth stage motor and payload sat in the centre of the two outer rings. When each stage fired, it broke shear pins that attached it to the lower stage and let that stage fall back to Earth. For greater accuracy, the upper stages were enclosed in a spinning tub that was powered by two battery-driven electric motors. The tub began spinning at 550 rpm before takeoff; about 70 seconds into the flight the rate gradually increased to about 750 rpm. This procedure eliminated "resonance between the spin frequency and the natural bending frequencies of the missile," which increased as the first stage propellants were consumed. The spinning tub imposed severe vibration and centrifugal force on the second stage. Extensive ground testing under simulated flight conditions showed that the motors performed well but small changes in the nozzle design were necessary. Throughout the design of the upper stages highly accurate positioning and balance were necessary to curb vibration and deflection [9].

The arrangement seemed somewhat 'Rube Goldbergish," in the words of Eisenhower's science advisor, Dr. George Kistiakowsky, of Harvard University; but it worked. The first was fired on 20 September 1956, from Cape Canaveral, Florida. Some Pentagon officials watched nervously because they feared the RTV was a ruse for a clandestine satellite launching. The first Jupiter C* set records for American missiles to that point: an altitude of 1091 km (682 mi) and a distance 5360 km (3350 mi). All the test objectives were met. The motor demonstrated the desired power, the aerodynamic design worked satisfactorily, and the Microlock system performed very close to theory. Since the Army was interdicted from attempting a satellite, the fourth stage was loaded with sandbags. Had the Jupiter contained a small Sergeant motor for just a little extra kick, JPL and ABMA would have put a satellite in orbit – a year before the Soviet Union [10].

In the second test, 15 May 1957, the missile took an erratic course because of a guidance malfunction shortly before the fuel cutoff. The nosecone was tracked to its point of impact but was not recovered. (The missile-men suspected sharks beat them to the cone since on some subsequent tests jaws had ripped open the balloons that kept the nosecones afloat). The third firing, on 8 August 1957, was a success. All major systems worked satisfactorily and

* The Jupiter and Jupiter C nomenclature is confusing, because of bureaucratic sleight-of-hand stemming from interservice missile rivalries of the time. The salient point is that the RTV, Orbiter, and Explorer all used the Redstone missile as a first stage. In these series the Redstone was designated Jupiter *C* by Medaris because they were therefore accorded a higher priority at the Cape. The Jupiter, an intermediate range ballistic missile, with solid propellant upper stage rockets, was used to launch the Pioneer space probes of 1958-59. The vehicle was called Juno 2. The common denominator in these series was that JPL's spinning cluster of solid propellant rocket stages was mounted on both the Redstone (or Jupiter C) and with a single rocket motor attached to the satellite, the Juno 1, and Jupiter missiles.

the nosecone was recovered at a range of 1856 km (1160 mi). The ablation-type nosecone proved superior to other techniques and was subsequently adopted in two other American intercontinental ballistic missiles. The design of the Jupiter had been validated and the tests ended with several sets of flight hardware in various stages of fabrication remaining. Indeed, the successful culmination of the programme appeared to thwart the efforts of ABMA and JPL personnel, particularly Stewart, who wanted to keep the series going as a backup to a Vanguard, which was expected to fail. With the firings terminated, ABMA and JPL did the next best thing. Medaris and von Braun put the surplus hardware in controlled storage, from which it could be made flight-ready in less than four months for "more spectacular purposes." JPL Jupiter C Project Manager Jack Froehlich assigned the remaining Sergeant motors to longterm life test, which had the same effect [11].

As the series concluded in the summer of 1957, JPL found itself in a period of self-analysis and frustration. The Sergeant missile programme was moving along well but more weapons projects were unattractive to JPL. Fearing that JPL might become just a 'job shop' for the Army, Pickering and CIT President Lee DuBridge had agreed in 1954 that the Sergeant would be the Laboratory's last major weapons development. The radio-inertial guidance programme the Laboratory had undertaken on Jupiter ranked as a backup to a backup in an interim development. Satellites seemed the best new direction for JPL. As Pickering noted in mid-1957, "the whole trend of rocketry is in this area." That seemed to mean working through the Army but the Air Force's near-monopoly on military satellite planning seemed to leave the Army with only the marginal activity of reconnaissance satellites limited to tactical uses. Indicative of the uncertainty at the Laboratory, as late as the summer of 1957, it seemed that primary attention over the next three years should be given to extending the Jupiter C flights. Then, on Friday night, 4 October 1957, JPL and the world discovered that Earth had a new satellite and that its name was Sputnik [12].

