Small Satellites: Past, Present, and Future

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Editors

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Chapter 1

The First Small Satellites: Sputnik, Explorer, and Vanguard

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1.1 Introduction

Three small satellites were the first to be launched into low Earth orbit during the International Geophysical Year (IGY) of 1957–1958 to begin the Space Age: Sputnik I, Explorer I, and Vanguard 1 (Figs. 1.1 and 1.2). At the time, the United States and the Soviet Union were engaged in a "Cold War." Both countries were developing thermonuclear warheads and intercontinental ballistic missiles (ICBMs) capable of delivering their horrific weapons of mass destruction onto the other's territory.

The fear and suspicion that pervaded the relations between these countries during the Cold War was so intense that the early Soviet satellite program was conducted in complete secrecy. In fact, the identity of Sergei Pavlovich Korolev, the leader of the Soviet space program, was hidden under the title "Chief Designer," apparently in fear that he would be kidnapped or assassinated. In the United States, the Explorer program was also conducted partially in secrecy. Only the U.S. Navy's Vanguard program was conducted completely in the open. As a result, much of the early history of the world's first three small satellites became badly misreported in the public press at the time, and many misconceptions about them still linger today. It is the purpose of the opening chapter of this book to describe this history in an objective manner, so the reader can judge the programs' true accomplishments, from the perspective of 50 years of intervening history.

1.2 The Historical Background

1.2.1 Sounding Rockets

The size of the launch vehicles and satellites that were flown during IGY were heavily influenced by the predecessor sounding rocket and missile programs that had been conducted by the United States and the Soviet Union before, during, and after World War II. The world's first sounding rockets were built and launched by Robert H. Goddard of Worcester, Massachusetts. His short-term objective was to develop a family of liquid-propelled rockets that could extend measurements of the atmosphere's characteristics to altitudes above those reachable by research balloons (~30 km). In the long term, he hoped to launch a rocket to the moon and

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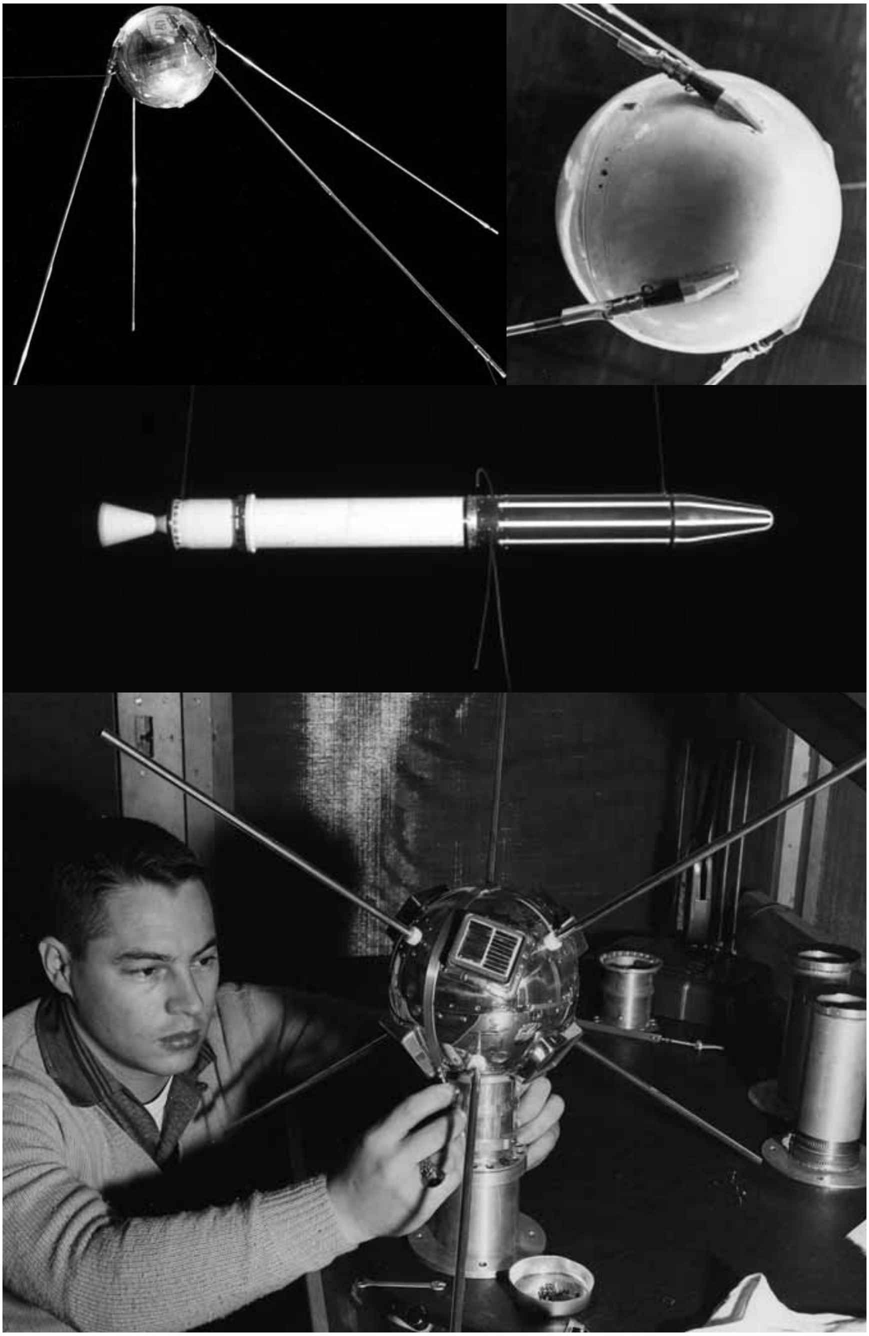
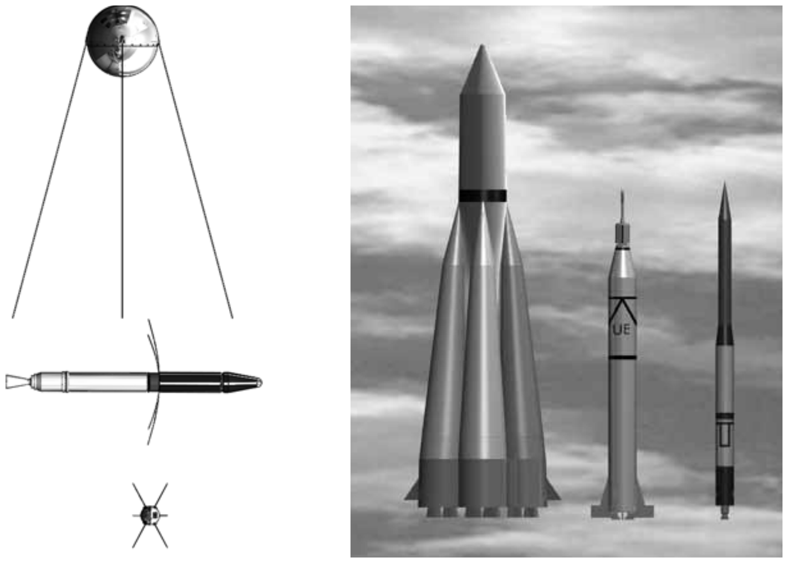


Courtesy of NASA

Courtesy of NASA

Courtesy of M. Votaw

Fig. 1.1. Two views of Sputnik I (top). Explorer I (middle). Robert Bauman with Vanguard 1 (bottom).



Courtesy of B. Fraze

Fig. 1.2. Comparative sizes of the Sputnik I, Explorer I, and Vanguard 1 satellites (left, top to bottom) and their respective launch vehicles, R-7, Juno I, and Vanguard (right, left to right).

set off a magnesium powder flash that would be visible to telescopes on Earth. He published his first formal paper on rocketry and space flight in a report to the Smithsonian Institution in 1919. He launched his first liquid-propelled rocket on 16 March 1926 (Fig. 1.3) from a farm near Auburn, Massachusetts, and followed up with a series of additional flights from that site; these flights were made possible by a small grant from the Smithsonian Institution in Washington, DC. However, under pressure from the local fire marshal and ridicule from local newspapers (including the *New York Times*), he moved his small team of technicians in 1930 to a ranch near Roswell, New Mexico, where he continued a series of launches out of the public eye, until 1941. During that time, he refused to meet or share data with other groups.

During his Roswell period, he demonstrated the use of turbine pumps to deliver liquid oxygen and alcohol to a regeneratively cooled rocket combustion chamber, gyro-stabilized control of coupled nozzle-mounted jet vanes and external fins, gimbaled nozzles, photography of Earth from a rocket, onboard recording of readings from scientific instruments, and parachute recovery of vehicle and payload—in short, most of the elements required to conduct rocket investigation of Earth's upper atmosphere.

Throughout this phase of his work, Goddard was sponsored by intermittent, small grants from the Guggenheim Foundation, to whom he also made periodic progress reports that eventually made their way into the public literature. In 1941, the U.S. Navy Bureau of Aeronautics and the U.S. Army Air Corps prevailed

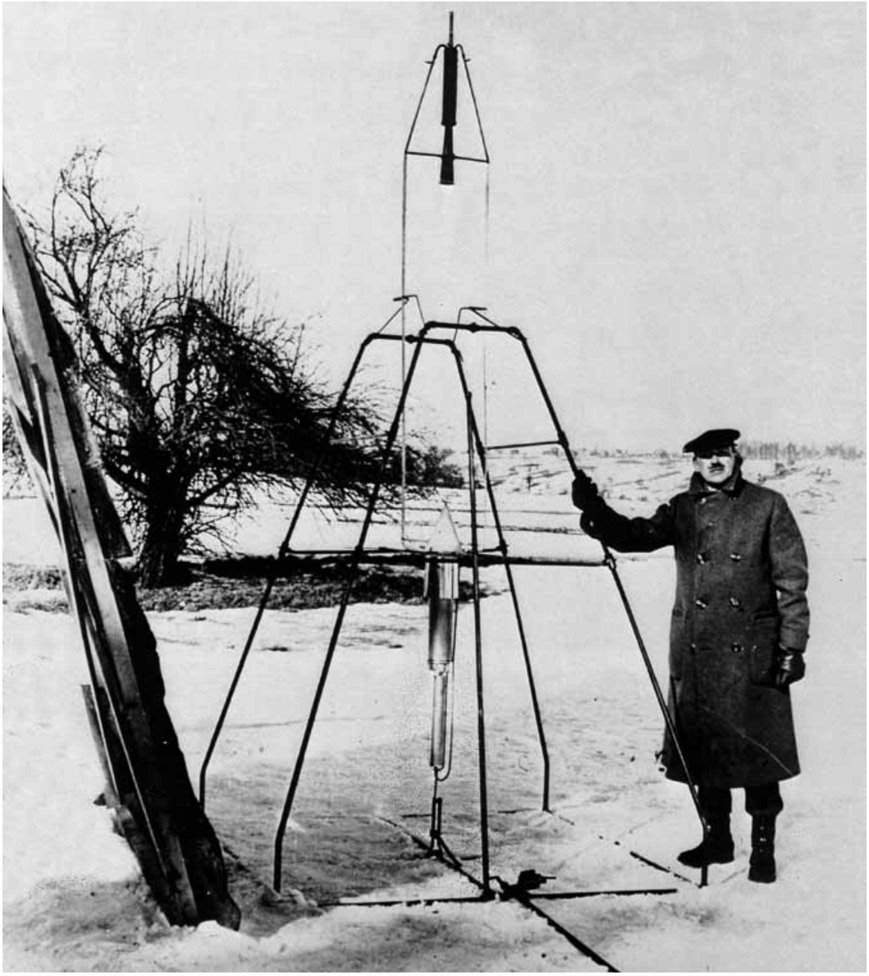


Fig. 1.3. Robert H. Goddard with his first successful liquid-fueled rocket.

upon Goddard to interrupt his private work and move his team to the Naval Research Station at Annapolis, Maryland, to develop a controllable, liquid-propelled jet-assisted-take-off rocket motor for use by search and rescue seaplanes and for short-field takeoffs by fighter aircraft. Goddard intended to move back to Roswell after the war to pursue his dream of launching a rocket to the moon; however, he died in July of 1945. If it were not for the subsequent efforts of his wife, Esther, to publicize his work through a series of public lectures and to publish his voluminous notes and patents, Goddard would never have received credit for his pioneering efforts in the propulsion field.

