nasa-jpl

THE MOON PROBE PIONEER IV


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America's newly established National Aeronautics and Space Administration now directs the space research program of the Jet Propulsion Laboratory, California Institute of Technology.

For the *Pioneer III* and *Pioneer IV* firings, the U.S. Army Ballistic Missile Agency of the Army Ordnance Missile Command supplied the *Jupiter* IRBM booster rockets, including the inertial launching guidance and the spatial attitude control systems. Radiation experiments were prepared by the State University of Iowa. Many other research groups and industrial contractors contributed to the success of the operation by supplying advanced components, propellants, and guidance and tracking equipment.

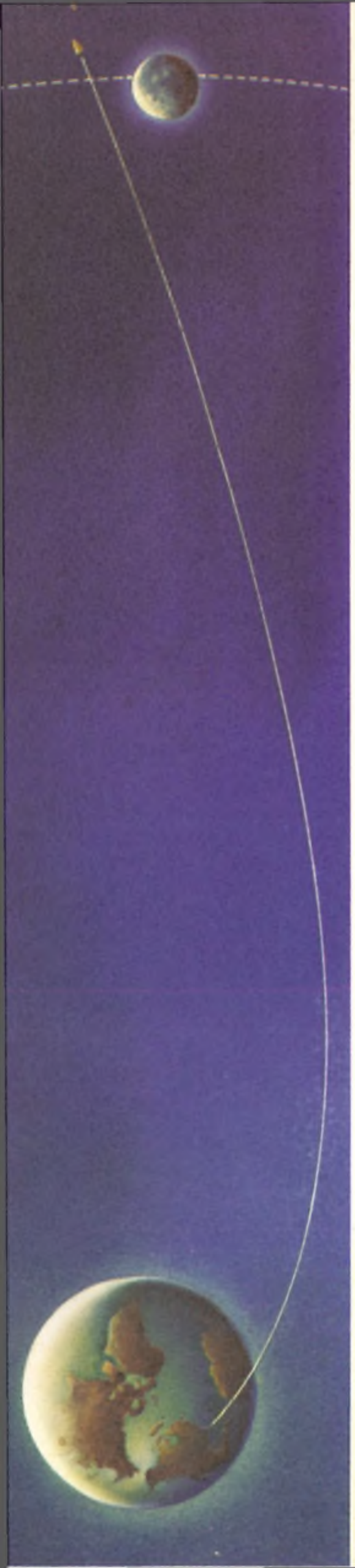

PLACE NO ARTICLES HERE

AMERICA'S FIRST ASTEROID

At 12:10:56 a.m., Eastern Standard Time, on March 3, 1959, the instrumented space probe *Pioneer IV* was hurled upward from the Atlantic Missile Range, Florida. Four and one-half minutes later, radio direction and velocity information derived from the payload transmitter signal revealed that the necessary 24,611 mile-per-hour Earth-escape velocity had been exceeded.

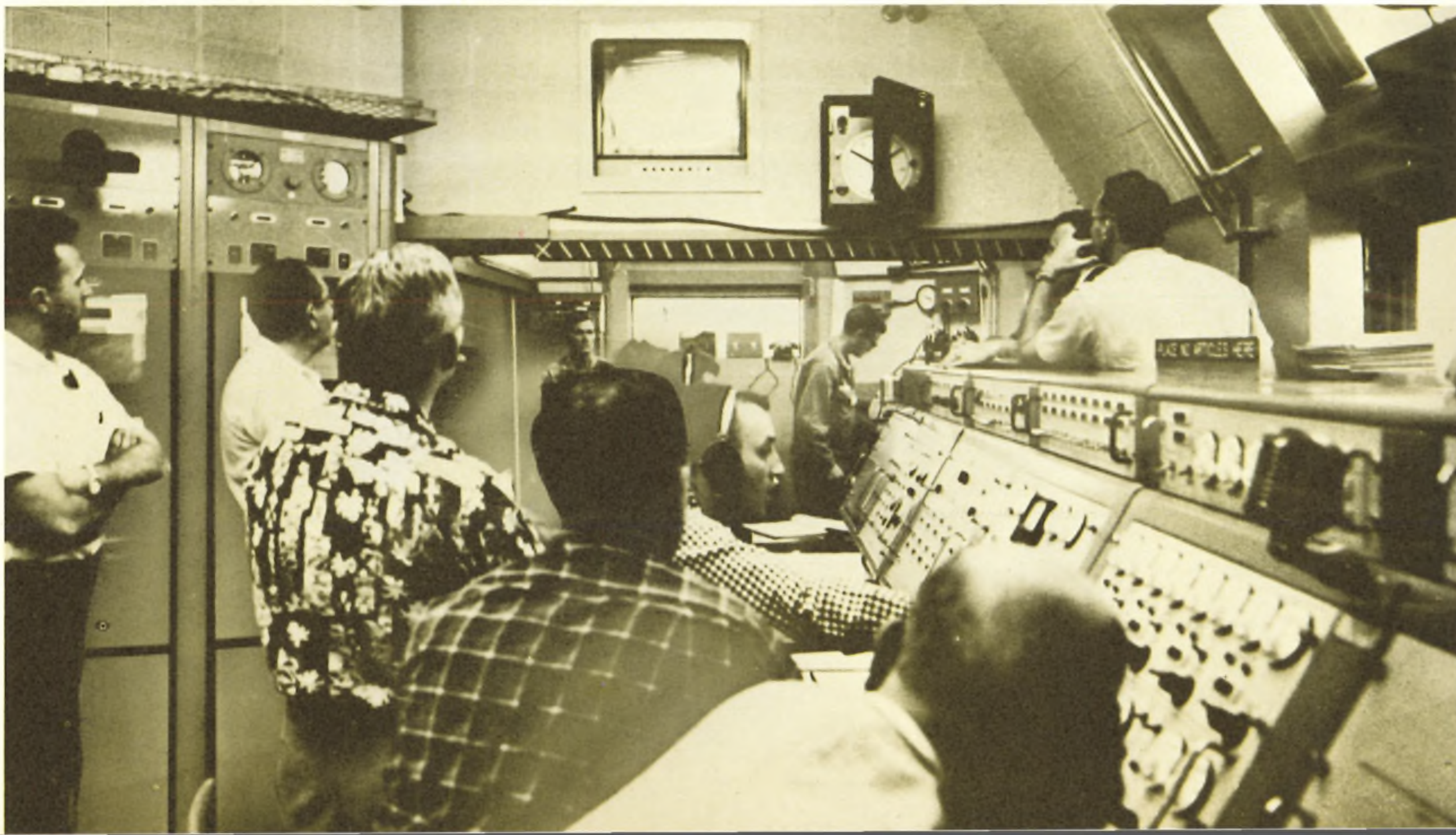
The velocity attained – 24,789 miles per hour – was a fraction of one per cent less than planned, but a new gold-plated 13.4-pound asteroid of the Sun was in the making.

Hour after hour, the digital computer at the Jet Propulsion Laboratory checked the probe-motion data which were being teletyped from three powerful JPL radio tracking stations. The trajectory was found to be within normal dispersion tolerances – 4.5° low in elevation and 1.3° south of the programmed azimuth heading. The probe would pass ahead of and below the moon.



On March 4, 1959, at 5:24 p.m. EST, after about 41 hours of flight, the *Pioneer IV* payload, with its 1.1-pound transmitter, passed 37,300 miles from the Moon's surface. Passage was 7.2° to the east and 5.7° south of the Moon's orbit. At its closest approach to the Moon, the probe was 236,500 miles from Earth, and its velocity was 4,490 miles per hour radially away from Earth. Since it had been injected in the general direction of Earth's orbital 66,600-mph motion around the Sun, the probe's velocity relative to the Sun was the vector sum of these two velocities.

For 24.6 hours of the lunar trip, one or more of the JPL tracking stations had been in line-of-sight position and recording the probe's telemetered information. Finally, 82 hours after liftoff, at 10:15 a.m. EST, on March 6, 1959, contact was lost when the mercury batteries were exhausted. But America had chalked up a new long-distance communication record of 407,000 miles. At that time, the probe's velocity radially away from Earth was 3,880 miles per hour.