Pickering had gone to Washington five days earlier for a week of IGY meetings. On Monday, he had heard a Russian scientist announce that the USSR would launch a satellite "in the near future," as the translator rendered the phrase; but an American scientist who knew Russian leaned over to Pickering and whispered, "That's not what he said – he said 'imminent.'" Even so, the JPL director was not prepared for what he heard at a party at the Soviet embassy the night of 4 October. Walter Sullivan, the *New York Times* science writer, bustled into the room and asked him what he knew about the satellite the Russians said they had just launched. It was the first that Pickering – and probably anyone else in the room, including the Russians – knew about Sputnik's success. Pickering hurriedly conferred with several persons, including Dr. Lloyd Berkner, who hushed the room and proposed a toast. Amid successive torrents of celebratory vodka, Pickering and his IGY colleagues slipped out to the IGY offices a few blocks away. There they pieced together what information they could to see whether Sputnik was in orbit, calculated when it would pass over New York, relayed the information to the press, and went to sleep – only to be awakened after an hour when their calculations proved mistaken, and they had to recalculate the time of passage and call the press again. It was a long night that left indelible impressions. JPL personnel could remember years later where they were when they heard the news, what they first thought, and what they did, much as other people could recall how they felt when they heard of the deaths of presidents or of the bombing of Pearl Harbor [13].

The night of Sputnik 1, von Braun and Medaris were chatting with the new Secretary of Defense Neil McElroy, who by coincidence was visiting Huntsville. "Vanguard will never make it," cried von Braun. "We have the hardware on the shelf. For God's sake turn us loose and let us do something. We can put up a satellite in 60 days, Mr. McElroy! Just give us a green light and 60 days." As von Braun kept repeating "60 days," Medaris cautioned; "No, Werhner, 90 days." McElroy returned to Washington noncommital [14].


Explorer before being mated with the final stage motor.

The Eisenhower administration took the news of Sputnik in its stride. At his first meeting to consider a response to the Russian satellite, on 9 October, the President asked Quarles if it was correct that the United States could have orbited a satellite more than a year earlier by using a Redstone. Quarles said yes. But Vanguard had two advantages, he continued. It stressed the "peaceful character of the effort," and it avoided "the inclusion of material, to which foreign scientists might be given access, which is used in our own military rockets." The Army still felt it could launch a satellite within four months, a month earlier than Vanguard. Eisenhower demurred. The need for military classification of the rocket still impressed him. The satellite had been tied to the IGY and had never been a crash programme, he recalled. "To make a sudden shift in our approach now would... belie the attitude we have had all along," he pointed out [15].

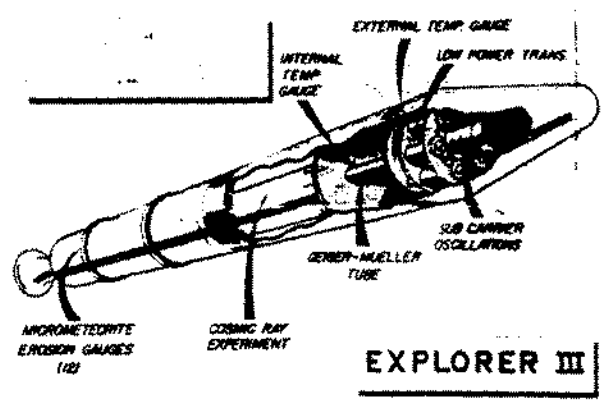
The administration soon agreed to advance Vanguard's first launch date; and on 31 October, the President cautiously accepted McElroy's suggestion to use the Army backup to Vanguard. Eisenhower also strengthened his science advisory system by appointing his first advisor on science and technology, James R. Killian, Jr., president of the Massachusetts Institute of Technology. On 8 November, Eisenhower delivered a nationally televised address designed to reassure citizens that their security was not endangered and that the presumed humiliation of Sputnik was only temporary. Among his props was the recovered nosecone from the ABMA-JPL Jupiter C [16].

Public opinion showed a mixture of alarm and concern, apathy and calm. But in Congress, the military, and the scientific and technical communities, a storm of recrimination was breaking. "We do not have as much time as we did after Pearl Harbor," said Senator Lyndon B. Johnson. The hysteria over Sputnik represented varying proportions of wounded pride, a domestic political weapon, a genuine international challenge and an opportunity for promoting institutions' projects of self-interest. Brigadier General Homer Boushey, U.S. Air Force, who had piloted the plane bearing the first JPL JATO's in 1940, deputy director of Air Force research and development, warned: "Who controls the Moon controls the Earth." Pickering remarked sourly: "It is pretty obvious that very few people in this country had any appreciation of the political significance of the Russian satellite," and that included the politicians "in a position to make decisions." It was an "obvious fact" that the Russians were "well ahead" in weapons technology he continued. To "recover national prestige" the United States did not need dramatic scientific breakthroughs but "good management and good engineering on programmes which already exist." Not coincidentally, this meant using the capabilities of ABMA and JPL on Jupiter, and perhaps on a more daring attempt to leapfrog the Russians [17].