In the early1930s, after learning of Goddard's work through his progress reports to the Smithsonian and Guggenheim organizations, members of the

American Interplanetary Society (later renamed the American Rocket Society, or ARS) attempted to visit him in New Mexico, but were refused access to his laboratory and launch facilities.

The ARS members developed and tested their own liquid rocket engines in New Jersey and launched complete rocket vehicles from Staten Island in New York harbor. They also visited members of amateur rocket societies in Germany, such as the Verein fur Raumschiffart (VfR), with whom they exchanged ideas on rocket engine development and flight testing. In the Soviet Union, similar groups started work under the leadership of Sergei Korolev, based on the early writings of a schoolteacher named Konstantin Tsiolkovsky. For reasons of military security, the work of the Soviet group was not divulged to the outside world until after the successful launch of Sputnik I.

The work of the German amateur rocket societies was inspired by the fictional writings of Jules Verne, the theoretical writings of Hermann Oberth (to whom Goddard sent his Smithsonian report, “A Method of Reaching Extreme Altitudes,” in 1922, at Oberth’s request, when Oberth was a student at the University of Heidelberg), and the writings and demonstrations of Austrian rocket enthusiast Max Valier. In 1934, the work of these groups and, in particular, the doctoral thesis of one of Oberth’s graduate students, Wernher von Braun, came to the attention of high-level German army officers. They decided to develop rocket weapons to circumvent the restrictions that had been placed on Germany regarding the development of artillery weapons after World War I. They placed the work of the VfR group under military security and assigned a captain named Walter Dornberger to establish a rocket research center on Usedom Island near the mouth of the Peene river (Peenemunde) on the Baltic coast.

Dornberger selected young von Braun as his technical director to develop a family of large ground-to-ground ballistic missiles. The most successful of these was the V-2 (Fig. 1.4). It had a maximum diameter of 1.5 m and a length of

Courtesy of White Sands Missile Range Museum

Fig. 1.4. Tactical V-2 rocket in Germany with mobile ground support vehicles (left). V-2 launch at White Sands Proving Ground on 22 August 1951 (right).

14 m and weighed 12,800 kg at launch. Its fuels were liquid oxygen and alcohol, pumped by a hydrogen peroxide steam turbine into an injector with 18 burner cups at the head end of a steel combustion chamber that produced a sea-level thrust of 245 kN. It was equipped with an amatol explosive warhead weighing 1000 kg; more than 3000 were launched at military and civilian targets in England, Belgium, France, and Holland in 1944 and 1945.

Near the conclusion of the war in 1945, crates of parts for approximately 100 V-2 rockets and complete sets of drawings were smuggled out of the Russian Zone of defeated Germany by the U.S. Army and transported to the White Sands Proving Ground in New Mexico. A contingent of 118 German rocket engineers and scientists, led by von Braun, were also taken to Ft. Bliss, Texas, to transfer their V-2 knowledge and ideas for future rocket weapon systems to American engineers. Additional missile parts and engineers were also transferred from Germany to the Soviet Union for similar purposes.

While the V-2 parts and engineers were being assembled in the United States, the California Institute of Technology's Jet Propulsion Laboratory (JPL) and Douglas Aircraft Company launched Private A and Tiny Tim boosters and Wac Corporal sounding rockets from White Sands (Fig. 1.5).

The U.S. Naval Research Laboratory (NRL) built new instrument sections to replace the warheads of the captured V-2 rockets and equipped them with radiotelemetry subsystems to support scientific studies of Earth's upper atmosphere.

Courtesy of U.S. Army

Fig. 1.5. Frank Malina of JPL with Wac Corporal sounding rocket.

They invited research scientists from across the country to a meeting in Washington, DC, on 16 January 1946, to discuss participation in these endeavors. The V-2 Rocket Panel was formed at this meeting, under the chairmanship of Ernst Krause of NRL, to set the agenda for upper atmospheric and space research in the United States. This panel underwent a series of name changes and member institutions during the following two decades, while its new chairman, James Van Allen of the Johns Hopkins University's Applied Physics Laboratory, continued Krause's efforts to assign rockets to its participating scientists. Between 1946 and 1955, 67 V-2 rockets were launched from White Sands by the U.S. Army and General Electric Company (GE) to altitudes as high as 210 km, carrying 1000 kg of instruments and electronic support systems (Fig. 1.6); one was also launched at sea. In the higher flights, investigators were able to make brief measurements of the spectrum of radiation from the sun and other stars in wavelengths that are normally absorbed by Earth's atmosphere. They were also able to measure the way in which Earth's atmospheric properties changed in response to dynamic processes on the sun, throughout an 11-year sun-spot cycle.

Still, there was one major drawback to the V-2 as a research vehicle: it depended on carbon vanes in its nozzle, plus linked tabs at the tips of a set of four fixed aerodynamic fins, for attitude control. When its engine shut down, and it rose above the stabilizing influence of the atmosphere, the rocket tended to roll uncontrollably about its longitudinal axis and then tumble end over end. This

Courtesy of APL

Fig. 1.6. Applied Physics Laboratory cosmic ray telescope in V-2 instrument section.

meant that the instruments in the payload section swept rapidly past discrete targets such as the sun and stars and allowed only a limited quantity of data to be collected from them. Attempts were made to compensate for this deficiency by developing sun-follower and star-tracker payloads to stabilize individual instruments at the tip of the V-2 nose cone (Fig. 1.7). Other problems were created by the substantial cost of refurbishing and launching these large rockets, coupled with the fact that there was a finite quantity of them available.

Anticipating the end of the V-2 program, Milton W. Rosen and Homer E. Newell of NRL and their contractor, Glenn L. Martin Company, developed two versions of a much smaller sounding rocket, which they named the Viking. They launched 11 of them from White Sands and one at sea between 1949 and 1957. The first version was 0.8 m in diameter and 12 m tall (Fig. 1.8). Its monocoque structure was made from aluminum, rather than the sheet steel of the V-2, which resulted in a launch mass of 4877 kg (as opposed to the V-2's 12,300 kg). The sea-level thrust of its turbine-fed, alcohol-liquid oxygen engine from Reaction Motors, Inc., was 92.7 kN, and its burning time was 72 sec. It carried 250 kg of instruments to a maximum altitude of 218 km.

The second version of the Viking was 1.2 m in diameter and 13 m tall, and it weighed 6820 kg. The sea-level thrust of its turbine-fed alcohol-liquid oxygen engine from GE was also 92.7 kN but its burning time was extended to 103 sec.

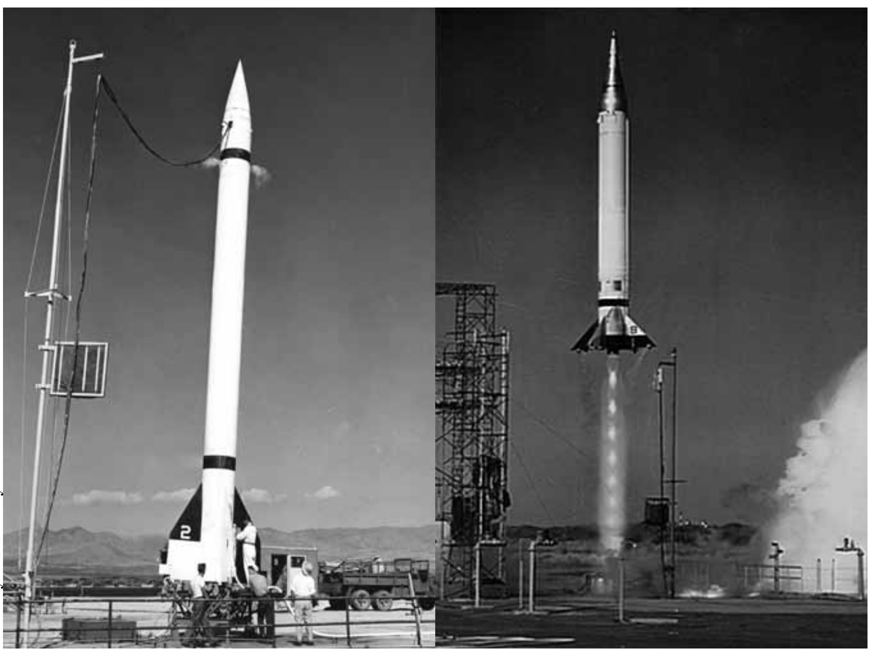
Courtesy of NRL

Fig. 1.7. Richard Tousey with NRL V-2 sun-follower payload.

It carried 250 kg of instruments to a maximum altitude of 253 km. Both versions were equipped with pitch and roll hydrogen-peroxide jets and gyroscopes for stability outside the atmosphere, thereby increasing the quantity and quality of data recovered from discrete sources such as the sun and stars without the weight penalty of a sun follower or star tracker.

During the same period, at the instigation of Van Allen, JPL and Aerojet General Corporation initiated development of an even smaller and more economical rocket, the Aerobee, which was powered by pressure-fed unsymmetric dimethyl hydrazine and white fuming nitric acid hypergolic fuels. This rocket was basically an evolution of the Wac Corporal. When mounted on top of an Aerojet solid propellant booster, it carried payloads of 70 kg to an average altitude greater than 160 km (Fig. 1.9a). More than 150 of them were launched between 1948 and 1956.

This trend toward smaller launch vehicles was made possible by continuous miniaturization of electronic components and improvements in batteries and detectors. The trend continued, as multistage solid-propellant rockets, boosted by surplus motors from the Nike air defense program and topped by Deacon and Cajun upper stages, were developed specifically for upper atmospheric and astronomical research by the National Advisory Committee on Aeronautics and the University of Michigan (Fig. 1.9b). These rockets carried 15 cm diameter payloads weighing 25 kg to altitudes of 160 km from portable launchers in the United States and Canada and ships at sea.



Courtesy of U.S. Army

Fig. 1.8. Viking 2 (left) and Viking 9 (right) launches at White Sands Proving Ground.

Fig. 1.9. Dual Aerobee launches at White Sands Missile Range (a), Richard Custer with Nike-Cajun rocket and HUGO payload at Wallops Island (b), Van Allen's Rockoon being launched from the icebreaker USS Eastwind (c), and Commander Gus Ebel, Carl McIwain, and Frank McDonald with a Loki rocket at sea (d).

When Van Allen moved to the State University of Iowa to become the head of the physics department in 1951, he lowered the cost of launches even further and greatly extended the lateral extent of the atmosphere being studied by developing the Rockoon (rocket-balloon). In this novel approach, a high-altitude research balloon carried a single-stage, 15 cm diameter, 2.5 m long, solid propellant Deacon rocket to an altitude of 30 km and ignited it to propel a 25 kg payload to a peak altitude of 70 km, without the need for a formal launch range (Fig. 1.9c). A second version of the Rockoon, in which a solid propellant Loki antiaircraft rocket was substituted for the Deacon to carry a 7.5 cm. diameter, 3.1 kg payload to an altitude of 91 km, represented the final stage of the miniaturization process (Fig. 1.9d).