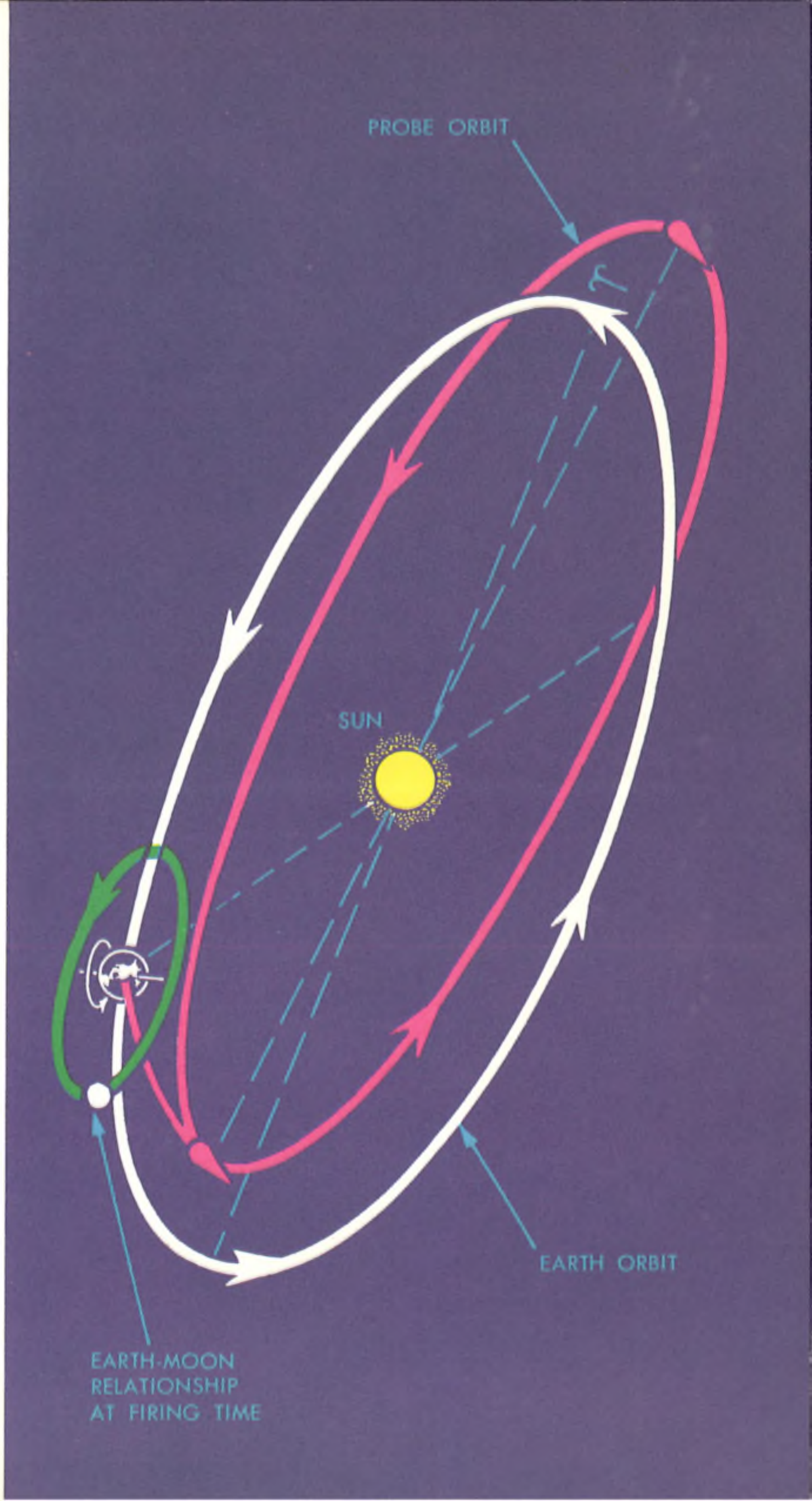


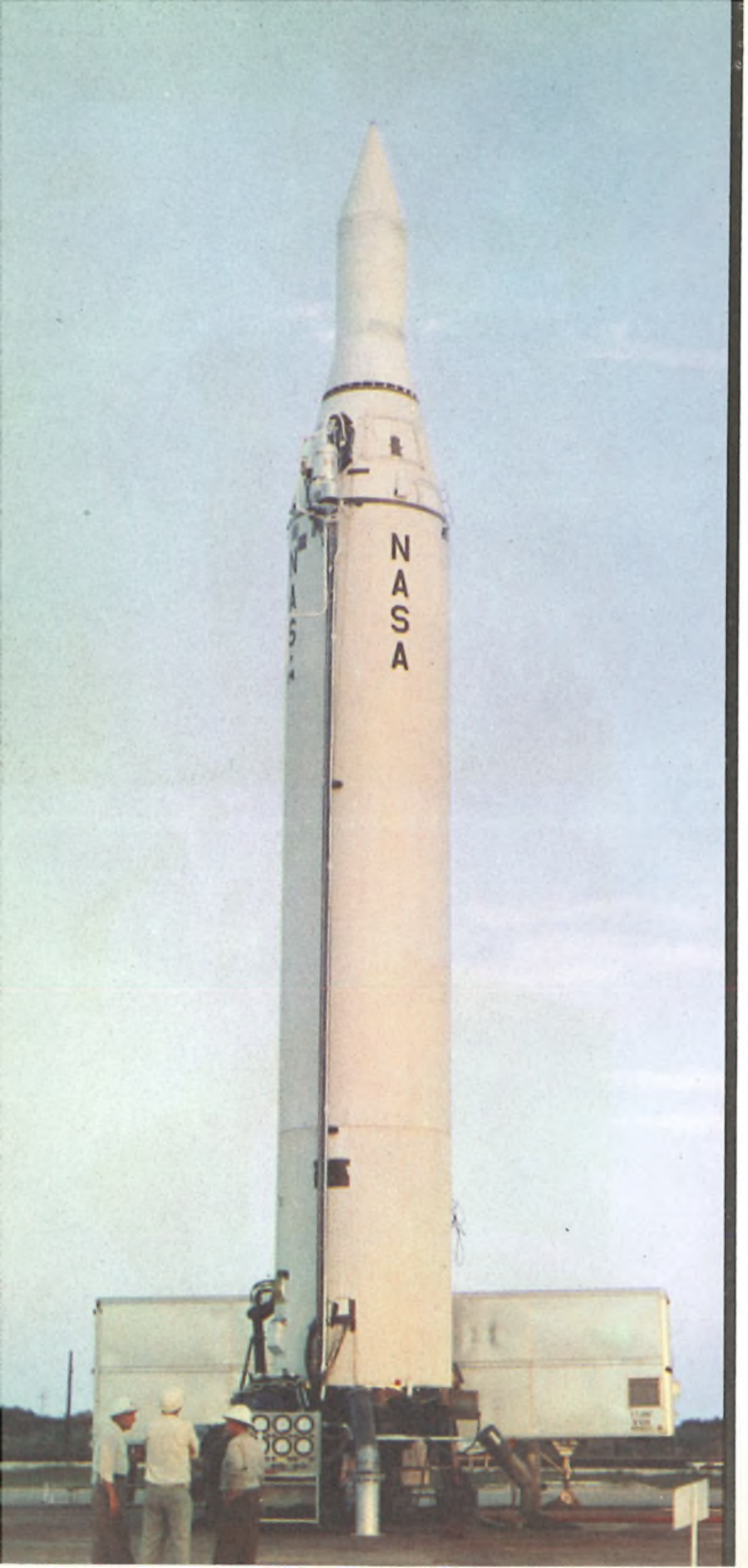
Eleven days later, on March 17, 1959, the probe was over 1.6 million miles away from Earth. At that time, *Pioneer IV* reached its closest approach (perihelion) to the Sun, 91.7 million miles, and had the greatest speed of its now solar orbit. This speed was the sum of the probe's 3,000-mph residual escape velocity and the Earth's 66,600-mph orbital velocity; thus the probe's total velocity in the solar system was 69,600 miles per hour at its perihelion.

The probe's speed was too great for a circular orbit around the Sun at this 91.7 million mile distance. In its elliptic orbit, it therefore gradually moved farther away from the Sun and its speed slowly diminished. After 6.6 months, on September 29, 1959, the probe reaches its greatest distance from the Sun (aphelion), about 106 million miles, and its slowest speed, 60,000 mph. The average speed for its orbit is 64,800 mph. The major axis (diameter) of the elliptic orbit is 198 million miles, whereas that of the Earth's orbit is 185.8 million miles. To complete its orbit, the probe requires 395 Earth days. This is about 30 days longer than the Earth's year, because the probe has farther to go and travels at a slower average velocity. Its orbit is inclined only 1.5° from the ecliptic plane.

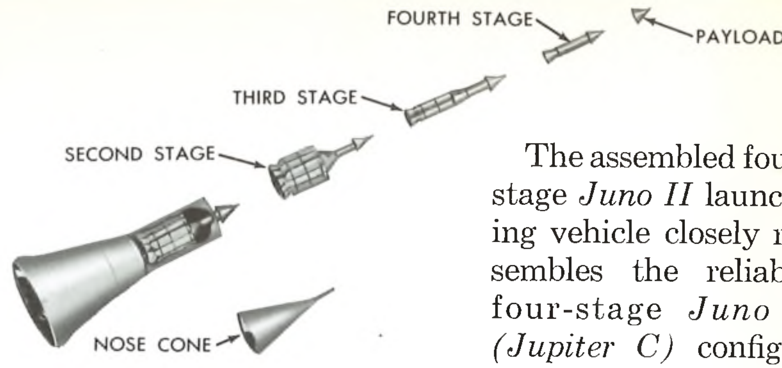
Only after another 12 years will the Earth and the probe approach within a million miles, near enough to each other so that the probe's motion will be even slightly affected by the Earth's gravity.