The Laboratory staff hastily drew up Project Red Socks, a plan to launch nine rockets to the Moon in great haste. The Laboratory used the full cachet of its parent in the proposal, dated 25 October, 1957: "The California Institute of Technology believes that it is essential for the United States to initiate an immediate programme for the scientific exploration of the Moon." Sputnik implied the Russians could send flights to the Moon, the proposal stated, "National interest appears to require the United States to demonstrate as soon as possible that US science likewise has this capability." The first rocket, which would use the RTV hardware, would be scheduled for June 1958, and send 6.7 kg (15 lb) around the Moon. The remaining eight flights would consist of scaled-up RTV equipment and send 54 kg (120 lb) payloads to the Moon from January 1959 to the end of 1960. The first flight would carry instruments to measure temperature, pressure and light intensity. The remaining flights would expand on these experiments, and the last several vehicles might incorporate more sophisticated guidance to refine the orbit around the Moon. In the quest for spectacular science, JPL officials flirted with even bolder ideas. Pickering and other scientists toyed with the idea of exploding an atomic bomb on the lunar surface, which would "shower the Earth with samples of surface dust in addition to producing beneficial psychological results" [18].

These schemes seemed audacious, even bizarre, for a space programme that had yet to get off the ground. Pickering and DuBridge peddled the Red Socks proposal through the corridors of the Pentagon. Lieutenant General James Gavin, head of Army research and development, liked it immensely and told JPL he would consider its approval the crowning achievement of his career. Donald Quarles, assistant secretary of defense for research and development, seemed interested; but he wanted to involve the Air Force. Back in the corridor, Pickering turned to DuBridge and said, "Well, that kills that." Red Socks never got into the race [19].

Through October and November, however, the pressure built for Juno I, the modified Redstone. A few days after Sputnik 1, the audacious Medaris told the crews at ABMA to take the rocket out of storage and begin readying it for launch. Medaris lacked higher authority for this action; in fact, he issued his instructions at the same time the President reaffirmed his attention to stick with the nonmilitary approach. Medaris figured the amount of money was relatively small and that he could bury it somewhere, if necessary. He was assuming, too, that Vanguard would falter. The Soviet Union bolstered his plans when, on 3 November, it orbited Sputnik 2 with a dramatic payload: 495 kg (1100 lb) in weight and a live dog, Laika. On 8 November, the DoD at last gave the Army and JPL authorisation to prepare their satellite. Explorer, as Orbiter was known, remained a backup; but it was the moment the two agencies had sought since 1954. Then on the night of



General layout of the early Explorer satellites.

20 November, Vanguard was readied for take-off, was fired, exploded, and sat burning on its launch pad in the flat glare of international publicity. Orbiter's moment had arrived [20].

When von Braun blurted to McElroy that the hardware was on the shelf, he was correct except for one detail: the satellite itself had yet to be built. Von Braun confidently assumed his team would get that plum, but Pickering was determined that it should go to JPL. The Laboratory had earned the job because of its work on Orbiter and Jupiter C, and the payload logically fitted in with JPL's communications work, particularly Microlock. Just prior to the meeting at which the roles would be assigned, Pickering asked Medaris for a few minutes alone. He argued that JPL should build the satellite; Medaris agreed. The General probably felt the Laboratory could handle the electronics work better than Redstone Arsenal and he wanted to keep JPL actively in the Army's orbit. Von Braun's jaw dropped when Medaris and Pickering walked into the meeting and informed them of the decision, but the collaboration proved fruitful; and there was more than enough work for both teams [21].

The quarter of an hour Pickering spent with Medaris was momentous. If Redstone Arsenal had built the Explorer I satellite, it would have had both the missile and the satellite. JPL would have been relegated to a minor supporting role, chiefly in its tracking network, from which it would have been highly unlikely to develop into a major space laboratory. Electronics, which had begun pushing propulsion aside as JPL's dominant activity during the Corporal weaponisation, opened a window to space for the Laboratory.

Laboratory personnel worked intensively on what was code-named at JPL "Project Deal." Project Manager Froehlich, a formidable poker player, had bestowed the name in the aftermath of the Sputniks with the remark: "When a big pot is won, the winner sits around and cracks bad jokes; and the loser cries, 'Deal!' " The next round was coming up even sooner than the 90 days Medaris had promised, for scheduling conflicts at Cape Canaveral dictated that the vehicle be ready for launching by 29 January 1958, just 80 days after the go-ahead. Although Vanguard had promised a 11 kg (25 lb) instrument payload, JPL more cautiously elected to limit its to 9 kg (20 lb). The payload structure weighed 13.9 kg (30.8 lb), including just 8 kg (18 lb) for the instrument compartment [22].