During these years, the Soviet Union also adapted captured German V-2 ballistic weapons for upper atmospheric and space research and launched them from the Baikonur launch range in Kazakhstan (Fig. 1.10). However, the USSR did not

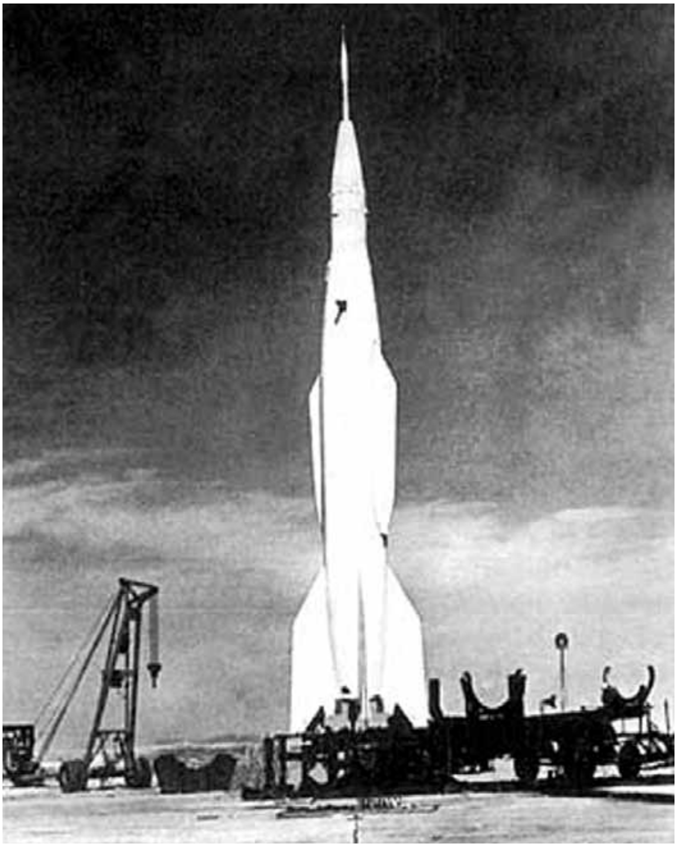


Fig. 1.10. Russian sounding rocket.

follow the U.S. lead in developing smaller launch vehicles, because they were not yet capable of building small payloads—probably owing to a lack of access to miniaturized electronic components. In fact, as late as 21 February 1958, the Soviet Union launched a 1500 kg atmospheric research payload on a single-stage sounding rocket to an altitude of 470 km.

1.2.2 IGY and the Birth of the Space Race

All during the decade described above, the engineers and scientists in the nascent space program dreamed of the day that they could place their instruments aboard artificial satellites and launch them into long-duration orbits. That way, they could make continuous measurements all around Earth, instead of performing them for only a few minutes at a time and at only a few discrete locations. They finally found the impetus for achieving that goal in the International Geophysical Year (IGY). This was an 18-month period from July 1957 to December 1958 that was designated by an international consortium of nations to be devoted to a coordinated study of Earth's physical characteristics and its relationship to the sun, centering on the most active part of a solar sunspot cycle.

The impetus for IGY took place years earlier, on the evening of 5 April 1950, at a dinner party in Van Allen's suburban Maryland home. One of the guests at that dinner, Lloyd V. Berkner, suggested to Sydney Chapman, a world-renowned geophysicist, that it was time to organize another International Polar Year. The usual interval between polar years had been 50 years, but Berkner felt that recent advances in geophysical measurements and sounding rocket launches into the upper atmosphere would justify shortening the interval to 25 years and centering it on an upcoming peak in solar activity in 1957–1958. A comprehensive program of rocket launchings was included in the planning for IGY, to be directed by the Upper Atmosphere Rocket Research Panel, headed by Van Allen.

Discussions about launching an artificial satellite into orbit were held in subcommittees of the IGY, and on 24 November 1954, the Space Flight Technical Committee of the ARS published a position paper entitled, "On the Utility of an Artificial Unmanned Earth Satellite," directed to the attention of the U.S. National Science Foundation. The committee, chaired by Rosen of NRL, recommended that the United States fund an effort to design and build a series of 12 scientific spacecraft and attempt to launch them into orbit during IGY. These spacecraft would carry instruments designed and built by the various scientific groups that were active in the U.S. sounding rocket program. The committee members were well aware of the enormous technical difficulties inherent in such an ambitious undertaking, but they felt that if one of these launches were successful, it would justify the expense.

On 28 July 1955, President Dwight Eisenhower's press secretary announced that the United States would conduct a program to launch an artificial satellite around Earth. Specifically, the objectives were to place a satellite in orbit during IGY, accomplish a scientific experiment in orbit, and track the satellite in orbit. The Soviet Union followed up with a similar announcement four days later. In the United States, a Technical Panel on the Earth Satellite Program was then established, with Richard Porter of GE as its chairman, to review and fund selected proposals for satellite experiments.

On 26–27 January 1956, the Upper Atmosphere Rocket Research Panel held a symposium in Ann Arbor, Michigan, to discuss the scientific aspects of the IGY satellite program; 33 satellite experiment proposals were presented at that meeting. Van Allen proposed flying a Geiger-Muller counter to study the cosmic-ray intensity above the appreciable atmosphere on a comprehensive geographical and temporal basis. He felt that this study would be especially valuable in helping to interpret the extensive but widely spaced ground, balloon, and rocket observations being planned for IGY.

Van Allen's proposal was selected for full funding, as were proposals by Herbert Friedman and James Heppner of NRL, William Stroud of the U.S. Army Signal Engineering Laboratory, Maurice Dubin and Edward Manring of the Air

Force Cambridge Research Center, and Werner Suomi of the University of Wisconsin. Other proposals were funded at a lower level for possible launch in the event that the primary experiments could not be completed in time.

In advance of the president's announcement about launching a satellite during IGY, two teams had vigorously competed to develop the launch vehicles to accomplish that goal. One team, led by Rosen of NRL, based its design on the experience gained from flying V-2 and Viking sounding rockets for upper atmospheric research. This team proposed using a modified Viking for their first stage, a modified Aerobee as their second stage, and a solid-propellant rocket for their third stage. This program would later be named Vanguard.

The second team was led by Maj. Gen. Bruce Medaris, von Braun, and Ernst Stuhlinger of the U.S. Army Ballistic Missile Agency (ABMA) and William Pickering of JPL. This team initially proposed to use a Redstone SRBM as their first stage and a total of 31 Loki solid rocket motors divided up into clusters to power their second, third, and fourth stages. These upper stages would be contained in an electrically powered "spin bucket," and their scientific instrument section would remain attached to the final stage. This program would later be named Explorer. During the evolution of the design, the team substituted 15 JPL-built Scale Sergeant rocket motors for the 31 Lokis, which greatly improved the performance of their launch vehicle. Since they had no payload of their own, Stuhlinger, the principal scientist, asked Van Allen to modify his Geiger-Mueller counter experiment to fit on the end of their fourth-stage Scale Sergeant. After some initial reluctance, Van Allen decided to hedge his bets by having his Iowa graduate student, George H. Ludwig, design an experiment to fit both the Vanguard and Explorer spacecraft.

Actually, a third team within the U.S. Air Force also wanted to offer a proposal to use the Atlas missile to launch a satellite into orbit, but Air Force top leadership, including Gen. Bernard Schriever, squelched the idea because of the negative impact that the work would have on the crucial schedule for developing an ICBM, which was the military's top priority at the time.

To settle the competition between the ABMA/JPL and NRL teams, U.S. Assistant Secretary of Defense Donald Quarles formed an Ad Hoc Committee on Special Capabilities, composed of eight distinguished scientists recommended by the Army, Navy, and Air Force and chaired by Homer Joe Stewart of JPL. After considerable deliberation, the committee recommended on 4 August 1956 that the NRL proposal be selected. Medaris and von Braun vigorously objected and demanded a second vote. After giving the matter due consideration, the committee voted in a special meeting on 23 August to confirm its selection of the NRL proposal.

The committee emphasized that their selection was partially based on the scientific breadth and quality of the experiments from various scientific groups around the country that the NRL team proposed to host in their satellite. Another important factor was that the NRL proposal contained a comprehensive "Minitrack" tracking system that would be installed in several countries to receive telemetry data from the orbiting satellites and to measure their orbits precisely by a phase comparison technique. Eisenhower concurred with the committee's selection—largely because the Army's proposal employed military weapons for all of its propulsion units, whereas the NRL proposal employed stages that had been used only for peaceful research. He felt that a civilian program would enable him to establish the legitimacy of peaceful overflight of all nations, without arousing the objections of those nations, especially the Soviet Union.

Following the President's decision, NRL formed Project Vanguard (named by Rosen's wife, Sally) to build a scientific satellite and its three-stage launch vehicle, under the overall leadership of John P. Hagen and the technical direction of Rosen, with Glenn L. Martin Company as the integrating contractor. In spite of serious funding delays from a patchwork of sponsoring agencies, together with a low national priority (because the program by definition had no military significance), Vanguard finally got off to a good start, with the successful launches of suborbital single-stage and two-stage test vehicles, designated TV-0 and TV-1 (TV for "Test Vehicle"), from Cape Canaveral in Florida during 1956 and early 1957. The first stages of these vehicles were made up of Vikings 13 (Fig. 1.11) and 14, originally intended for launch from White Sands. A test transmitter was ejected from TV-1 at the peak of its suborbital flight and was successfully tracked by a Minitrack system installed at the Cape.

However, the Soviet Union, which most people had not taken seriously when it announced its intention to launch a satellite during IGY, shocked the world with the launches of Sputnik I on 4 October 1957 and Sputnik II on 3 November 1957. To compound matters, an attempt to launch a Vanguard engineering test satellite ended in a spectacular explosion on the launchpad on 6 December 1957. This launch was not expected to attract significant press attention, since the TV-0 and TV-1 launches had been rather routine; however, the Sputnik launches changed all that, and a large media contingent was present to relay images of the explosion to the nation and the world.

Fig. 1.11. Vanguard TV-0 (Viking 13).

Eisenhower was initially unconcerned by the Sputnik launches; in fact, he was privately pleased that those launches had automatically resolved the right of international overflight, which he had been so determined to establish. However, the enormous international press coverage generated by Sputnik I led him to authorize the ABMA/JPL team to undertake a backup effort to the Navy Vanguard program. An all-out effort was mounted to take a Jupiter C three-stage test vehicle out from under canvas in a hangar (where it had been set aside earlier by an ever-optimistic and determined von Braun) and add to it a fourth stage to create the Juno I orbital launch vehicle. At the same time, a 200-person team at JPL raced to complete the design and fabrication of a satellite.

Unfortunately, Van Allen, whose cosmic-ray experiment they hoped to feature in this satellite, was on a Navy ship in the South Pacific during that time, launching a series of Rockoons to define the geographic distribution of cosmic rays above the atmosphere. Since the Army program was conducted under strict military secrecy, meaningful conversations between ABMA, JPL, and Van Allen by radio were nearly impossible. Pickering therefore decided to hire George H. Ludwig, Van Allen's graduate student who had built the original Vanguard cosmic ray experiment as a master's thesis project, and move him to JPL in Pasadena to modify his Vanguard experiment as necessary to fit into the new satellite, which was called "Deal I" up until the time of its launch and "Explorer I" thereafter (Fig. 1.12). Pickering also got permission from Newell at NRL to transfer a Minitrack spacecraft transmitter and receiver to the Explorer program—otherwise, there would have been no way to measure the Explorer I satellite's orbit

Courtesy of G. H. Ludwig

Fig. 1.12. George H. Ludwig with the Deal I (Explorer I) instrument section at the University of Iowa.

precisely, since the JPL Microlock telemetry system was not designed for orbit determination.