Although gold-plated *Pioneer IV* may never be seen again, it will probably continue to orbit the Sun as long as the solar system exists!





THE LAUNCHING VEHICLE



The assembled four-stage *Juno II* launching vehicle closely resembles the reliable four-stage *Juno I (Jupiter C)* configuration which on January 31, 1958, gave America its first Earth satellite, *Explorer I*. Both *Pioneer III* and *Pioneer IV* were launched by the *Juno II* system.

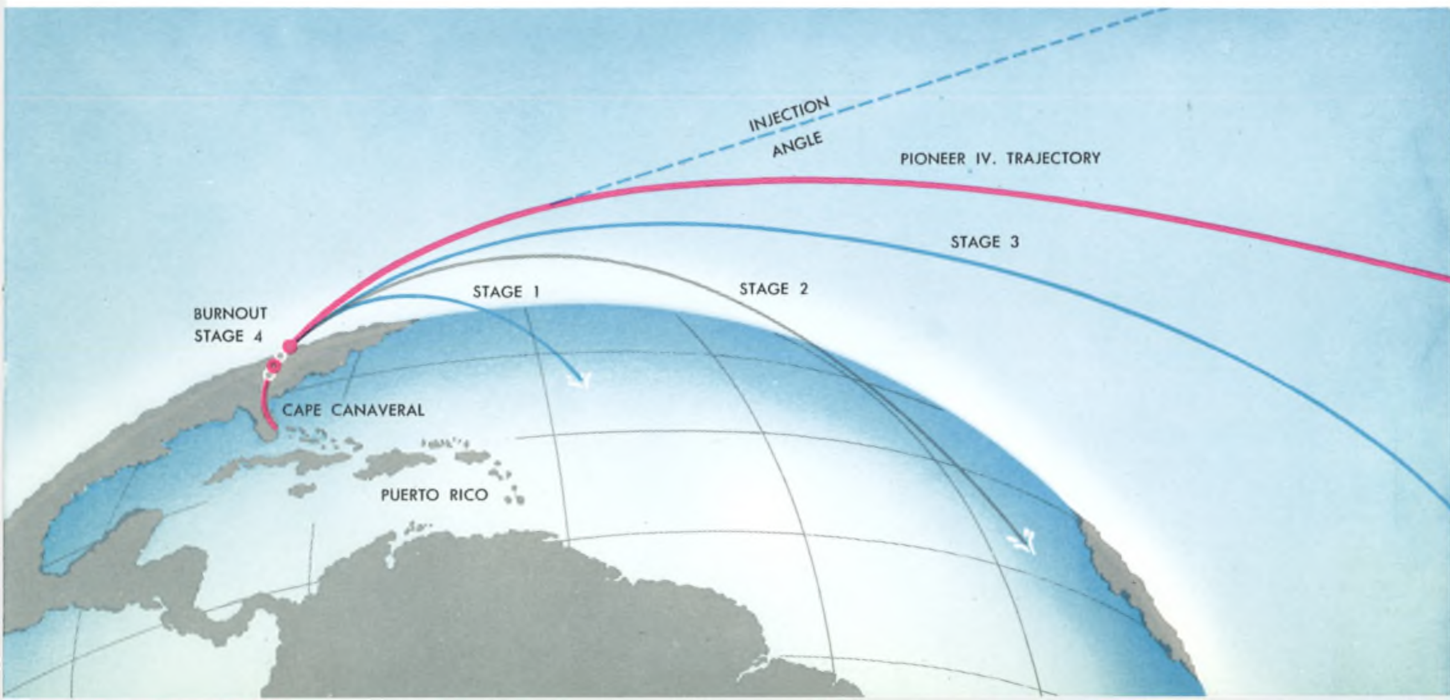
Stage 1 of the 76.7-foot-long *Juno II* vehicle is a modified Army *Jupiter* IRBM missile. Located on top of the *Jupiter* propulsion section is a guidance and control compartment which supports a rotating tub containing the high-speed assembly — rocket Stages 2, 3, and 4. The *Pioneer IV* payload was mounted on the top of Stage 4.

Stage 1. For this space mission, the *Jupiter* (Stage 1) was elongated to 64 feet to provide for additional propellants. The first stage assembly weighed over 100,000 pounds. The liquid-propellant rocket engine burned an RP-1 petroleum fraction and liquid oxygen at the rate of about 75 gallons per second for a nominal 183-second thrust period.

Before liftoff, two electric motors located at the forward end of the control compartment began the spinup of the tub which contained the high-speed assembly. At liftoff, the tub was rotating at 400 rpm. After liftoff, the motors gradually increased the spin velocity to 600 rpm in order that resonant vibration frequencies might be avoided. The spinning of the high-speed cluster provided directional stability.

During the burning period of the first stage, the gyros and accelerometers contained in the guidance and control compartment sent signals to servos which swiveled the gimbal-mounted main engine and thus tilted the vehicle into its preprogrammed trajectory. The jet exhaust from the propellant pump turbine was used to prevent roll.

Stage 1 lifted *Pioneer IV* to a 70-mile altitude and boosted it to a velocity greater than 10,000 miles per hour. At about 5 seconds after Stage 1 burnout, the propulsion section containing the main engine and propellant tanks was separated from the guidance compartment (with the spinning high-speed stages) by explosive bolts. The detached propulsion portion was then pushed backward by a small retrorocket. For the next 55 seconds, the guidance and control equipment proceeded to align the nose compartment to the proper space attitude—essentially aiming the spinning high-speed stages at the target. During this alignment period, the gyroscopes and accelerometers in the inertial platform signaled corrections for the differences between actual and desired space alignment. Eight tangentially-directed compressed-air nozzles at the tail of the instrument compartment aligned the three spinning upper stages to the proper injection angles while at the same time preventing instrument compartment roll. All sequences were programmed and controlled automatically, the only ground-to-missile control being an emergency destruction system.