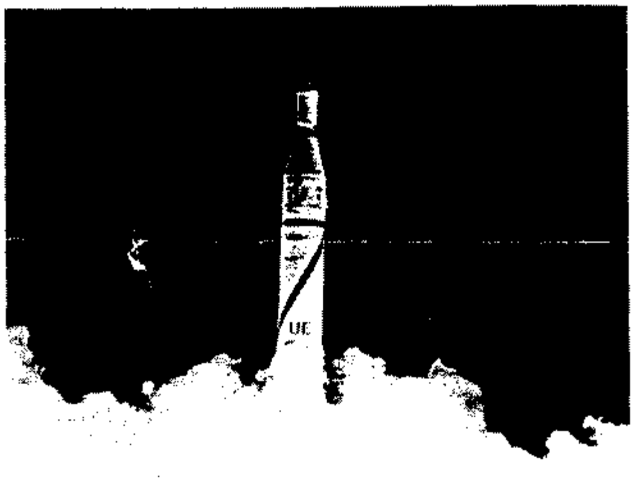
Three relatively simple experiments were chosen to investigate the satellite's environment, about which little was known. The first two, although having some scientific merit, were designed primarily to furnish information for future satellite design. The first experiment tested the extreme temperatures the satellite would encounter as it passed from full sunlight to the complete shadow of the Earth. A thermistor recorded the internal temperature of the high-power transmitter and the satellite's skin temperature. Resistance thermometers performed a second skin measurement as well as one of the nosecones. The second experiment recorded the impact of micrometeorites on the satellite's surface by means of an impact microphone, an amplifier, and a circuit of 11 wire grids. The third experiment was primarily scientific and resulted in the most dramatic findings of the early satellite programmes. This was the cosmic-ray experiment of Dr. James Van Allen, State University of Iowa, and involved placing a Geiger-Mueller counter and associated equipment in the satellite to measure radiation. Originally programmed for Vanguard, the Van Allen experiment was added to Explorer at Pickering's suggestion [23].

JPL's work on Explorer was straightforward, and surprisingly informal. Two considerations – shape and temperature – were among the main constraints in designing the fourth stage. At first, JPL engineers considered but later rejected a spherical shape. A sphere probably could not be made rugged enough to survive launching through the atmosphere without either adding too much weight for strengthening or adding a protective shroud. A cylindrical shape seemed preferable. This shape was consistent with the last stage rocket motor and with the instrumentation to be carried. The final stage measured 203 cm (80 in) long and 15 cm (6 in) in diameter. The easiest and most reliable way to counteract the extremes suggested extensive insulation and a careful ratio of bare steel, which provided a relatively high temperature, and aluminium oxide, which furnished a low temperature [24].

Two typical JPL approaches to design characterised the design and fabrication. First, simple and reliable components were used instead of more complicated designs which might have yielded higher performance but presented more design risks. The booster stages, for instance, used the relatively small scale Sergeant motors. These units had undergone more than 300 static tests, 50 flight tests and 290 ignition-system firings without a failure [25].

Second, the Laboratory used to the maximum the experience its engineers had derived from the minute details of manufacturing. For instance, it was very difficult to determine misalignment of the components because the simple methods of measurement were less accurate than the misalignment itself. JPL engineers thus precalculated the misalignment of all components "with only experience as a guide;" this made possible field assembly of the large rotating second stage with a discrepancy of less than 0.0025 cm (0.001 in). In another case, a structural engineer checked the strength of a motor case by standing on it until it was deformed the maximum amount and observing that it suffered no apparent ill effects; these informal findings were later confirmed by sophisticated spin tests. Such techniques had contributed to JPL's problems in preparing drawings and insuring reproducibility when dealing with contractors in its missile programmes, but for producing a limited-edition prototype under severe time pressure experience proved a trustworthy guide [26].

Third, dual or triple systems were used wherever possible so that a malfunction would not endanger a system or the entire mission. The igniter, for instance, might have to be fired in a vacuum; its failure would abort the mission. Three safeguards were employed: the igniter was designed to fire in a vacuum, the motor was sealed to hold atmospheric pressure, and the igniter was sealed in a container holding atmospheric pressure. The last two considerations made it slightly heavier, but the added weight purchased much greater reliability at low cost. The concept of redundancy came to play a vital role in space missions [27].



The night-time launching of Explorer 1 by Juno I 'UE' (missile 29).

Besides work on the Explorer itself, JPL had to quickly expand the tracking network. Two primary Microlock stations already existed from previous experiments, at Earthquake Valley near San Diego, California and the Air Force Missile Test Center in Florida. JPL designed equipment for new stations which were set up in Nigeria and Singapore in cooperation with the British IGY committee. These stations were to receive telemetry data from the experiments. The orbital calculations would be handled through the Florida and California stations; and since Explorer 1 was launched eastward, 1 hour and 45 minutes would elapse before confirmation of orbit would be possible [28].

By early January, JPL had finished its upper stages and satellite and moved them to Cape Canaveral under extraordinary secrecy. After the Vanguard failure, the Army had clamped maximum security restrictions around Explorer, which was known even in highly classified cables between ABMA and JPL only as "Missile 29." Medaris wanted to make the preparations for launch appear to be just another Redstone missile test. Any JPL personnel who could be obviously related to a satellite launch, particularly Froehlich, moved under elaborate decoy plans. Secrecy during the erection of the missile and mating of the upper stages was particularly important. The upper stages were to be covered with canvas for the hurried predawn movement to the launch pad. Then, the launching structure was brought up so that the top section was not visible away from the launching area. Missile 29 could then be "identified as a Redstone since the part in view will appear the same as a Redstone booster." Medaris warned: "I cannot overemphasize the importance of these decoy plans and the absolute necessity of covering this launching as a normal test of a Redstone missile, and I desire well understood that the individual who violates these instructions will be handled severely" [29].