Ludwig moved to Pasadena and worked as a junior engineer at JPL to complete fabrication, integration, and testing of his cosmic-ray experiment—just in time to ship the package to Cape Canaveral for launch. He stayed behind in Pasadena until the last possible minute to complete some critical calibrations and arrived at the Cape on the day of the launch. To his surprise, he was not permitted to enter the Army blockhouse or any of the JPL telemetry receiving areas to monitor his instrument's performance during launch. Fortunately, his old Vanguard friends, Roger Easton and Marty Votaw, invited him into their NRL telemetry trailer to monitor his signals. They did so in spite of the fact that the ABMA Florida launch crew (not including George) had stood on the roof of their hangar and cheered loudly when the Vanguard TV-3 launch perished in a ball of fire seven weeks earlier.

In any event, the aggressive spirit of the ABMA/JPL/Iowa team was finally rewarded on the night of 31 January 1958, when the Juno I launch vehicle ascended into the Florida night sky with its striped payload spinning and winking in the launchpad's floodlights.

With this historical context in mind, we turn now to the satellites themselves.

1.3 Sputnik I

Sputnik I was launched from the Baikonur launch complex on 4 October 1957. It was propelled by a modified R-7 ICBM into an elliptical orbit, inclined 65.1 deg to Earth's equator, with a perigee of 215 km, an apogee of 939 km, and an orbital period of 96 min.

The mass of the assembled Sputnik I was 83.6 kg. Its exterior shell was a polished aluminum-magnesium-titanium sphere, 2 mm thick and 58.5 cm in diameter (Fig. 1.13). It was pressurized to 1.3 atm with dry nitrogen. It contained a 1 W, 3.5 kg vacuum-tube radio transmitter, operating alternately on two frequencies, 20.005 MHz and 40.002 MHz, through two external pairs of spring-loaded whip antennas 2.9 m and 2.0 m long. The antennas were initially restrained inside the nose cone of the launch vehicle and were then released in orbit into a configuration swept aft 65 deg from the longitudinal axis of the satellite.

The power supply for the spacecraft weighed 51 kg and contained two sets of silver-zinc batteries that powered its transmitter and a third set that powered an electric fan to help control the spacecraft's internal temperature. The fan was commanded on by a thermostat when the temperature rose above 36°C and turned off when it dropped below 20°C. The modulation scheme for the spacecraft's telemetry transmitter consisted of sending out an alternating series of pulses of 0.3 sec duration on its two radio frequencies, so long as the spacecraft's internal temperature was between 0°C and 50°C. When the temperature exceeded that range, the pulse duration changed on both frequencies. The duration was also designed to change if the pressure inside the spacecraft dropped below one third of

Courtesy of NASA

Fig. 1.13. Internal view of Sputnik I components.

an atmosphere, to indicate that its shell had been punctured by a meteorite. A view of the satellite's interior is given in Fig. 1.13. The octagonal objects are the battery packs; the radio transmitter was mounted in a cavity in their center.

Sputnik I's launch vehicle, designated 8K71PS, was a two-stage, parallel-burn vehicle with a mass of 267 metric tons, and it was propelled by four sets of liquid propellant rocket boosters wrapped around a liquid propellant core stage (Fig. 1.14). Each booster was powered by an RD-107 engine, comprising four main thrust chambers and two vernier chambers, all fed from a common turbopump assembly. The core stage was powered by an RD-108 engine, comprising the same four main thrust chambers operating at a lower pressure and four vernier chambers, again fed from a common turbopump assembly. All 20 main thrust chambers and 12 verniers were ignited at launch, producing an aggregate thrust of 3,900 kN. Its strap-on boosters fell away when their fuel was depleted 116 sec after launch. Its core stage continued to burn for an additional 178 sec, after which the nose cone was shed. At 314 sec after liftoff, Sputnik I separated from the spent core stage, and its radio transmissions were immediately received by one of a string of government ground stations located downrange from the launch site within the Soviet Union.

Signals from the transmitter were again received 96 min after launch by the official tracking stations, and a formal announcement was made that Sputnik I was successfully in orbit. The frequencies on which the transmitter was operating

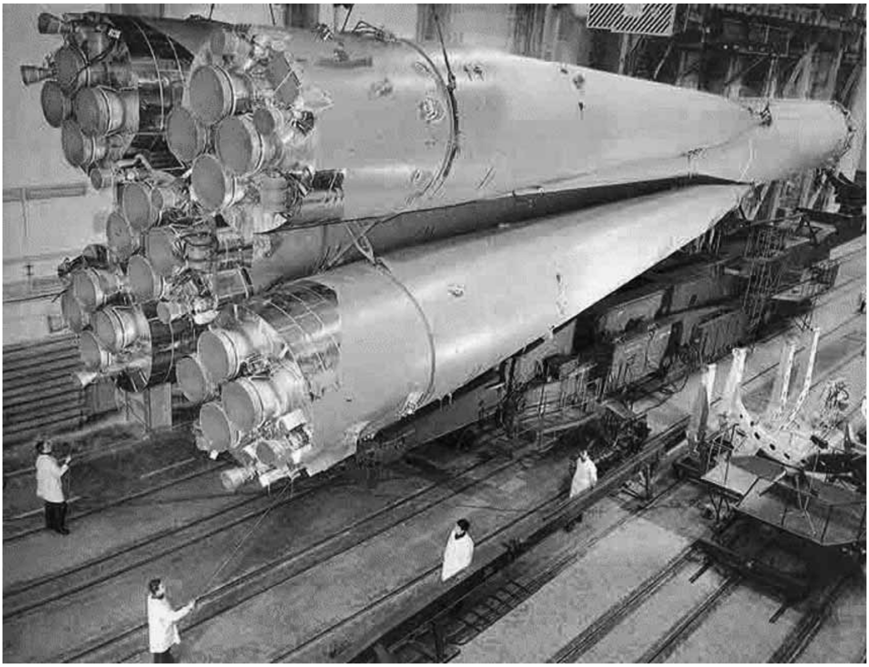

Courtesy of NASA

Fig. 1.14. R-7 launch vehicle for Sputnik satellite.

were publicly announced, and amateur radio operators all over the world started tuning into the signals and measuring their Doppler shifts to help estimate the satellite's orbit. Operators of a newly installed NRL "fence" of Minitrack ground stations, which had been installed to track upcoming Vanguard satellites on 108 MHz, also reconfigured their equipment to receive Sputnik's frequencies, so they could measure the satellite's orbit with much greater precision.

Sputnik I, although quite simple, was a complete technical success, proving that an orbiting spacecraft could survive in the hostile environment of space, without being punctured by meteorites or having its vacuum-tube electronics damaged by solar or cosmic radiation above the shielding effects of Earth's atmosphere. It also proved that the internal temperature of an orbiting object could be controlled within limits acceptable for standard electronic equipment. It radioed useful internal and skin temperature data to the ground for three weeks, before its batteries became depleted, while international teams of physicists measured alterations in the paths of its radio transmissions to determine the density of ions in Earth's upper atmosphere.

It was also observed optically at twilight by "Moonwatch" volunteers, who had been organized into teams all over the world earlier in 1957 by Fred Whipple of the Smithsonian Astronomical Observatory at Harvard University. These teams used arrays of small, homemade telescopes, built to Whipple's specifications, to determine the meridian crossing times of the satellite and the core stage of its rocket. They reported their sightings to Observatory staff members, who worked with the Massachusetts Institute of Technology (MIT) to calculate their orbits and publish forecasts of when they would pass over various places around the world.

In addition to its engineering and scientific accomplishments, Sputnik I was an even greater propaganda success. People around the world were astounded that, armed with the Moonwatch forecasts, they could go outside at morning or evening twilight and watch bright flashes of sunlight reflecting from the tumbling core stage of Sputnik's launch vehicle, which was 29 m long by 3 m in diameter and covered with special reflectors to increase its visibility, as it swept across the sky at an amazing rate. Most of them erroneously thought they were seeing the satellite itself; however, at only 58.5 cm in diameter, it couldn't reflect enough sunlight to be seen without a telescope. Scientists around the world heaped praise on the Soviet Union for achieving an engineering and scientific triumph. The man in the street and the leaders of the Western nations, however, were chilled by the thought that if the Soviets could orbit a spacecraft around Earth, they must surely be able to launch thermonuclear weapons anywhere in the world.

Even after Sputnik's batteries died, Moonwatch teams continued tracking the satellite and its rocket body. The Harvard/MIT team used the amateurs' sightings to calculate the gradual shrinkage of the orbits caused by aerodynamic drag. In this manner, they were able to estimate the density of the upper atmosphere at the various altitudes through which the objects passed. Sputnik I orbited Earth 1440 times until 4 January 1958, a total of 90 days after its launch, before descending deep enough into the upper atmosphere to become vaporized by aerodynamic heating. After Sputnik, no additional small satellites were flown by the Soviets, who instead increased the size of their later spacecraft enormously.

1.4 Explorer I

Explorer I (Fig. 1.15) was launched from Cape Canaveral on 31 January 1958 on a four-stage Juno I launch vehicle into an elliptical orbit, inclined 33.3 deg to Earth's equator, with a perigee of 360 km, an apogee of 2535 km, and an orbital period of 114 min.

The launch mass of the spacecraft was 13.9 kg, which included 8.3 kg of payload that remained attached to the 5.6 kg cylindrical steel casing of its expended fourth-stage Scale Sergeant rocket motor. Three scientific instruments were incorporated into the payload. The first, as mentioned previously, was the Anton 314 omnidirectional Geiger-Mueller counter built by Ludwig; its purpose was to measure the intensity of cosmic radiation above the atmosphere and define the extent of Earth's magnetic field. Ludwig made extensive use of transistors in his circuits. The other two scientific instruments were detectors built by Maurice Dubin and Edward Manring of the Air Force Cambridge Research Center to measure the frequency and energy distribution of meteorites above Earth's atmosphere. The first

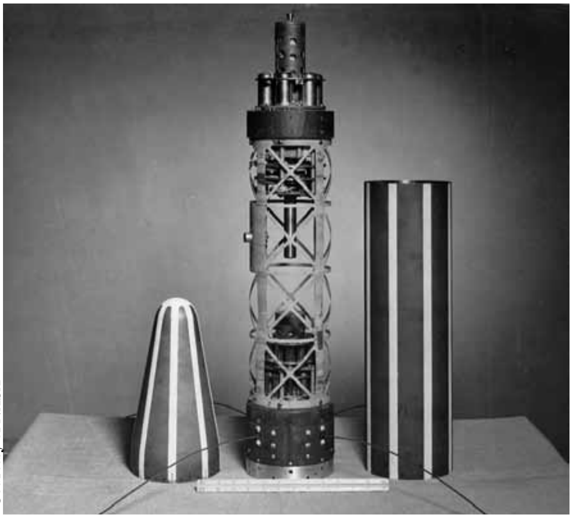
Courtesy of NASA

Fig. 1.15. Explorer I instrument section being installed on Scale Sergeant fourth-stage motor.

detector employed a crystal transducer and solid-state amplifier to acoustically record the energy of meteor impacts. The second was a wire-grid detector that recorded micrometeorite impacts by the fracture of wires in its grid.