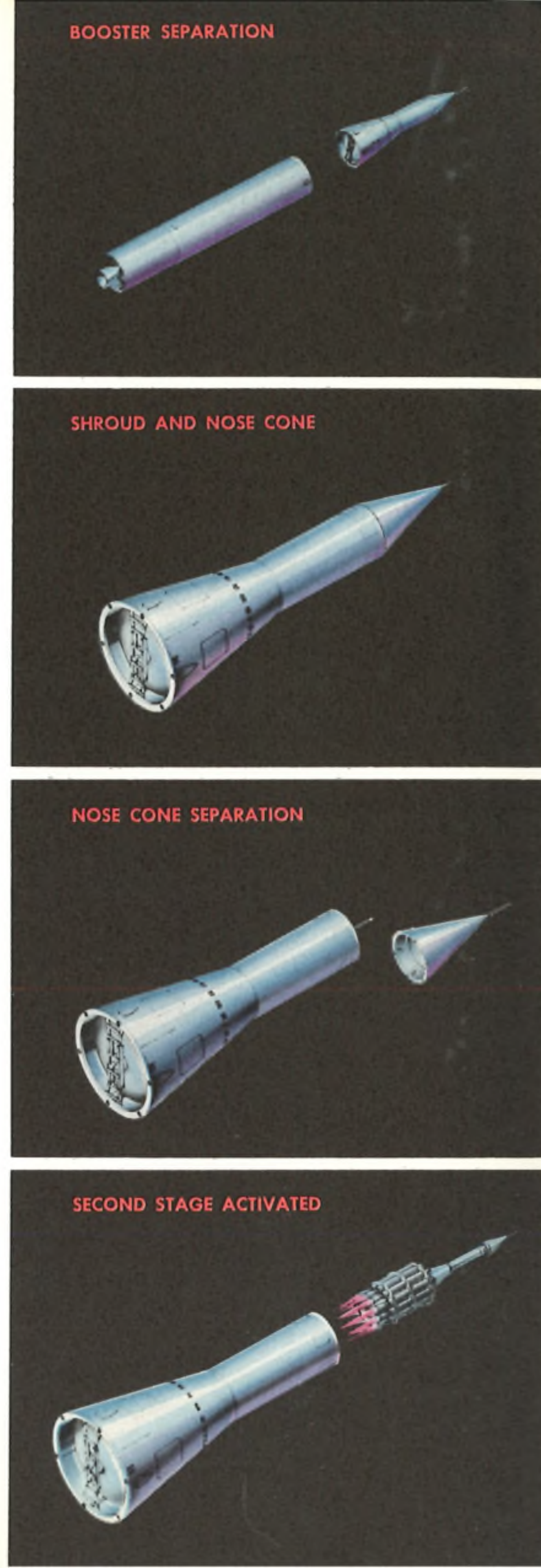


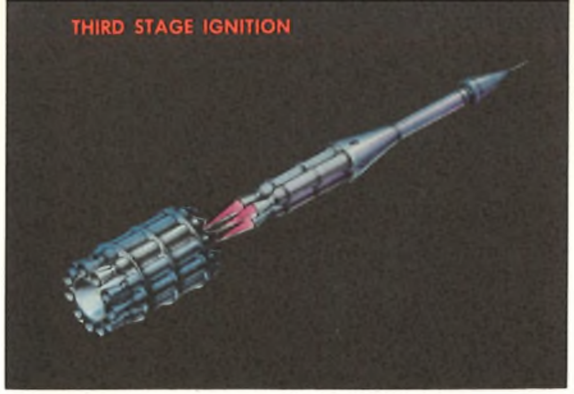
Protective Nose Cone and Shroud. To protect the payload and the upper-stage solid-propellant rockets from aerodynamic heating, a fiberglass-coated aluminum nose cone with a cylindrical supporting shroud was used to cover the entire high-speed assembly. This shroud had 12 plastic windows, each about 15 inches square, to permit transmission of payload radio signals to the tracking stations on the ground. Vents near the shroud's flared base were provided to allow the burning gases to escape when the Stage-2 rockets fired. About 13 seconds after first-stage separation, when the vehicle was safely out of the atmosphere, explosive bolts and springs released the protective nose cone and kicked it ahead. It was then pushed to one side, out of the way of the payload, by a lateral-thrust rocket in the cone, itself.

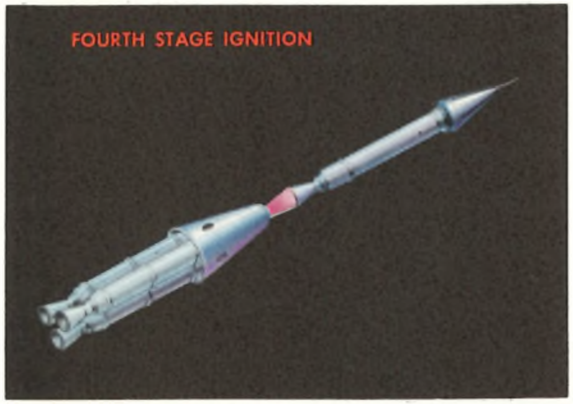
The High-Speed Stages. Except for the use of new higher-performance JPL solid propellants and a titanium motor case for Stage 4, the three spin-stabilized upper stages used for accelerating *Pioneer IV* to escape velocity were identical to those so successfully used for launching *Explorer* satellites.

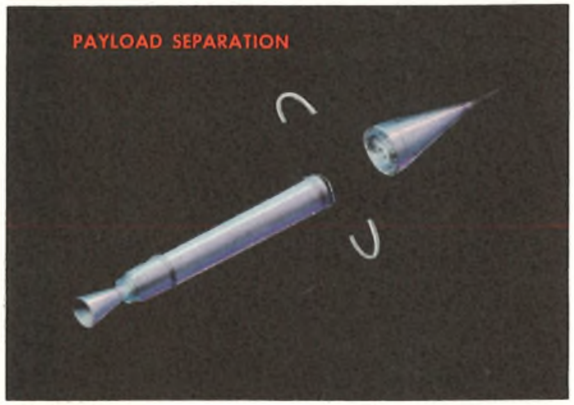
An annular group of 11 scaled-down JPL *Sergeant* rockets formed Stage 2. These 6-inch-diameter motors were held by 3 bulkheads around a tube that housed Stage 3. The base of the launching bucket that held the spinning rocket clusters ready for firing was mounted on a bearing and spun by two electric motors located in the guidance control compartment. Within 37 seconds after the protective nose cone had been removed, all transient fluctuations in spatial attitude had been corrected by the airjets in the tail of the control compartment, and the entire assembly was pointed in the programmed direction. An electric timer then sent the firing current to the igniters inside the solid-propellant motors. All motors in Stage 2 fired, and the high-speed assembly left the spinning tub behind.

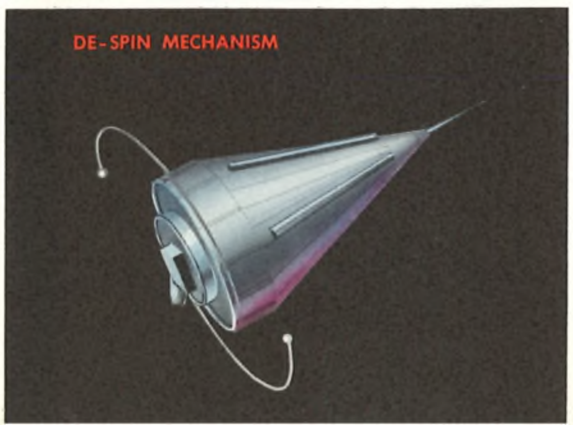
A cluster of three scaled-down *Sergeant* rockets formed Stage 3. They were nested within the annular second stage. About 9 seconds after the ignition of Stage 2, this solid-rocket assembly was ignited by a timer and shot out











of the center tube of Stage 2. During the upper stage firings, the spin rate slowed to 480 rpm.

A single scaled-down *Sergeant* rocket, its light titanium case mounted within a cone above Stage 3, served as the Stage-4 motor. At its top end, explosive bolts and a ring clamp held the conical payload—the gold-plated *Pioneer IV* probe. About 9 seconds after the ignition of Stage 3, a timer ignited this high-performance motor. A few seconds after motor ignition, at about a 140-mile altitude, the Earth-escape velocity was exceeded. After Stage-4 propellant burnout, about 4.5 minutes after launch, the empty motor case was separated from the instrumented payload by small explosive charge and spring arrangement. Motor separation was necessary because an optical scanning device was located in the probe base. The burnt-out motor case and the clamps released during payload separation also continued to travel on through the vacuum of space but in a path separate from that of the payload.

De-spin Mechanism. A relatively slow spin rate was required for proper operation of a photo-sensitive trigger later on while the probe was passing near the Moon. This scanning device was being tested in the *Pioneer IV* firing for use in future probes to activate either a film or vidicon camera for mapping the far side of the Moon. A braking action to slow the payload spin rate was obtained by two 6-gram weights fastened to the ends of two 60-inch-long wires wound around the base of the payload cone. About 11 hours after launch, a mechanism released the tiny weights and permitted both wires to pay out. While the wires were unwinding the centrifugal force of the weights pulled in a direction opposite to that of payload rotation. In one-fourth of a second, the probe's spin rate was slowed down from 480 to 11 rpm, in the same way that a pirouetting skater slows down by extending his arms. Both weights and wires were then released to fly off into space, leaving the payload spinning at this slower rate.

PROBE STRUCTURE AND INSTRUMENTATION

Structure. Externally, the *Pioneer IV* payload consisted of a thin glass-fiber cone, 20 inches long with a base diameter a little over 9 inches, housing the environment-sensing and telemetering elements. The fiber cone was covered with a gold-wash coating to make it electrically conducting and with black stripes to maintain a balance between the heat absorbed from the sun and that radiated to space; internal temperature stabilized at about 107°F. A 3-inch-long aluminum spike tip on the probe cone was electrically insulated from the cone; with the gilded cone, this arrangement served as the dipole radiating antenna. Total weight, including Microlock transmitter, environment sensing and telemetering instruments, and mercury batteries, was 13.4 pounds.

Transmitter. The payload contained a tiny transistorized 1.1-pound transmitter which operated at a 960.05-mc frequency. During the countdown, at X −13 seconds, the transmitter began broadcasting on its own battery power. The total effective radiated power, including the modulation, was 180 mw. Three standard telemeter channels were used for transmitting data on the space environment and on probe operation. Gradual or stepwise changes in the musical tone pitch of the audiofrequency modulations were used to convey the desired space environment and probe-function data. An indication of the probe spin rate was obtained from fluctuations in the recorded carrier signal strength.

Channel 1 conveyed information on the payload internal temperature obtained by resistance thermometers, and on the optical scan device operation.

Channel 2 indicated the intensity of high-energy ionization between 5 and 100 roentgens per hour, using a Geiger counter combined with a pulse rate circuit.

Channel 3 indicated intensity of the low-level but penetrating radiation from 0 to 10 roentgens per hour. These modulated signals were recorded on the ground by several powerful tracking stations.

Electric Power Supply. Power to operate the measuring instruments, the telemeter oscillators, and the transmitter circuitry was furnished by a battery of 18 mercury cells. To assure uninterrupted peak voltage for signal transmission, these cells must be kept within the temperature range of 40 to 120°F. Continuous clear transmission from *Pioneer IV* was received until battery exhaustion, which occurred at 7:15 a.m. PST (10:15 EST), March 6, when the probe was 407,000 miles from Earth.