The preparations moved smoothly and by 29 January, Missile 29 sat ready for countdown. The secrecy had to end somewhere, of course, and by then a crowd of VIP's and newsmen had journeyed to Cape Canaveral, but under an agreement by which no news was released until after the launch. Missile 29 perched on the pad for two days while flight personnel consulted weather forecasts as anxiously as General Eisenhower before D-Day. On the 29th and 30th high winds from the jet stream forced postponement; the engineers feared the missile could not withstand the force. But on the 31st the winds, while still strong, subsided enough to justify the risk. The countdown proceeded

Press conference 31 January 1958 at the National Academy of Science following the launch of Explorer 1 by the Jupiter C. Left to right are Dr. William H. Pickering, Director, Jet Propulsion Lab; Dr. James Van Allen, Head, Physics Department, State University of Iowa; and Dr. Wernher von Braun, Director of Development Operations, Army Ballistic Missile Agency.

Vice-President Richard Nixon visits the Jet Propulsion Laboratory after the successful launching of Explorer 1. Left to right: Clark Millikan, Dr. DuBridge, Dr. Pickering, Jack Froehlich, Val Larsen and Robert Parks.

normally and was only 25 minutes behind schedule. After 428.6 seconds of flight – 9 more than predicted – Explorer 1 reached an altitude of 365 km (228 mi), 16 km (10 mi) higher than forecast. The fourth stage rocket ignited and gave the final stage a kick that should have sent the satellite into orbit. At the Pentagon, where another watch party was going on, von Braun turned to Pickering and said, "It's yours now." JPL took control. "Right, it's our now," said Pickering [30].

But JPL personnel felt helpless. There was no way of knowing for an hour and a half whether the satellite had achieved orbit. There was nothing to do but "sweat it out," as Medaris said, and be poised to pick up Explorer's signal, if it was in orbit. Froehlich, Stewart and other JPL personnel at Cape Canaveral pored over the telemetry from the down-range stations, in order to send their West Coast colleagues a prediction of when the satellite should pass. The velocity seemed adequate for orbit, they knew, but they had no data on the angle of inclination. "The thing could be pointing up too high or pointing down so low from the horizontal that it would have been a disastrous launching," Stewart recalled. As best they could figure, Explorer should pass within about 105 minutes, or certainly by 110 minutes. But Explorer did not show. Seven minutes late; everyone throughout the organisation was "really getting pretty upset." Eight minutes late [31].

Finally an improbable source, the San Gabriel Valley Radio Amateur Club near Pasadena picked up the signal. The Earthquake Valley Microlock Station soon confirmed the orbit. The satellite was late because the jet stream had given it an extra kick of about 30 m/s (100 fps), which sent it into an orbit with a higher apogee, and, hence, longer transit time, than JPL trackers had thought possible. When injected into orbit, the satellite had ample margin for error. Its position was only about 0.8 deg from the horizontal, but a satisfactory orbit would have been possible with a deviation as great as 4 degrees. Explorer 1's apogee was 2541 km (1580 mi) and its perigee 357 km (223 mi). The period was 2528 km (113.2 min). Explorer 1 was in orbit, and JPL was jubilant [32].

When the Microlock received the signal from Explorer, it also turned the international limelight on JPL. No longer an obscure Army laboratory known chiefly to missile cognoscenti, JPL basked happily in the warm glow of favourable publicity. Pickering, Van Allen and von Braun hoisted a model of the Explorer 1 satellite over their heads at a Washington news conference the next day; and a wire-service photograph of the occasion appeared in hundreds of American newspapers. The *New York Times* ran a story on the Laboratory, and *Time* magazine included a profile of Pickering with those of Medaris and von Braun. Most of the attention focused on von Braun and his colleagues; preoccupation with the more dramatic and more easily understood rocket, and with the human-interest story of the former Germans working for America, was perhaps understandable. However, JPL, with pride, began preparing for a major role in space exploration. In triumph, and in defeat, JPL would not return to its former obscurity [33].

JPL and ABMA continued to collaborate on a series of Explorers through to July, 1958. These satellites were designed to exact quickly the maximum use from existing technology, and they focused on the intriguing cosmic-ray data returned from Explorer 1. While basically similar to the first satellite, they introduced some refinements. Explorer 2, launched on 5 March 1958, did not achieve orbit when, because of a structural failure, the fourth stage failed to ignite. Explorer 3 placed the second successful American satellite into orbit on 26 March 1958. Meteorite and temperature measurements were in close agreement with those on Explorer 1. The major innovation was a tape recorder that made it possible to transmit much more cosmic-ray data. Because of the small number of tracking stations, the entire orbit could not be tracked; just as this had caused an anxious two hours on 31 January, it also meant that much of the telemetered data was lost. Explorer

3 contained a miniature tape recorder. Moving at a very slow rate of 0.013 cm/s (0.0005 in/s), the recorder needed less than 1 m (3 ft) of tape to record data from an orbit. When the satellite neared a tracking station, a ground signal switched on the playback head and the high-power transmitter. In less than 5 seconds all data from the orbit were sent, and the tape was erased and reset [34].