The Explorer I instrument section contained two telemetry transmitters. The first was a 10 mW JPL Microlock operating on 108.0 MHz and feeding a turnstile antenna that consisted of four flexible steel wires, each 56 cm long. The second was the 60 mW Minitrack, originally built by NRL for Vanguard, operating on 108.030 MHz and connected to two fiberglass slot antennas in the body of the satellite. A package of mercury batteries and packages of control electronics were also contained in the payload. The satellite's exterior shell was an aluminum cylinder, 16.5 cm in diameter and 64 cm long, tipped by a blunt cone 32 cm long. It was painted in a pattern of alternating white and green longitudinal stripes (Fig. 1.16) to control the temperature of the satellite.

The low-powered JPL telemetry transmitter operated for 105 days, during which time, Microlock ground stations received housekeeping and scientific data from the satellite. NRL Minitrack ground stations also received signals from its high-powered transmitter for 31 days and relayed them to the Vanguard Computing Center, which was operated on a volunteer basis by IBM Corporation in Washington, DC, to compute the satellite's orbit with high precision. After its batteries were depleted, Explorer I remained in orbit for 12 years, and Moonwatch volunteers continued to track it through small telescopes. In addition, specially designed professional Baker-Nunn tracking cameras were installed around the world not long after Explorer I was launched. Their observations allowed the



Courtesy of NASA

Fig. 1.16. Explorer I components and external shell. The cosmic ray experiment is mounted on the upper portion of the compartment, and the telemetry section, flexible antennas, and micrometeor detectors are mounted at the bottom. The white stripes are designed for thermal control of the spinning satellite.

Courtesy of U.S. Army/ Redstone Arsenal

Fig. 1.17. Night launch of Explorer I aboard the Juno I launch vehicle.

Harvard/MIT team to determine the satellite's orbit much more precisely than they had been able to do using the values calculated from the amateur sightings.

Explorer I's launch vehicle, Juno I, was 21.2 m tall and 1.78 m in diameter and weighed 29,060 kg (Fig. 1.17). Its first stage was a modified Redstone containing one North American Rocketdyne A-7 motor that used liquid oxygen as its oxidizer and hydyne (60% unsymmetrical dimethylhydrazine and 40% diethylenetryamine) as its fuel to generate 369.4 kN of thrust for 155 sec. Its three upper stages consisted of clusters of Scale Sergeant solid-propellant (polysulfide-aluminum/ammonium perchlorate) rockets mounted in a "spin bucket" (Fig. 1.18) that was attached by a bearing to the top of the Redstone booster and rotated at a rate of 750 rpm by an electric motor to provide gyroscopic stability to the upper stages and average out their nozzle misalignments during thrusting.

Its second stage comprised a cluster of eleven 15.2 cm diameter Scale Sergeants that were ignited simultaneously to generate a 78.3 kN total thrust for 6.5 sec. Its third stage contained a cluster of three similar Scale Sergeants that

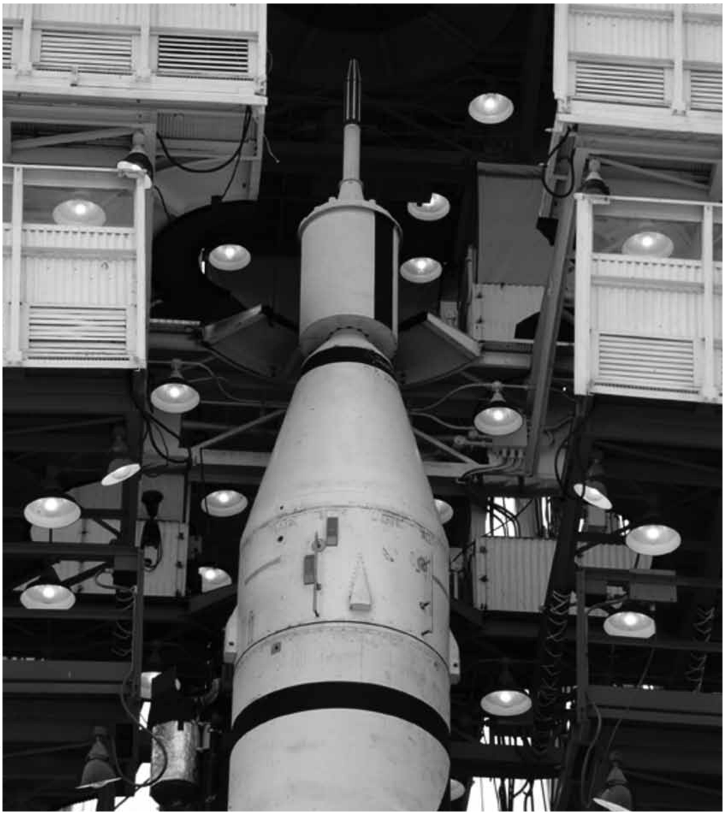

Courtesy of U.S. Army

Fig. 1.18. Upper-stage spin bucket on top of a modified Redstone first stage.

generated a total of 21.4 kN for 6.5 sec. Its fourth stage was a single Scale Sergeant that generated 8 kN for 6.5 sec and stayed attached to the Explorer I satellite in orbit.

Shortly after achieving orbit, Explorer I and its attached fourth stage stopped spinning about its longitudinal axis and, instead, tumbled end over end, as a result of a phenomenon well known to sounding rocket engineers of that era as "roll-pitch coupling." A long, slender, cylindrical body, such as the combined satellite and rocket motor, is most stable while rotating about its transverse axis. If an attempt is made to spin it about its longitudinal axis instead, any asymmetry in its transverse mass distribution will cause its spin energy to become coupled into pitch energy, and it will precess into larger and larger coning angles until all the energy is transferred into its pitch mode. The flexible antennas on Explorer I served as the coupling mechanism, in this case. The tumbling behavior caused intermittent dropouts in the satellite's data transmissions to receiving stations on the ground and complicated the analysis of measurements made by its instruments.

Further complicating the analysis was the fact that telemetered data were received from its instruments for only the few minutes during each orbit when the satellite was passing over any of the Microlock or Minitrack receivers on the ground. In spite of these limitations, the Air Force Cambridge Research Center scientists deduced that their micrometeorite acoustic detector reported 145 hits of cosmic dust in a 12-day period, which equates to an impact rate of $8 \times 10^{-3}/(\mathrm{m}^2 - \mathrm{sec})$.

The satellite's eccentric orbit, coupled with Earth's rotation, caused its brief periods of data transmission to the Microlock stations to occur when the satellite was at varying altitudes, ranging from 358 km to 2550 km. When the satellite was passing over a receiving station at altitudes near perigee or up to 1000 km or so, the Geiger-Mueller counting rates remained in the expected range, increasing steadily with altitude—but when the satellite was at higher altitudes, the counting rates dropped to zero. This unexpected behavior caused Van Allen and Ludwig to suspect that the instrument might be failing intermittently. However,

Courtesy of C. McIlwain

Fig. 1.19. Iowa graduate student Carl E. McIlwain with the cosmic ray experiment that he flew on a Nike-Cajun rocket from Ft. Churchill, Canada, into an auroral substorm at about the same time that Explorer I flew. His analysis of the flux of energetic particles detected on his Nike-Cajun flight allowed him to explain to Van Allen why the Explorer I Geiger counter saturated.

Carl McIlwain, another of Van Allen's graduate students, had recently returned from launching an instrumented cosmic-ray payload (Fig. 1.19) on a Nike-Cajun sounding rocket into an active aurora at Canada's Ft. Churchill Launch Range on the shore of Hudson's Bay, and he reported that his instrument had encountered unusually large fluxes of energetic particles above the atmosphere at high geomagnetic latitudes. His interpretation of the confusing results from the Explorer I instrument was that it was being overwhelmed by a huge flux of energetic particles at the satellite's higher altitudes that was driving its Geiger tube into such hard saturation that it did not count at all. Van Allen and Ludwig agreed with that interpretation and changed the counting rate of their next instrument.

1.5 Vanguard 1

In preparation for the first Vanguard orbital launch attempt, three successful suborbital test vehicles, TV-0, TV-1, and TV-2, were launched to flight certify the individual stages and the overall configuration of the launch vehicle.

Then, two unsuccessful attempts to launch a Vanguard satellite preceded its first success. The first attempt, designated TV-3, briefly rose from its launchpad on 6 December 1957, fell back, and exploded, due to a first-stage motor turbine underpressurization problem. The second attempt, TV-3 Backup, took place on 5 February 1958, but yawed and broke up 57 sec after launch, due to a control system failure.

Fig. 1.20. Vanguard 1 during final installation and checkout on its TV-4 launch vehicle.

On 17 March 1958, six weeks after the successful launch of Explorer I, the Vanguard 1 satellite (Fig. 1.20) was successfully launched from the Cape Canaveral Air Force Station on a three-stage Vanguard launch vehicle (Fig. 1.21) into an elliptical orbit, inclined 34.25 deg to Earth's equator, with an initial perigee of 654 km, an apogee of 3969 km, and an orbital period of 134 min. The launch vehicle was designated TV-4.

The launch of the Vanguard 1 satellite was used to verify the performance of the launch vehicle and to define the environment in which future siblings would be expected to operate. Vanguard 1 was spherical in shape, 16.5 cm in diameter, and weighed 1.47 kg. Its exterior shell was made from two spun aluminum hemispheres, coated with alternating layers of silicon dioxide and aluminum for thermal control, and it housed a cylindrical aluminum instrument compartment,

Courtesy of NASA

Fig. 1.21. Successful launch of Vanguard 1 on 17 March 1958.

10 cm in diameter, that was suspended within the craft by Teflon rods that served as electrical and thermal insulators (Fig. 1.22). The instrument compartment contained two radio telemetry transmitters, one of which was powered by seven Mallory 1.3 V mercury cells and radiated a 10 mW signal on 108.0 MHz (Fig. 1.23). The other was powered by six arrays of glass-covered silicon solar cells that were mounted in square aluminum frames on the satellite's external shell and radiated a 5 mW signal at 108.030 MHz.

The quartz crystals that drove the oscillators in the telemetry transmitters were thermally sensitive, and this property was employed to measure the internal temperatures of the satellite and its thermally isolated cylindrical instrument package. The 108.030 MHz transmitter fed four 10 in. long, circularly polarized, rigid, aluminum stub antennas that were electrically loaded to perform as quarter-wave

Fig. 1.22. Dave Corbin assembling Vanguard 1 satellite.