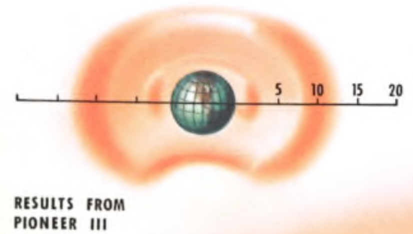
Radiation Counters. A more complete survey was desired of the Van Allen radiation belts which had been discovered by the *Explorer* satellites and *Pioneer III*. One of two cigarette-size Geiger-Mueller tubes used for measuring the ionizing radiation was shielded with a ⅛-inch-thick layer of lead. Thus, it could respond to protons above 50 million electron volts (MEV) energy, electrons above 10 MEV, or very hard X-rays or gamma rays. The other counter tube was not intentionally shielded, but its walls were thick enough to exclude protons below 20 MEV or electrons below 3 MEV.

IGY scientists at the State University of Iowa had proposed the preliminary design of the radiation measuring system. The power supply, scalers, and associated circuitry were designed and built by JPL.

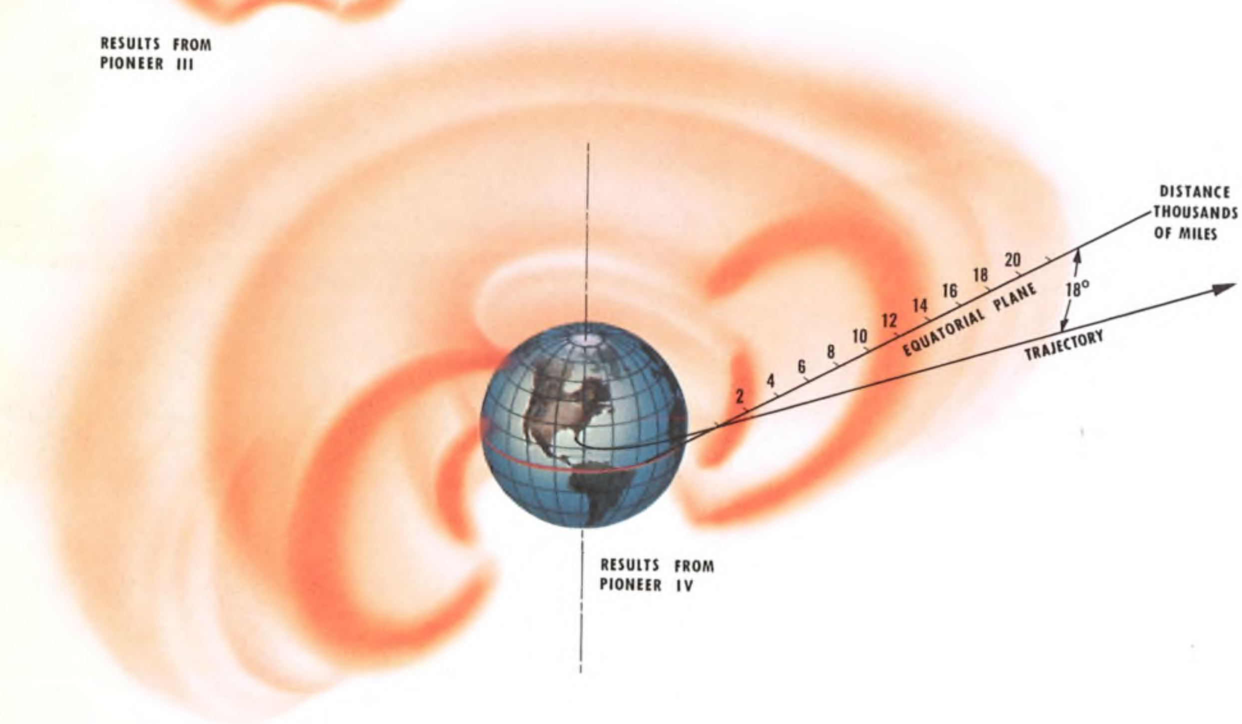
PIONEER IV TRANSMITTER CHARACTERISTICS

CARRIER AND TELEMETER CHANNELS	POWER, DBM	CENTER FREQUENCY AND MODULATION
CARRIER SIGNAL	19.8	960.05 mc
SUBCARRIER 1	11.5	400 +15 cps
SUBCARRIER 2	11.5	560 ±30 cps
SUBCARRIER 3	15.5	730 −20 cps

NEW DATA ON THE PLASMA BELT AROUND THE EARTH



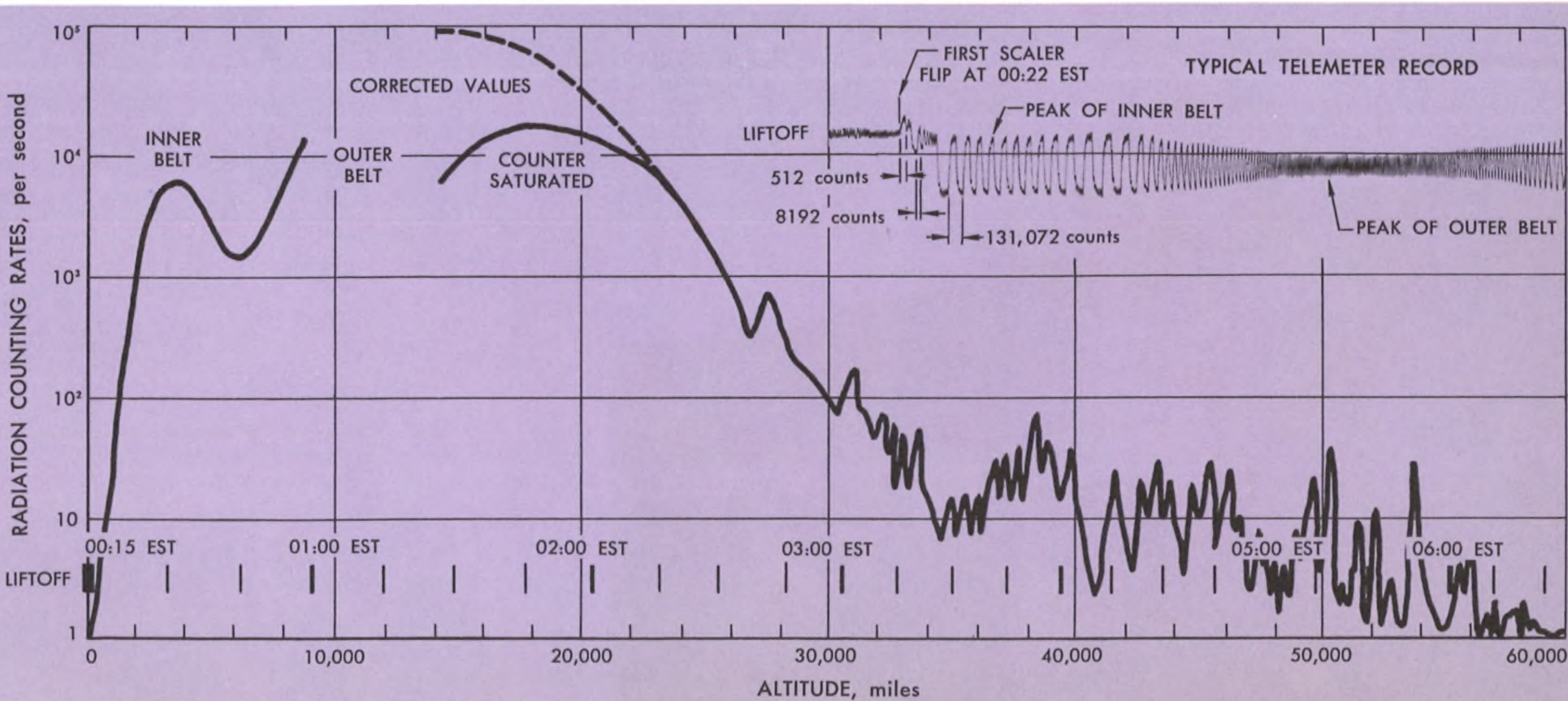
Interesting new data were obtained on the Van Allen belts of charged particles that were first explored by the *Explorer* satellites and *Pioneer III*. The most striking discovery was that the intensity of the upper belt had changed during the three months between *Pioneer III* and *IV* firings. The peak counting rate of the unshielded counter in *Pioneer IV* was approximately 100,000 times the normal cosmic ray background in cislunar space, whereas that measured by *Pioneer III* three months before was about 12,000. The probable explanation is the unusual amount of solar flare activity during the six days just prior to the launching of *Pioneer IV*. That this intense solar magnetic storm injected charged particles into the Earth's atmosphere was proved by the observation of strong auroral displays for five consecutive nights before the *Pioneer IV* firing. No similar phenomenon had occurred for many months prior to these firings. Apparently the Sun is the source of the particles trapped by the earth's magnetic field in the upper Van Allen belt. The drastic change in intensity in only three months indicates that the lifetimes of particles in the upper band may be the order of a few years, or perhaps as low as a few weeks, but certainly not centuries. The absence of any such significant variation in the lower belt may indicate that its particles probably do not come from the Sun.