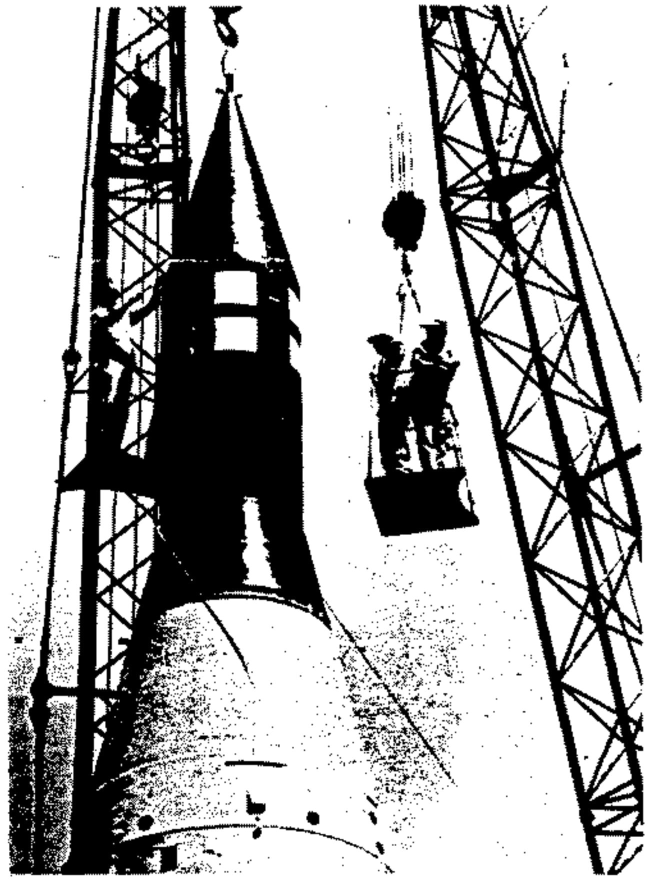
The returns from Explorer 3 continued to astound scientists. Pulse rates at the apogee registered at least a thousand times what had been expected; counts exceeded 35,000 per second at the highest altitudes, over South America, and saturated the Geiger-Mueller counter. The data from Explorers 1 and 3 enabled Van Allen to announce on 1 May 1958, the discovery of "a very great intensity of radiation about altitudes of some 800 km (500 mi) over 34 degrees north and south of the Equator." He theorised that these phenomena, ultimately known as the Van Allen belts, consisted of charged particles trapped in Earth's magnetic field [35].

These extraordinary findings led JPL, ABMA and IGY scientists to devote Explorer 4 entirely to radiation studies, in conjunction with the novel Argus experiment. The satellite was launched successfully on 26 July 1958, and carried almost twice the weight of instrumentation of the earlier satellites. Van Allen developed new instruments that could record 60,000 particles cm^2/sec, several thousand times that previously measured. Explorer 4 recorded data from areas not sampled previously. Its predecessors had ranged between 35 degrees north and south latitude; Explorer 4 covered most of the Earth's surface, with extremities at 51 degrees. The Argus experiment provided unique data. In late August and September, the US Navy sent three rockets to an altitude of 480 km (300 mi) over the South Atlantic, where small atomic bombs were exploded in brilliant pyrotechnic displays. Explorer 4's instruments recorded the radiation from the explosions that was trapped in the atmosphere and made possible considerable refinement of the knowledge of the Van Allen belts and related phenomena. Explorer 5 failed to achieve orbit. The radiation experiments of the three successful Explorers had scored a scientific coup with what Van Allen aptly termed "the most interesting and least expected results" of the probes [36].

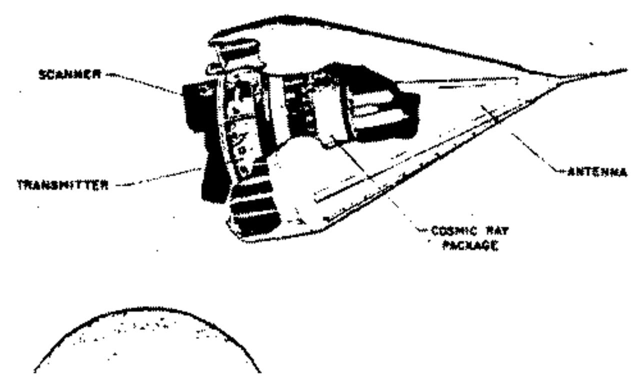
The last major phase of the programme to adapt existing technology to quick and easy projects bore fruit in the space probes Pioneers 3 and 4. These probes were essentially simplified modifications of the ill-fated Red Socks proposal. ABMA used the Juno 2, which developed 67,500 kgf (150,000 lbf) of thrust. JPL's three spinning upper propulsion stages remained basically the same. The payload contained the familiar temperature sensors and Geiger-Mueller counters; the Laboratory added a shutter-trigger mechanism that was supposed to be tripped by the reflected light of the Moon. The 5.8 kg (12.95 lb) of instruments were housed under a striped cone that somewhat resembled the canopy of a carrousel [37].