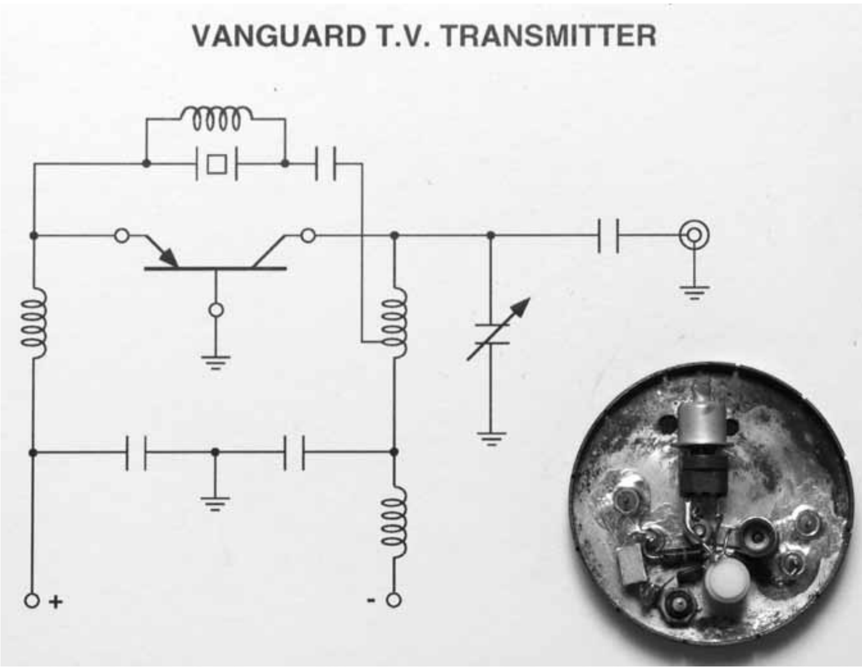
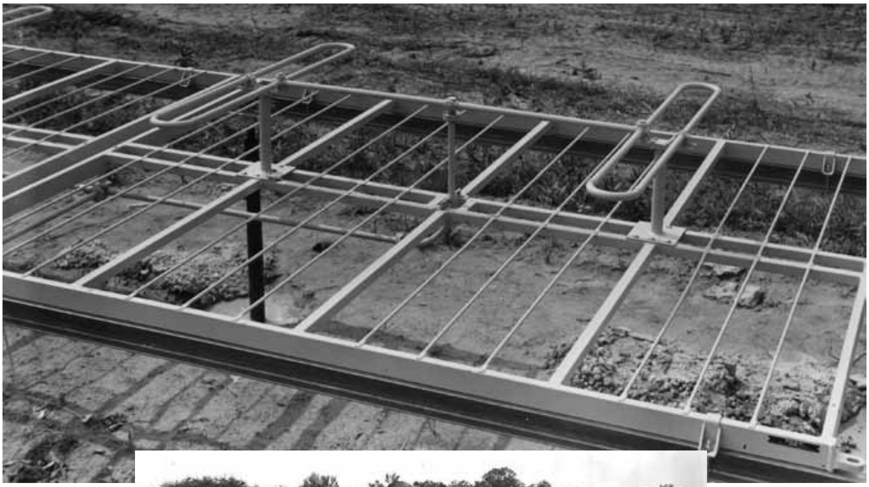


Fig. 1.23. Vanguard 1 battery-operated transmitter.

antennas at their transmitter's frequency. The 108 MHz transmitter fed a dipole pair of similar antennas. The transmissions were received on the ground by fixed arrays of antennas (Fig. 1.24) in 12 Minitrack interferometer tracking stations arranged in a north-south fence in the Western Hemisphere plus one additional station on the west coast of the United States and one each in South Africa and Australia.

The launch vehicle that placed Vanguard 1 in orbit was built by Glenn L. Martin Company under the direction of NRL. It was 23 m tall, 1.1 m in diameter, and weighed 10,050 kg. It consisted of two liquid-rocket powered stages and one solid-propellant stage. The first stage was derived from the Viking sounding rocket. It was powered by an upgraded X-405 engine manufactured by GE that burned liquid oxygen and kerosene to deliver a sea-level thrust of 123.8 kN for 2 min 25 sec. The second stage was derived from the Aerobee Hi sounding rocket (Fig. 1.25). It was powered by an AJ10-37 motor that burned white inhibited-fuming nitric acid and unsymmetrical dimethylhydrazine to deliver a vacuum thrust of 33.4 kN for 1 min 55 sec. The third stage was a Grand Central Rocket Company solid rocket motor that burned a polysulfide fuel and ammonium perchlorate oxidizer to deliver a vacuum thrust of 11.6 kN for 33 sec.

After the first-stage engine shut down 2.5 min after launch, explosive bolts released the second/third-stage combination, and the second stage engine fired



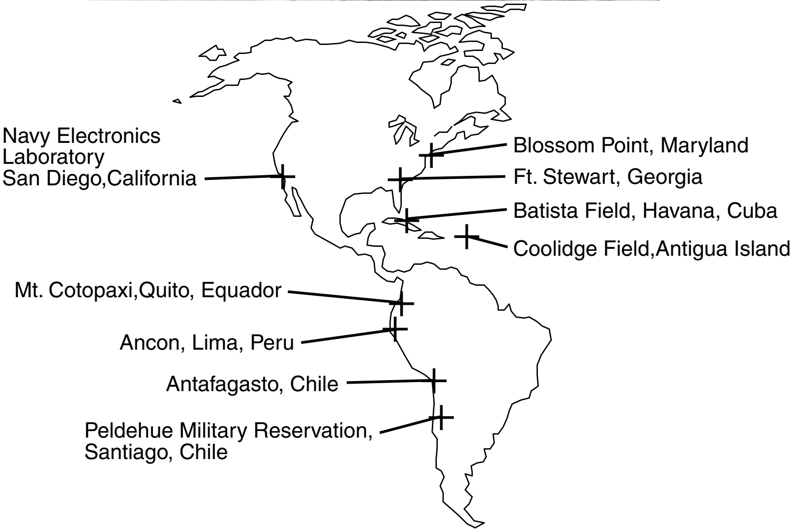


Fig. 1.24. Minitrack antenna dipole feed (top). Typical segment of a Minitrack interferometer antenna array (middle). Minitrack locations in the Western hemisphere (bottom).

for 2 min. The nose cone of the launch vehicle was pyrotechnically released, and two Atlantic Research Corporation 1XS50 solid rocket motors, 3.8 cm in diameter and 12.2 cm long, that each delivered 178 N of thrust for 1 sec, were fired to spin a platform on which the third-stage motor and satellite were mounted. The motor/payload combination was then pyrotechnically released from the platform, and two additional 1XS50 rocket motors, mounted in a reverse direction on the outside skin of the second stage, were fired to back the second stage away from the third-stage/payload combination. A pyrotechnic delay fuse ignited the third-stage motor 15 sec later, and it burned for 31 sec to achieve orbital velocity. A 30 sec mechanical timer and battery then actuated a pair of pyrotechnic pin pullers to release the ends of a spring steel strap that had encircled the satellite and held it to its separation system during launch. Three compressed leaf springs separated the satellite into its own orbit from the 21.4 kg empty third stage motor case at a rate of 30 cm/sec.

Vanguard 1's battery-powered transmitter provided internal package temperature for 16 days and sent tracking signals for 20 days. Its solar-powered transmitter provided measurements of the temperature of the inside surface of the satellite's external shell and sent tracking signals for more than six years and 25,000 orbits. Vanguard 1 and its third-stage motor are still orbiting Earth, as of this writing, and are expected to do so for another 150 years or so. The satellite's radio transmissions were employed by geophysicists during six years of repeated measurements to determine the detailed pear shape of Earth and establish the locations of the continents and the mass concentrations in various regions of the planet, as well as the density of neutral gases and ions in the upper atmosphere, to great precision. (The spherical shape of the Vanguard satellite results in lower scatter in its tracking data than did the tumbling cylindrical Explorer I, because the drag coefficient of a sphere is independent of orientation.) Continued optical

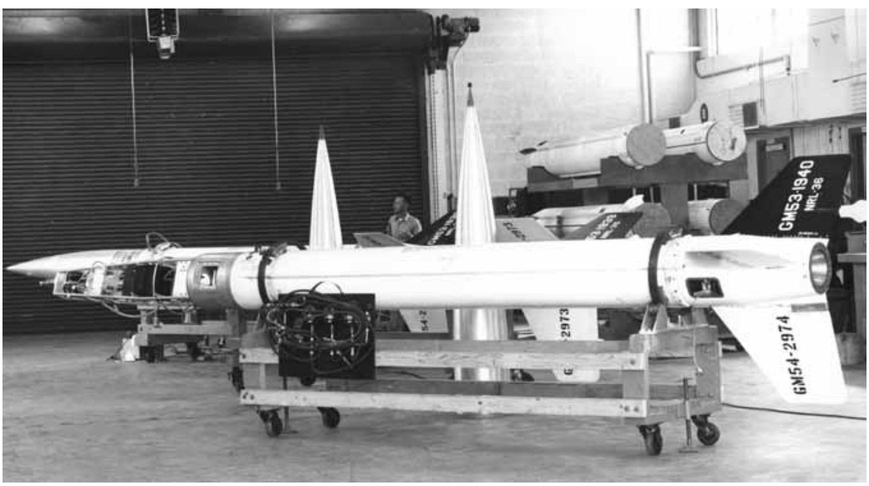


Fig. 1.25. Aerobee Hi in hangar with payload exposed.

and, later, radar tracking of Vanguard 1 during the nearly five complete 11-year solar cycles that have taken place since its launch has further refined our knowledge of the effects of extreme UV radiation from solar flares on the density of the upper atmosphere and the way that this density variability influences satellite orbits.

1.6 Additional Sputnik Launches

A few days after Sputnik I's launch, Soviet Premier Nikita Krushchev, greatly pleased by the overwhelming international acclaim for his nation's pioneering achievement in launching the world's first artificial satellite, directed Korolev to put into orbit another, even more impressive satellite, designated Sputnik II, to celebrate the 40th anniversary of the Soviet revolution on November 7. In the astonishingly short timespan of a few weeks, Korolev's team took the backup satellite for the Sputnik I launch and installed it in a three-part payload (Fig. 1.26). The second part was an aluminum, self-contained, hermetically sealed life-support capsule that contained a small dog named Laika ("Barker" in English). The temperature of the capsule was regulated by a combination of reflectivity of the spacecraft's external surfaces, thermal insulating blankets, and a forced-air circulating system. The team taped instruments to the dog to measure her pulse,

Fig. 1.26. Sputnik II three-part payload, with science instrument package on top, spherical Sputnik I type shell below that, and Laika the dog's capsule on the bottom.

respiration, and blood pressure and take electrocardiograms. They also mounted other instruments inside the capsule to monitor its pressure and temperature. The batteries for the entire payload were designed to last seven days in orbit, so the designers provided a seven-day supply of food and water for the dog.

The third section of the payload consisted of a separate scientific instrument package that would measure cosmic radiation and solar UV and x-ray emissions and was mounted on top of the spherical Sputnik package. The entire payload was designed to be deployed as a unit from the final stage of a modified R-7, which would also accompany it in a separate orbit. The total mass of the payload was 508 kg. It was launched on 3 November 1957 from Baikonur into a 212 × 1660 km orbit with a 65.3 deg inclination. Its orbital period was 103.7 min. The spherical capsule that had been a backup satellite for the Sputnik I mission served as the data transmission system for the combined Sputnik II payload. Its 15 MHz transmitter provided the same series of beeps that its predecessor had, but its 7.5 MHz transmitter generated a continuous signal that was commutated to relay the much larger data set of the Sputnik II mission to the ground stations.

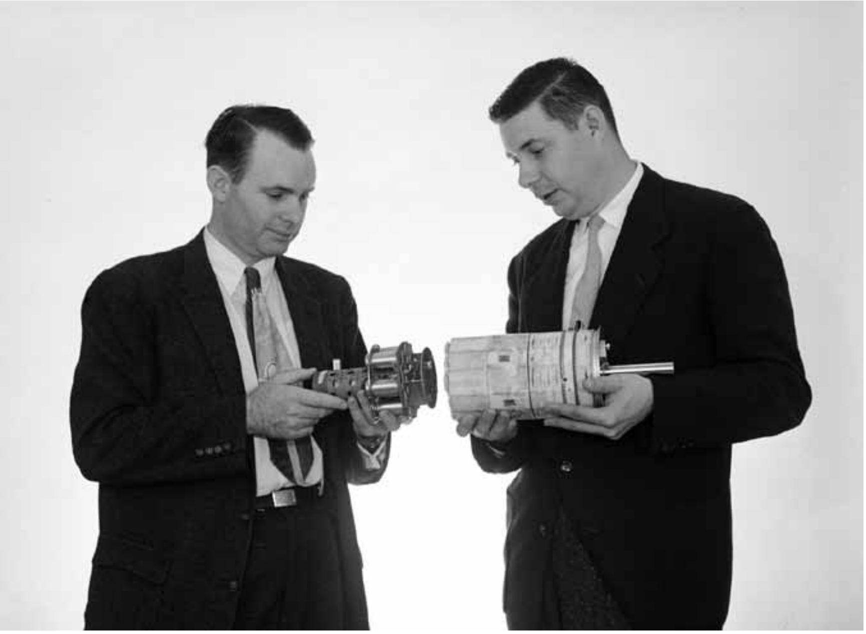
Following a successful launch, the launch vehicle's nose cone, which protected the triple stack of capsules during ascent, separated on schedule, but a layer of thermal insulation was torn loose in the process. Postflight telemetry analysis revealed that Laika survived the effects of launch but died a few hours afterward from the loss of temperature control in her capsule—a fact that was not announced to the public until decades later. Sputnik II's scientific instruments and telemetry system continued to operate for seven days, until their batteries were exhausted. The Moonwatch network and Baker-Nunn cameras provided optical measurements of Sputnik II's orbit until it burned up in the atmosphere on 13 April 1958, a little more than five months after launch.