Another surprise was the discovery of what might be called a third belt at a still higher altitude than the others, in a region where little trapped radiation existed in December. In the region between 30,000 and 60,000 miles above the surface of the Earth, about 20 regions were observed in which the counting rate rose suddenly and then abruptly dropped again. The exact nature of these streams or bands or waves of charged particles is not known, and they will require much more careful study. A surprising fact is their extreme narrowness, some of them being not over 50 miles thick.

The other significant result was the discovery that the shielded counter showed little if any effect from the upper belt (or belts). Findings of the *Explorer IV* satellite showed that the lower band contained very penetrating particles (probably high energy protons). The results from *Pioneers III* and *IV* showed that the upper belt consists of less penetrating particles, probably electrons. For future space travel it is, of course, important to know how much shielding is required to reduce the radiation inside a space ship to a tolerable level for some particular flight plan.

Peak radiation dose rates encountered by space probes passing through these ionizing belts range from 10 to 100 roentgens per hour, at least 100 times the dosage considered safe for humans. In the American atomic industry, maximum dosages of 0.1 roentgen during any 1 day and 0.3 roentgen within 1 week are considered permissible exposures. It is possible that the cone-shaped zones centered around the Earth's magnetic poles may normally have particle counting rates below 100 per second, rather than the 10,000 to 100,000 experienced by *Pioneer IV*. Vehicles taking off into space through these holes should be able to escape severe bombardment from cosmic radiation.



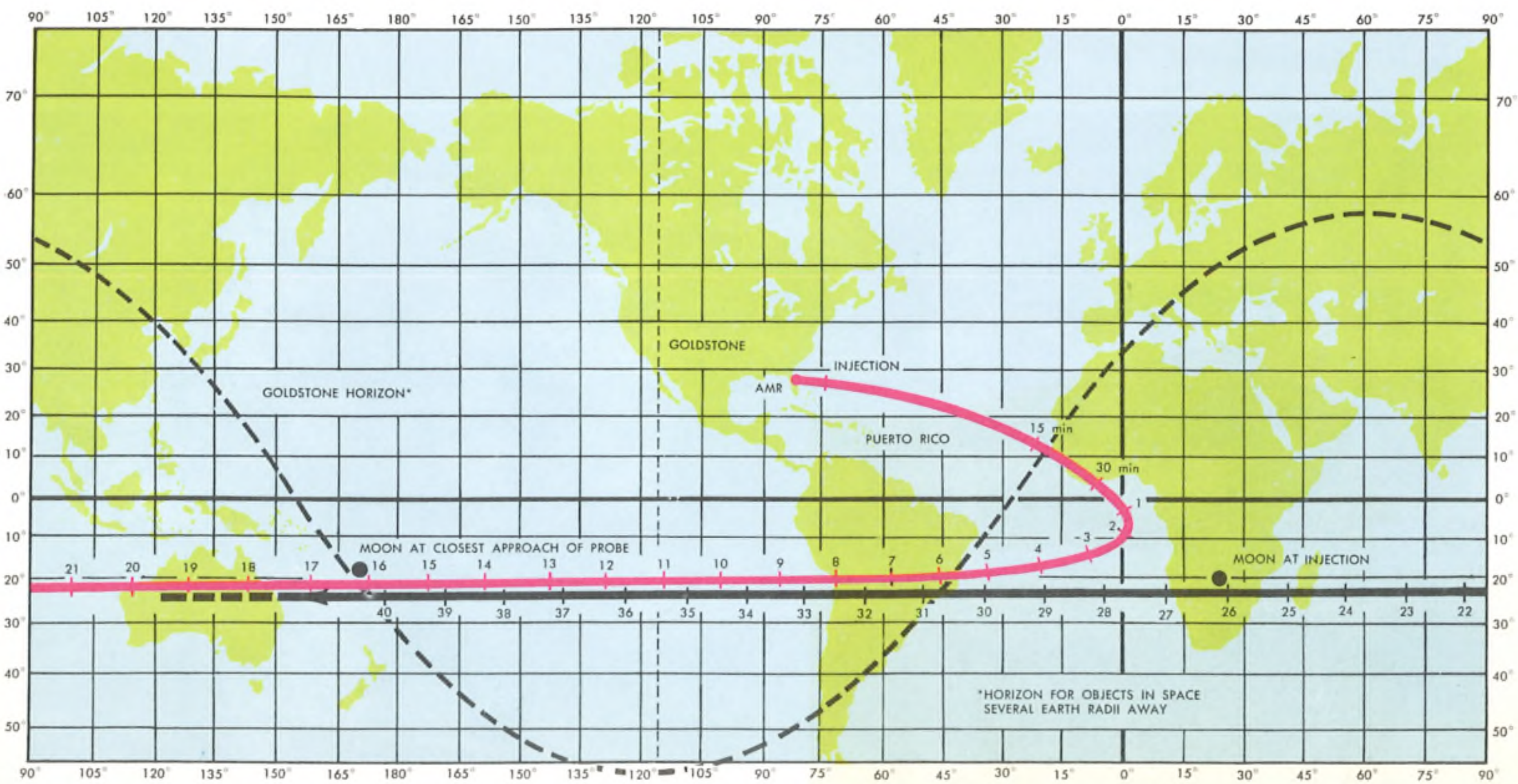
PROBE TRACKING AND TRAJECTORY COMPUTATION

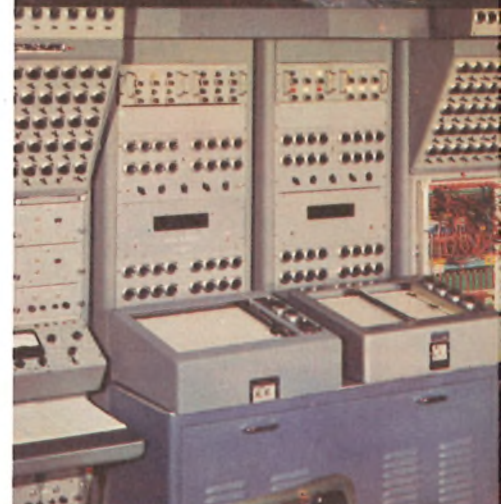
Tracking Station Operations. Several tracking stations were used to measure the *Pioneer IV* flight-path velocity, altitude, and direction. In the later phases of the flight, after the probe was over 100,000 miles from Earth, only the huge Goldstone tracking station in California and the even larger radio-astronomical antenna at Jodrell Bank, Manchester, England, were able to receive the 180-mw radio signal from the speeding probe.

At the time of *Pioneer IV* launching, two JPL tracking stations, located in Florida and downrange in Puerto Rico, were responsible for obtaining initial trajectory data. Liftoff at 12:11 a.m. EST was at an elevation angle of 11.8° from local horizontal and an azimuth heading of 93.6° from local north. For the first 4 minutes, the JPL and Army Ballistic Missile Agency (ABMA) tracking installations for the Atlantic Missile Range launch site were the only stations in line-of-sight position to receive the radio transmission from the probe. However, before the probe signal was lost temporarily over Florida's eastern horizon, the Puerto Rico tracking station was informed where on its northwestern horizon to acquire the signal. The 10-foot dish near Mayaguez, Puerto Rico, acquired the signal at 12:16 a.m. EST, 5 minutes after launch and a few seconds after probe injection. Subsequently, Puerto Rico also lost the signal for 30 minutes over the horizon; but, because of the Earth's rotation and the probe's rapid rise away from Earth both the Florida and Puerto Rico stations reacquired it at 1:30 a.m. almost simultaneously with acquisition at Manchester. On each of the three succeeding days, Manchester maintained contact during a portion of the times JPL stations did not have the probe in line-of-sight.

During initial tracking, the big IBM 704 digital computer at JPL had accumulated enough data to direct the aiming of the Goldstone antenna toward the exact east-southeast horizon point at which the probe was to appear. Computer predictions were accurate, and at 3:47 a.m. PST (6:47 a.m. EST) the 85-foot-diameter, 120-ton dish antenna at Goldstone Dry Lake acquired the probe signal, 6.5 hours after launch. *Pioneer IV* was then 60,000 miles from the Earth, and its speed had diminished to 7,080 mph.