Two Pioneers, designed by the Air Force and Space Technology Laboratories, preceded the JPL-ABMA probes in the fall of 1958. Neither worked, and JPL and the Army again had a chance to upstage a rival service. Pioneer 2 was launched from Cape Canaveral on 6 December 1958; but it did not achieve escape velocity when the first stage cut off prematurely. The payload rose to a height of 101,600 km (63,500 mi), about 11,200 km (7,000 mi) short of that attained by the previous Pioneer. Nevertheless, two of the flight objectives were partially met; the new Goldstone station tracked the probe without a hitch and the radiation counters returned further refinements of data on the Van Allen belts [38].

Before JPL-ABMA had a chance to try again, the Soviet Union sent Luna 1 toward the Moon on 2 January 1959.

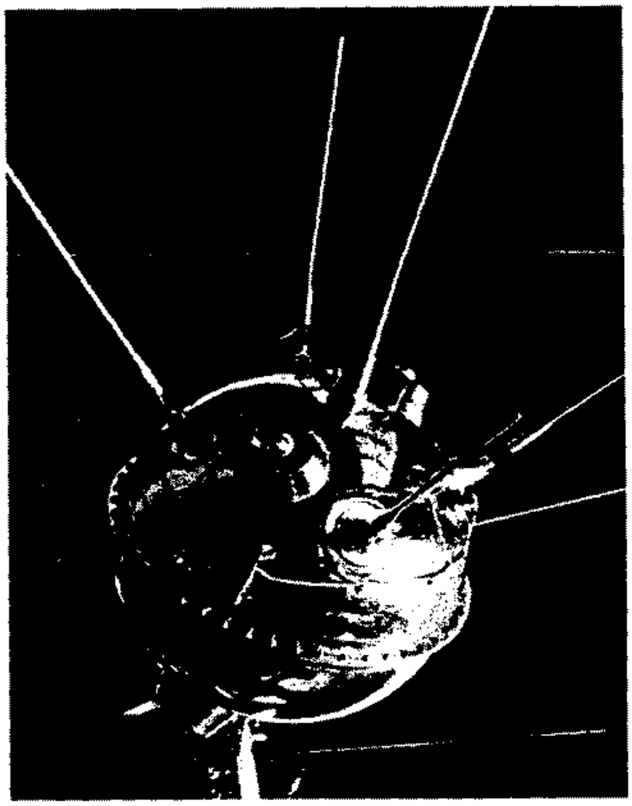


The Pioneer 3 lunar probe underneath its protective shroud atop the Juno 2 launcher. The same kind of spin assembly that launched Explorer 1 was used but the greater speeds in the atmosphere meant that a protective cover had to be carried.



The basic units of the Pioneer 3 and 4 lunar probes. Both failed to reach the Moon.

Later renamed Mechta, or "Dream," Luna 1 passed within 5,965 km (3,728 mi) of the Moon and passed on into orbit around the Sun – the first vehicle to attain Earth escape velocity. The flight of Pioneer 4, launched on 3 March 1959, therefore seemed anticlimatic, although it was by far the most successful of the Pioneer series. The probe passed within 59,520 km (37,200 mi) of the Moon 41 hours and 30 minutes after injection. The light mechanism stayed dark because it had been programmed to operate when Pioneer came within 32,000 km (20,000 mi) of the Moon. The tracking system worked superbly, however, and received Pioneer's



The Soviet Luna 2 was the first man-made object to hit the Moon. On 13 September 1959 it struck the lunar surface at 3.3 km/s but it did not carry equipment for returning close-up pictures. It was soon followed by Luna 3 which flew around the far side and gave us our first glimpse of that hidden face.

signals until the probe's batteries failed about 651,200 km (407,000 mi) from Earth. Pioneer 4 followed Luna 1 into orbit around the Sun, becoming a satellite that completed an orbit every 395 days [39].

Pioneer 4 reinforced JPL's sense of accomplishment and feeling of superiority; the Laboratory and the Army had again bested its American rivals. Hastily modified existing technology had put the United States back into the space race with the USSR. But the Soviet successes continued both to rankle and encourage JPL officials to press for a more vigorous space programme. Modifications of existing technology had reached their limits. JPL engineers had recognised in early 1958 that the Juno 1 and 2 launch vehicles represented improvisations – useful for the moment, perhaps, but not at all what they believed a credible United States space programme demanded. Building on its successes with Explorer and Pioneer, JPL would soon become a dynamic, and sometimes abrasive, presence in NASA and its ambitious space programme.