The Soviets had been preparing an enormous payload, which Korolev referred to as the "Object D" spacecraft, for many months, but had not been able to complete it until after Sputnik I and II had been flown. It was finally launched from Baikonur on 27 April 1958. However, it failed to reach orbit, due to a breakup of its R-7 launch vehicle 88 sec after ignition. Undeterred by this failure, the Soviet team installed a backup Object D spacecraft on another R-7 and successfully sent it into a 215 × 1863 km orbit inclined 65.2 deg to the equator on 15 May 1958 in a mission designated as Sputnik III.

This spacecraft was conical in shape, 3.57 m long and 1.73 m wide at its base. It weighed 1327 kg, including 968 kg of scientific instruments and power and radio telemetry subsystems. It used a combination of silver-zinc batteries and silicon solar cells to power its electrical subsystems. Its multichannel telemetry system transmitted pulses ranging from 150 to 300 msec in duration on a frequency of 20.005 MHz. Its internal temperature was controlled by a system of adjustable louvers on the surface of the spacecraft that opened and closed over a series of thermal radiators. The spacecraft contained 12 scientific instruments that measured pressure and composition of the upper atmosphere, concentration of charged particles, photons in cosmic rays, heavy nuclei in cosmic rays, magnetic and electrostatic fields, and meteorites. Its tape recorder failed prior to launch, so although it detected enhanced radiation at high altitudes, it was unable to map the radiation belt that had been encountered earlier by Explorer I. Sputnik III remained in orbit, with its radio transmitter continuing to operate, until 6 April 1960. However, useful measurements were not transmitted from its instruments after the first few weeks of its mission, apparently due to a failure of its modulation system.

1.7 Additional Explorer Launches

Buoyed by the success of the Explorer I launch, the JPL/Iowa team moved forward with their original plans to incorporate a tape recorder that could be commanded to play back complete orbits of data every time the satellite passed over the Vanguard fence (Fig. 1.27). This satellite, designated Explorer II, was launched on a second Juno I on 5 March 1958. It did not achieve orbit, due to a failure to ignite the fourth-stage Scale Sergeant motor. (Note: The Explorer program office originally assigned numbers to all the Explorer launch attempts, regardless of whether they were successful, until Explorer VI, at which time they numbered only the



Courtesy of George H. Ludwig

Fig. 1.27. Henry Richter of JPL (left) and Iowa graduate student George H. Ludwig with prototype equipment for the Explorer II cosmic ray experiment, which added a tape recorder to the basic Explorer I package. The satellite failed to reach orbit, but an identical payload was flown successfully on the Explorer III mission on 26 March 1958.

successful launches. They also used Roman numerals in their titles, while the Vanguard program used Arabic.)

A duplicate payload was prepared and launched successfully as Explorer III on 26 March 1958, one week after the start of the first successful Vanguard mission. Explorer III's initial perigee was 190 km, its apogee was 2784 km, and its orbital inclination was 34.4 deg. Ludwig's tape recorder and the Minitrack tracking system worked flawlessly, and Van Allen was able to perceive a pattern in the puzzling "zero count" behavior of his cosmic-ray instrument. His graduate student, McIlwain, exposed a Geiger counter, identical to the one flying in Explorer III, to a 250 kV x-ray machine in his laboratory and produced a data set that matched the slope of counting rates from the Geiger tube in orbit. He proved that fluxes that would ideally produce more than 35,000 counts per second instead drove the count rate to zero. The Van Allen team therefore concluded that telemetered data from the Explorer III mission indicated an enormous band of trapped energetic particles circled Earth at altitudes higher than 550 km, and that the shape

Fig. 1.28. A Juno II rocket.

of the band was a function of Earth's magnetic field. Van Allen announced this discovery to the world at a joint session of the American Physical Society and the National Academy of Sciences in Washington, DC, on 1 May 1958. This region subsequently became known as the inner of two "Van Allen radiation belts."

The next satellite in the series, Explorer IV, was propelled into a much more highly inclined orbit than usual by a Juno I launch vehicle on 26 July 1958. Its objectives were to extend its measurements over a much broader latitude range of the trapped particle radiation belt that had been discovered on the previous Explorer flights and to measure the effects on that natural radiation belt of the three 1.7 kt W-25 "Argus" nuclear devices that were detonated above the atmosphere in an experiment conducted by the U.S. Advanced Research Projects Agency (ARPA). Explorer IV's initial apogee altitude was 2180 km, its perigee was 260 km, and its inclination was 50.3 deg. Its 11.5 kg payload contained two Geiger-Mueller counters, two scintillation counters, and several temperature sensors. It proved that the effects of the nuclear detonations were transient and not the source of the original belts of trapped particles, as had been alleged by the Soviets.

Explorer V was a twin spacecraft to Explorer IV, but it failed to reach orbit on 24 August 1958 because its Juno first stage collided with its upper-stage cluster at separation.

The next spacecraft in the Explorer series contained an inflatable aluminized Mylar balloon, 3.7 m in diameter, which was intended to be tracked by radar to provide atmospheric density data. It was launched on a modified Juno I that contained a fifth stage; however, the spacecraft failed to reach orbit on 22 October 1958 because it broke free from its upper-stage motor 112 sec after liftoff, due to spin resonance effects.

By the end of 1958, the International Geophysical Year had produced such comprehensive results and had raised so many new questions about geophysics

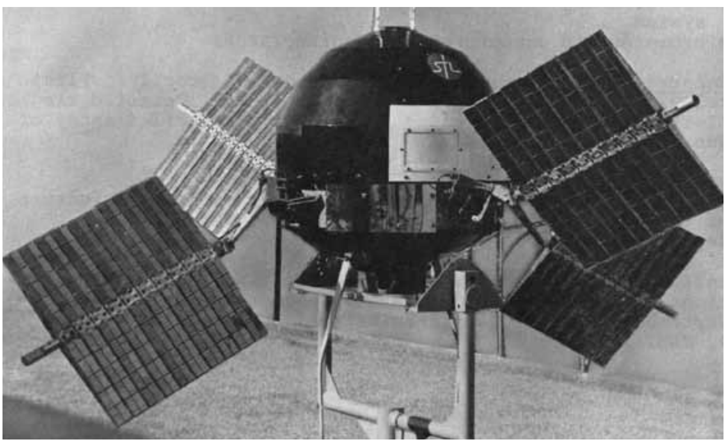


Fig. 1.29. The Explorer VI satellite.

that an agreement was made to extend the coordinated worldwide research for an additional year.

At this point, a new Juno II launch vehicle (Fig. 1.28) was developed, consisting of the substitution of a much larger Jupiter IRBM for the modified Redstone, or Jupiter C, first stage that was used in the Juno I. A double-truncated conical Explorer spacecraft, with a mass of 42 kg, was launched on the first Juno II on 16 July 1959, but a failure of the guidance inverter caused the vehicle to yaw sharply and break up some 5 sec after liftoff.

Explorer VI (Fig. 1.29) was a small, spheroidal satellite designed to study trapped radiation of various energies, galactic cosmic rays, geomagnetism, radio propagation in the upper atmosphere, and the flux of micrometeorites. It also tested a scanning device for photographing Earth's cloud cover, and it transmitted the first televised images of Earth from orbit. The satellite was launched on 7 August 1959 aboard a Thor-DM-18 Able III launcher that consisted of a military Thor IRBM as a first stage and the top two stages of the Vanguard launch vehicle as

Fig. 1.30. The Thor Able III launch vehicle.

its second and third stages (Fig.1.30). Its initial orbit had a perigee of 237 km, an apogee of 41,900 km, and an inclination of 47 deg.

Four solar-cell paddles mounted near its equator recharged the storage batteries in orbit. Each experiment except the television scanner had two outputs, digital and analog. A UHF transmitter was used for the digital telemetry and the television signal. Two VHF transmitters were used to transmit the analog signal. The VHF transmitters were operated continuously, while the UHF transmitter was operated for only a few hours each day. Only three of the solar-cell paddles fully erected, and this occurred during spin up, rather than before spin up as planned. Consequently, initial operation of the payload power supply was 63% nominal, and this decreased with time. The decreased power caused a lower signal-to-noise ratio, which affected most of the data, especially near apogee. One VHF transmitter failed on 11 September 1959, and the last contact with the payload was made on 6 October 1959, at which time the solar-cell charging current had fallen below

Fig. 1.31. The Explorer VII satellite.

that required to maintain the satellite equipment. The satellite's orbit decayed on 1 July 1961.

Explorer VII, a double-truncated conical spacecraft with a mass of 42 kg (Fig. 1.31), was successfully launched on 13 October 1959 on a Juno II into an orbit with an inclination of 50.3 deg, a perigee of 552 km, and an apogee of 1090 km. It contained instruments that measured micrometeoroid frequency, cosmic-ray distribution, heavy-nuclei spectrum, Earth energy balance, solar x rays, and solar Lyman alpha radiation. It was powered by an array of solar cells and 15 nickel-cadmium batteries. It transmitted useful scientific data for 15 months, and its transmitter continued to broadcast a carrier frequency for an additional five months. Explorer VII is still in orbit today.