For a 15-minute period, four tracking stations, Florida, Puerto Rico, California, and England, were all locked onto the *Pioneer IV* transmission. A unique opportunity was thus provided to obtain a four-way fix on the probe's exact position in space. Goldstone maintained contact for almost 10 hours until the Earth's rotation caused the probe to set like a star





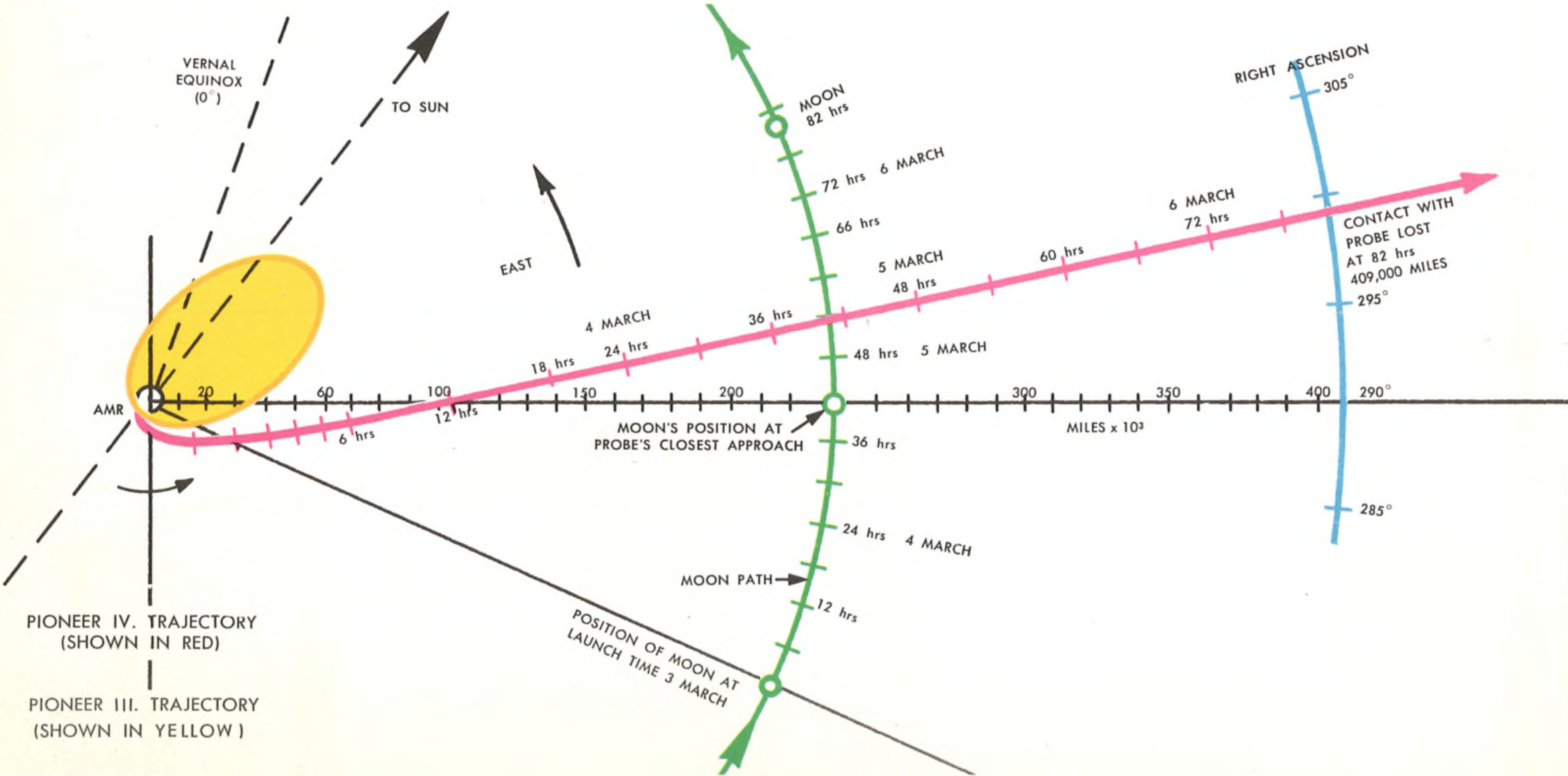
117,000 miles away over the hills on the western horizon at 1:04 p.m. PST.

During the next 14 hours without JPL contact, the computer at JPL calculated the new aiming point on the eastern horizon. On schedule to the second, the *Pioneer IV* signal was reacquired by Goldstone at 4:33 a.m. PST, March 4. At that time, the probe was 195,000 miles away and traveling 4,810 mph. It was now in a position where the gravitational forces of Sun and Earth were approximately equal. After about 9 hours of tracking, the probe again set, at 1:14 p.m. PST.

Later on that same day, the closest approach to the Moon occurred at 2:24 p.m. PST, March 4, 41 hours and 13 minutes after launch. The miss distance was computed to be 37,300 miles from the Moon, 5.7° to the south and 7.2° to the east. Coordinates were right ascension 297.6° and declination 22.6°S.

Next morning, March 5, at 4:37 a.m. PST, Goldstone made its third acquisition. At that time, *Pioneer IV* was 303,000 miles away and was still moving away from the earth at a rate of 4,200 mph. Contact was maintained for almost 8 hours. When the probe set, it was 340,000 miles away.

On March 6, Goldstone made its fourth and last acquisition at 4:50 a.m.

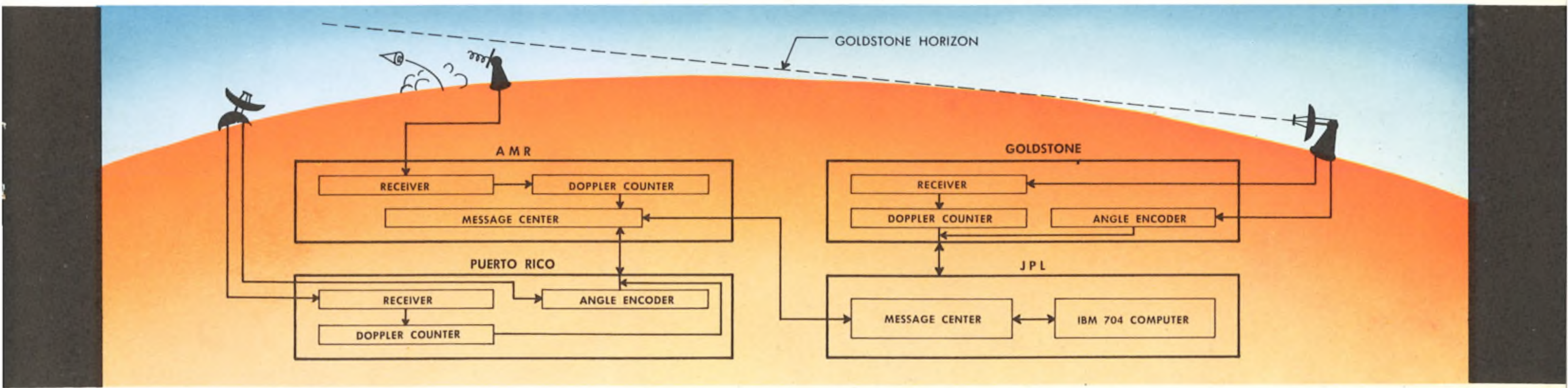


PST. Now the probe was 399,000 miles away and had slowed to 3,884 mph. Loss of signal occurred during this tracking period when the probe batteries became exhausted at X+82 hours (7:15 a.m. PST). At that time, *Pioneer IV* was 407,000 miles away from Earth, and a new world's record for long-distance communication had been established. From the signal strength, scientists at Goldstone, who supervised construction of the big dish, estimated that they could have held contact out to a distance of at least 700,000 miles if the batteries had held out that long.

All tracking stations were interconnected by radio and by direct wire telephone communications. Teletype circuits converged at JPL, where the punched-paper telemetry data were transferred to punched cards and fed into the computer for reduction.

Goldstone Tracking Facility. A natural bcwl-shaped area just south of Death Valley in the Mojave Desert was selected as the ideal site for the principal probe tracking station. This remote region is exceptionally free from background noise, or radio interference. Goldstone's 85-foot diameter reflecting dish turns on a polar-parallel axis atop a 110-foot high tower. This parabolic antenna is constructed of punched aluminum panels that are bolted on an open steel framework, similar to the giant radio telescopes used to find and track radio signals from stars and spiral nebulae. Although it outwardly resembles a radio telescope, the Goldstone antenna is built to track at high angular rates for communicating with either satellites or deep-space vehicles.

Scientists at the Jet Propulsion Laboratory used the tracking lessons learned from earlier successful launchings of *Explorer* satellites to provide the basis for extremely long-range communications systems. Goldstone has been shown to possess at present a tracking capability for receiving radio signals from deep space up to 700,000 miles from the Earth. By increasing the efficiency of the 1-degree beamwidth 151-dbm dish as a receiver, and also by increasing the power and size of radio transmitters in future space vehicles, it is expected that the tracking capability will eventually be extended to 20 billion miles. Tracking accuracy is within 0.05°. With the help of the IBM 704 computer, the hundreds of position points recorded by the Goldstone and Puerto Rico tracking stations are combined to give the best averaged fit to the actual trajectory. Thus the accuracy of each separate point is increased to better than 0.01°.