REFERENCES

1. S. P. Johnson, E. M. Purcell, Herbert York, *et al.*, "The Scientific Exploration of Outer Space," March 12, 1958, Records of the Office of the Special Assistant for Science and Technology, White House Office, Dwight D. Eisenhower Library, Abilene, Kansas; R. Cargill Hall, "Early U.S. Satellite Proposals," *Technology and Culture*, IV (Fall 1963), 410-434.
2. Clayton R. Koppes, "JPL: A History of the Jet Propulsion Laboratory, 1936-1976," book manuscript in progress.
3. William H. Pickering with James H. Wilson, "Countdown to Space Exploration: A Memoir of the Jet Propulsion Laboratory, 1944-1958," Oct. 1972, JPL/HR-4, hereafter cited as "Countdown"; James H. Wilson interview with Homer J. Stewart, Aug. 30, 1972, JPL History File 3-644 (hereafter JPLHF).
4. H. J. Stewart to W. H. Pickering, April 19, 1955, roll 10-3, JPL Vellum Center (hereafter JPLVC).
5. "Report of Ad Hoc Advisory Group on Special Capabilities," Aug. 1955, and related materials, roll 10-3, JPLVC; R. Cargill Hall, "Origins and Development of the Vanguard and Explorer Satellite Programs," *Aerospace Historian*, IX (1964), 106-109.
6. Pickering and Wilson, "Countdown"; Constance M. Green and Milton Lomask, *Vanguard: A History* (Washington: Smithsonian Institution Press, 1971), pp. 53-56.
7. *Ibid.*
8. *Ibid.*, pp. 22-32.
9. *Ibid.*, pp. 33-40; G. Robillard, "Explorer Rocket Research Program," *American Rocket Society Journal*, XXIX (July 1959), 492-496.
10. George Kistiakowsky, *A Scientist at the White House: The Private Diary of President Eisenhower's Special Assistant for Science and Technology* (Cambridge: Harvard University Press, 1976), p. 97; Wolfe and Truscott, *Juno I*, pp. 38-40; John B. Medaris with Arthur Gordon, *Countdown for Decision* (New York: Putnam's, 1960), pp. 119-124.
11. Medaris and Gordon, *Countdown for Decision*, pp. 122-124; Stewart to W. M. Holaday, June 12, 1957, roll 10-3, JPLVC.
12. Minutes of satellite proposal meeting, Sep. 6, 20, 1957, roll 211-5; J. D. Burke, "JPL Research & Development Programs 1958-1960," Aug.6, 1957, roll 211-2, JPLVC.
13. Author's interview with Pickering, June 9, 1977.
14. Medaris and Gordon, *Countdown for Decision*, pp. 155-156.
15. Memorandum of conference with the president, Oct. 9, 1957, box 22, Staff Notes, Dwight D. Eisenhower Papers as President, Eisenhower Library.
16. Memorandum of conference with the president, Oct. 31, box 22, Staff Notes, Dwight D. Eisenhower as President, Eisenhower Library; *Public Papers of the Presidents: Dwight D. Eisenhower, 1957* (Washington: Government Printing Office, 1958), 789-799.
17. Robert D. Lapidus, "Sputnik and Its Repercussions: A Historical Catalyst," *Aerospace Historian*, XVII (Summer-Fall 1970), 88-93, Homer Boushey, "Who Controls the Moon Controls the Earth," *U.S. News and World Report*, Feb. 7, 1958, 54; *Los Angeles Times*, Dec. 18, 1957; Pickering to Shafer, Nov. 2, 1957, roll 211-2, JPLVC.
18. Pickering to DuBridge with summary of Red Socks proposal, Oct. 25, 1957, JPLHF 2-581.
19. Author's interview with Pickering, June 9, 1977; Pickering and Wilson, "Countdown."
20. Medaris, *Countdown for Decision*, pp. 159, 165-179; Green and Lomask, *Vanguard: A History*, p. 200.
21. Author's interview with Pickering, June 9, 1977.
22. *Washington Star*, Feb. 5, 1959, JPLHF 3-152b; Pickering and Wilson, "Countdown."
23. *Ibid.*; "Explorer 1," JPL external publication No. 461 (Feb. 28, 1958).
24. "Explorer 1," pp. 7-12.
25. *Ibid.*
26. *Ibid.*
27. Robillard, "Explorer Rocket Research Program," 493.
28. Wolfe and Truscott, *Juno I*, pp. 56-57.
29. Medaris to Pickering, Dec. 24, 1957, Froelich to Medaris, Dec. 30, 1957, roll 614-217, JPLVC.
30. Teletype messages between Cape Canaveral and JPL, Jan. 31, 1958, roll 614-217; "Up There – At Last," *Newsweek*, (Feb. 10, 1958), 27-29; Pickering and Wilson, "Countdown."
31. Wilson interview with Stewart, Aug. 30, 1972.
32. Wolfe and Truscott, *Juno I*, p. 70.
33. *Time*, (Feb. 17, 1958), p. 25; *New York Times*, Feb. 1, 1958.
34. Wolfe and Truscott, *Juno I*, pp. 72-73.
35. *Ibid.*, pp. 73-74; James A. Van Allen, "Radiation Belts around the Earth," *Scientific American*, CC (March 1959), 39-47.
36. *Ibid.*; *Science*, CXXIX (April 10, 1959), 949-951.
37. Allen E. Wolfe, *Juno Final Report*, v. II, *Juno II: Space Probes* (JPL technical report No. 32-31), pp. 1-5, 53-57, 73-74.
38. *Ibid.*
39. *Ibid.*