1.8 Additional Vanguard Launches

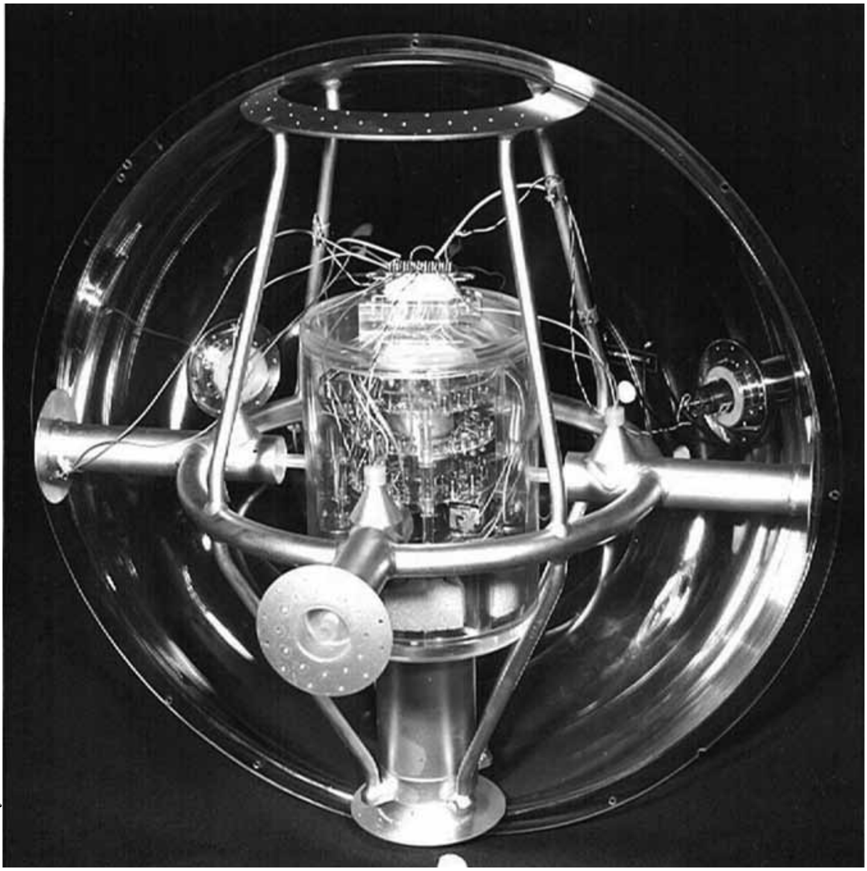
In addition to the Vanguard 1 engineering test satellite, several full-scale, fully instrumented, 51 cm diameter scientific spacecraft were prepared by NRL (Fig. 1.32). In addition to the normal Minitrack telemetry and tracking transmitter and receiver, the first one of them contained photon counters designed by Herbert Friedman and his team in the NRL Electron Optics Branch to measure the x-ray spectrum of the sun in the 1-8 Å band, while a second and third satellite contained similar photon counters to measure the solar spectrum in the 1100–1300 Å band. All three payloads also contained devices to monitor the space environment. Each spacecraft weighed 10 kg.

The first of these spacecraft was launched on Vanguard TV-5 on 28 April 1958. The flight was normal through second stage burning, but the second-stage shutdown sequence was not completed electrically, so the third stage was not properly separated and fired. The spacecraft did not achieve orbit.

The second of the scientific spacecraft was launched on 27 May 1958, on the first production Vanguard launch vehicle, designated Satellite Launch Vehicle 1, or SLV-1, which was basically the same as one of the test vehicles, minus some of the vehicle performance instrumentation. Once again, the flight was normal through second stage burn, but at that point, an attitude disturbance caused the third stage to be fired at an incorrect angle. The spacecraft did not achieve orbit.

The third spacecraft in the series was launched on SLV-2 on 26 June 1958, but failed to reach orbit because of a shut down of the second-stage engine after only 8 sec of thrusting.

The fourth and fifth spacecraft in this scientific series contained photoelectric instruments designed by William Stroud and his team at the U.S. Army Signal Corps Engineering Laboratory to measure the global distribution and movement of cloud cover and to contribute to the basic knowledge of Earth's energy budget. Each of these satellites weighed 10.7 kg. The first was launched on SLV-3 on 26 June 1958, but failed to achieve orbit because of a slight underperformance of the launch vehicle's second-stage engine, which resulted in the satellite being 76.2 m/sec short of its required orbital velocity of 7622 m/sec. The second (Fig. 1.33)



Courtesy of NASA

Fig. 1.32. Transparent view of 51 cm Vanguard satellite interior.

achieved orbit on SLV-4 on 17 February 1959 and was designated Vanguard 2. Its initial orbit had a perigee of 554 km and an apogee of 3301 km. It was the pathfinder for the highly successful TIROS weather satellites that followed in the next decade. Vanguard 2 and its 21.4 kg third-stage motor case are still in orbit today. The National Aeronautics and Space Administration (NASA) had been created on 29 July 1958, so although the satellite was built by NRL, the mission is recorded as a NASA success.

The next in the series of Vanguard science spacecraft contained a proton precessional magnetometer experiment built by James Heppner, originally of NRL and later of the NASA Goddard Space Flight Center. It was designed to survey Earth's magnetic field and to determine whether the predicted Stormer-Chapman ring current existed. Its external configuration consisted of a magnesium hemisphere, 51 cm in diameter, and a matching fiberglass hemisphere with a fiberglass cone that contained the magnetometer protruding out its top. An inflatable

Courtesy of NASA

Fig. 1.33. Vanguard 2 satellite on launch vehicle.

aluminized Mylar sphere designed by William J. O'Sullivan Jr. of the National Advisory Committee on Aeronautics and, later, of the NASA Langley Research Center, was also carried on this mission in a deflated condition, placed between the magnetometer satellite and its ejection system. Its objective was to provide a smooth, lightweight, spherical reflective target, 72 cm in diameter, that would be tracked optically and by radar to measure atmospheric density at very high altitudes. These two satellites were launched on the Vanguard SLV-5 on 13 April 1959, but failed to achieve orbit as a result of a loss of the launch vehicle's second-stage pitch attitude control.

At this point, an upgraded solid-propellant motor, the Allegheny Ballistics Laboratory X-248 Altair, was substituted for the Grand Central Rocket Company motor in the Vanguard SLV third stage. The X-248 used a fiberglass case and a nitroglycerine, nitrocellulose "double-base" propellant to provide a significant improvement over the former third-stage motor.

Fig. 1.34. Vanguard 3 satellite with magnetometer boom protruding from top.

The penultimate spacecraft in the Vanguard program was a fully instrumented, 51cm diameter, 11 kg sphere that contained a radiation balance experiment devised by Suomi of the University of Wisconsin. It was intended to be launched into an orbit inclined 48 deg to the equator, so as to cover a wide latitudinal band of Earth and its atmosphere. Its instruments were designed to measure direct solar radiation as well as radiation reflected and reemitted from Earth and its atmosphere. This satellite was launched on the Vanguard SLV-6 on 22 June 1959, but failed to achieve orbit due to a rapid decay of pressure in the second-stage propellant tanks that occurred shortly after second-stage ignition. The radiation balance experiment was later flown successfully on the Explorer VII satellite.

The final satellite in the Vanguard program was a fully instrumented, 51 cm diameter, 24 kg magnesium sphere, with a fiberglass boom (Fig. 1.34) that contained a second magnetometer built by Heppner. An additional solar x-ray payload built by Friedman and his NRL associates, basically identical to a payload flown earlier on an unsuccessful Vanguard mission, was integrated with the magnetometer payload. This satellite, designated Vanguard 3, was successfully propelled into a 507 × 3721 km orbit with a 33.3 deg inclination on 18 September 1959. Measurements it made helped to define the lower boundary of the inner Van Allen radiation belt. Again, this satellite was built by NRL, but the mission was recorded as a NASA success.

The total mass placed in orbit by the launch, including the 24 kg spacecraft and its 19 kg third-stage motor, was 43 kg—a record for the Vanguard program. All three of the Vanguard satellites and Explorer VII are still in orbit today, because their launch vehicles placed them in orbits with higher perigees than did all the other launches of that era. This approach significantly reduced atmospheric drag and extended the orbital lifetimes of these four satellites.

1.9 Conclusions

The Sputnik, Explorer, and Vanguard programs were all highly successful in opening the door to spaceflight in the late 1950s (see Table 1.1). Collectively, they pioneered in-space thermal control, radio telemetry transmission from orbit, Earth-based telemetry reception, precision interferometer ground-based tracking, solar cells for onboard power collection, transistors to minimize weight of spacecraft electronics, and an array of scientific instruments that could measure the characteristics of Earth and space while surviving the rigors of launch and orbital flight.

The Sputnik and Explorer programs have received their fair share of accolades over the past 50 years; however, the Vanguard program, which launched three times as many satellites into long-lived orbits as it was originally charged to do, all of which contributed materially to our knowledge of the geophysics of Earth and its surroundings, has been basically written out of the history books, with one or two exceptions. In fact, the Executive Committee of the U.S. National Academy's Space Studies Board refused repeated requests in 2007 by myself and others to acknowledge the existence of the Vanguard program in a brochure commemorating the 50th anniversary of IGY. The stated rationale for their refusal was: "Because we don't want to insult the Russians by claiming we had two satellite programs during IGY when they had only one." Hopefully, this chapter will have confirmed that we definitely did have two successful satellite programs during IGY.

The Explorer program continued to flourish and make major discoveries for many years following the end of the extended IGY, under the auspices of the NASA Goddard Space Flight Center. The Vanguard program came to an end in late 1959, but many of the technologies it demonstrated were adopted by other programs. Interestingly, the two upper stages of the Vanguard launch vehicle were adopted by the Thor Able program to launch Explorer VI to an apogee of 41,900 km and provide additional details about the outer Van Allen radiation belt. These stages were also used in the early versions of the popular Delta series of launchers. In addition, the Minitrack system evolved into the Navy Space Surveillance

Table 1.1 Summary of Launches from July 1957 to December 1959

	Sputnik	Explorer	Vanguard
Orbital launch attempts	4	9	11
Satellites placed in orbit	3	5	3
Satellites still in orbit	0	1	3
Launch vehicle failures	1	4	8

System "fence" that added powerful transmitters to track noncooperative satellites for the next 50 years. This, in turn, led to the Timation satellite navigation program, which laid the technological foundation for the Global Positioning System.

1.10 Reflections

With the luxury of 50 years of hindsight, we can now say that the Sputnik launches were probably the best thing that ever happened to the United States after World War II. Military successes during the war, coupled with a burgeoning economy and growing national pride in the postwar years, made the country extremely complacent and even arrogant about its place in the world. The U.S. general public had absolutely no inkling that the "backward" Soviet Union had advanced so far in developing large launch vehicles and satellites until Sputnik came beeping overhead. The resulting fear and outrage on the part of that public sparked a revolution in science and engineering and allowed the U.S. government to increase the budget for civilian and military space to levels unthinkable before Sputnik.

Shaking off its lethargy, the United States mounted a furious effort in space program development. For a time, the Russians continued to pull off a series of space "firsts"—first man in space, first woman in space, first man to perform an extravehicular activity (EVA), first woman to perform an EVA, first spacecraft to photograph the backside of the moon, first automated vehicle on the moon, first samples of lunar regolith returned to Earth, etc. However, the momentum generated in response to Sputnik I, II, and III resulted in the United States' finally plucking off the big prize—landing the first men on the moon and returning them safely to Earth. That momentum also resulted in this country's building up over the past 50 years the finest civilian and military space programs in the world, and in working together with most of the world's spacefaring nations on a staggering variety of manned and unmanned ventures in near-Earth and deep space. America's recognition of its debt to Sputnik I is best epitomized by the photograph

Courtesy of NASA

Fig. 1.35. NASA Marshall Space Flight Center team toasting Sputnik I.

(Fig. 1.35) of Konrad Dannenberg, Homer Hickam, William Lucas, Ernst Stuhlinger, and Julian Davidson offering a champagne 50th birthday "thank you" toast to a replica of Sputnik I at NASA's Marshall Space Flight Center on 4 October 2007.

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Conversations with U.S. Air Force Gen. Bernard Schriever and with Yvonne Brill, one of the participants in the original 1946 Project RAND study, shed light on the U.S. Air Force's early plans for Earth orbiting satellites and the difficult decisions that had to be made concerning missile and satellite program priorities. I particularly treasure discussions with Esther Goddard, Edward Francisco, Lowell Randall, Charles Mansur, and Fred Durant about Robert Goddard's Roswell years. Peter Wilhelm, Leo Slater, Gayle Fullerton, James Tugman, and Marybeth Dowdell of the current staff of NRL have been most helpful in providing documentation and many of the NRL photos reproduced here. A special thanks to Raymond (Bud) Fraze of Design Consulting, Tomas Svitek of Stellar Exploration Inc., Al Whitaker of the U.S. Space and Rocket Center, and Doyle Piland of the White Sands Missile Range archives for reference materials and photos. Thanks also to George H. Ludwig and Carl McIlwain for the use of their photos.

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