CHOICE OF PIONEER IV

LAUNCH TIMES AND ANGLES

The Moon as a Target. Imagine the problem of trying to hit a fast-moving clay pigeon from a spinning merry-go-round, using a rifle fastened to the platform! An even more complex situation confronted the mathematicians who had to figure out not only the lead angles, the launch angles and firing times, but also the exact weight for *Pioneer IV*. At the fastest speed attainable with the then-available propellant energy for a significant instrumented payload, it would take longer then one complete turn of the earth to reach the moon.

The Moon forms a target the size of a dime held out at arm's length, Every hour it moves eastward 2,290 miles in its orbit around the Earth, or more than its own diameter of 2,160 miles. At the *Pioneer IV* arrival time on March 4, the Moon was 236,000 miles from the Earth, about 14,000-miles farther away than it was during the *Pioneer III* firing, December 6, 1958. Every month, the Moon spirals back and forth from north to south and back again across the celestial equator (Earth's equator projected outward into space).

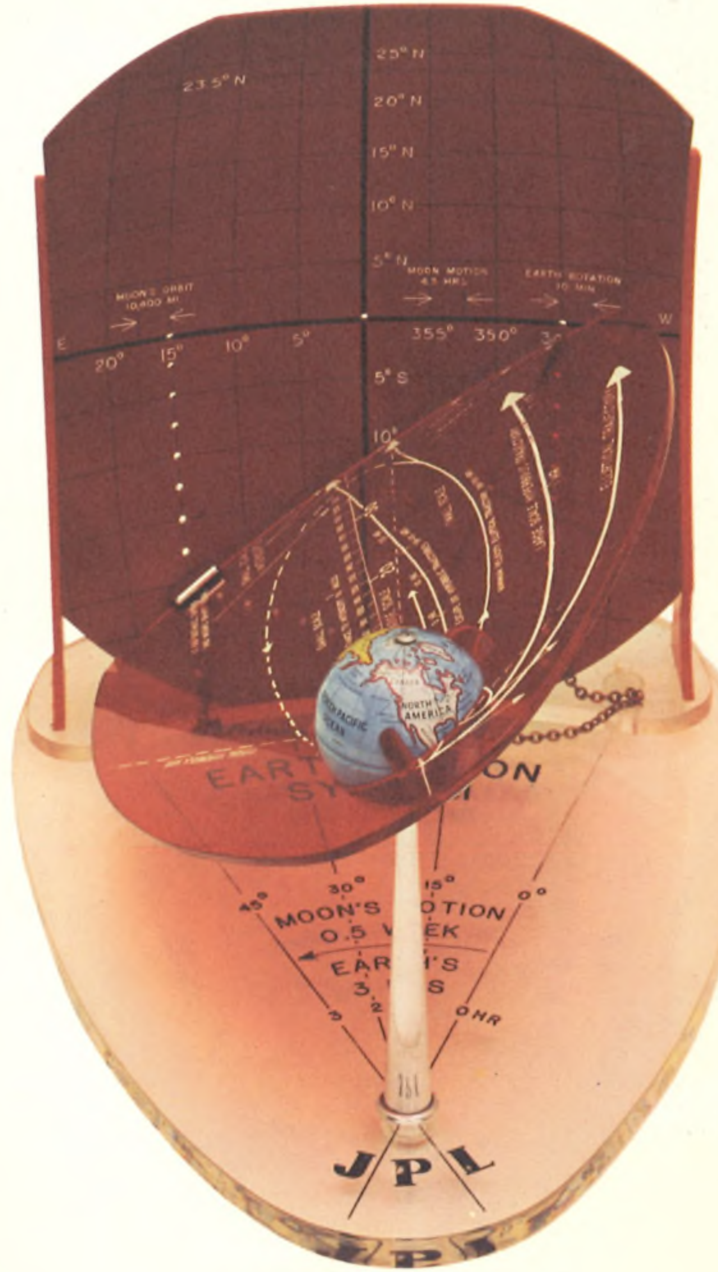
To take advantage of the extra 920-mph surface rotational speed of the launch site, resulting from the rotation of the Earth on its axis, *Pioneer IV* was fired eastward. As a consequence of the Earth's force of gravity, this launching direction and location caused the probe's initial plane of motion to be tilted with respect to both the Earth's equator and the Moon's orbit plane. This imaginary plane, along which the probe moves during the first part of its flight, does not rotate with the Earth. Imagine it pinned down to the center of Earth and to some stars out in space, and thus fixed in its direction.

Now if the Earth were a perfect sphere and were the only body in all the Universe, the probe would continue throughout its life to move in this first plane. In such a case, its trajectory would be easy to compute, and could be done with a pencil and paper. Unfortunately, the Earth is not perfectly spherical nor is it alone in space. Both the bulge around the Earth's center and other bodies, particularly those near by such as the Moon and those which are very heavy such as the Sun, pull the probe out of this ideal plane. Actually, until the probe moves quite near the Moon, the Moon's gravity is not important. And until the probe moves several million miles from Earth, the Sun's gravity has only a negligible effect.

If the probe were a satellite, it would swing around the Earth in this plane from then on, going south of the equator on half of its orbit and coming around north again on the other half. But *Pioneer IV* was not a satellite. It had enough speed to escape from Earth forever. It started its flight north of the equator, a few hundred miles away from AMR, Florida. Then following its plane of motion it coasted down across the equator to the southern hemisphere and then kept right on going. It never returned to complete an orbit around the Earth, but continued to move out into space on the southern portion of its plane of motion.

It was intended to pass quite close to the Moon, and since by this time it had moved onto the southern portion of its plane of motion, it could intercept the Moon only if the Moon, too, was south of the Earth's equator at the time of intercept. This meant that the probe had to be fired during that portion of the month when the Moon is south of Earth's equator.

If the probe should pass quite close to the Moon, its motion would be changed by Moon's gravitational field. Another plane of motion would be temporarily established this time centered in the Moon. Then, as the probe moved further away from both Earth and Moon, the gravitational field of the Sun would eventually control its motion. Thus the third and final plane of motion would be established, this time centered on the Sun. The probe becomes an artificial planet.



Accuracy requirements. To us the Earth seems to rotate slowly, but at the distance of the Moon's orbit the projected aiming point is sweeping by at 1040 miles a minute. Since the Moon's radius is only 1080 miles, even a two-minute delay in firing time would result in a miss. Variations in speed also result in a miss for two reasons. First, the shape of the probe's trajectory depends upon its launching speed. If the speed is wrong then the shape is not as predicted and the point at which the trajectory crosses the Moon's orbit will not lie at the predicted intercept point. Second, an error in speed of launching will mean an error in time of flight between Earth and Moon; when the probe arrives at the Moon's orbit, the Moon is not likely to be close since it, too, is moving in its orbit.

For *Pioneer IV*, it was estimated that if everything worked as predicted the probe would miss the Moon by about 5000 miles, and would arrive at this closest point between 29 and 37 hours after lift-off. The actual errors in speed and aiming direction, resulted in a miss of more than 37,000 miles and a flight time of 41 hours.

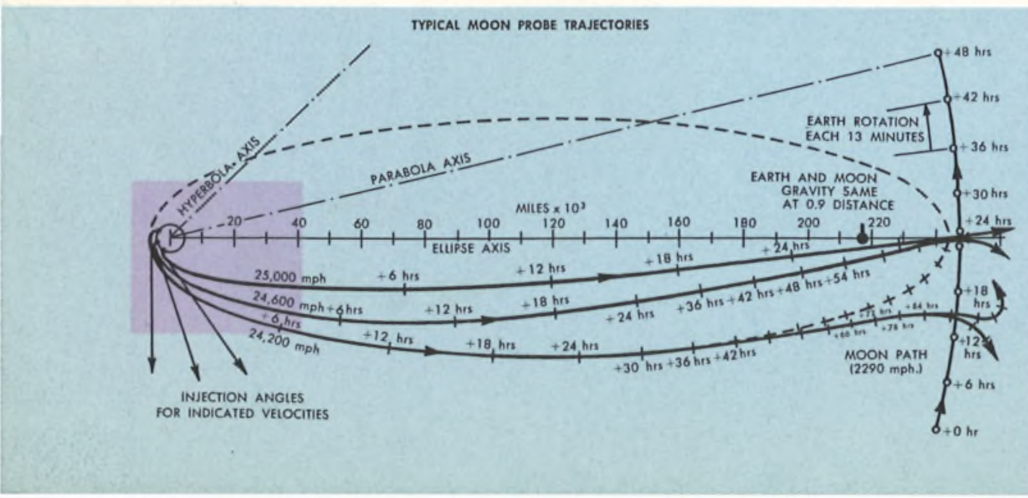
Several possible launching times, firing directions, and speeds were available on each of several successive days. For each of these possible launch times a new trajectory had to be computed.

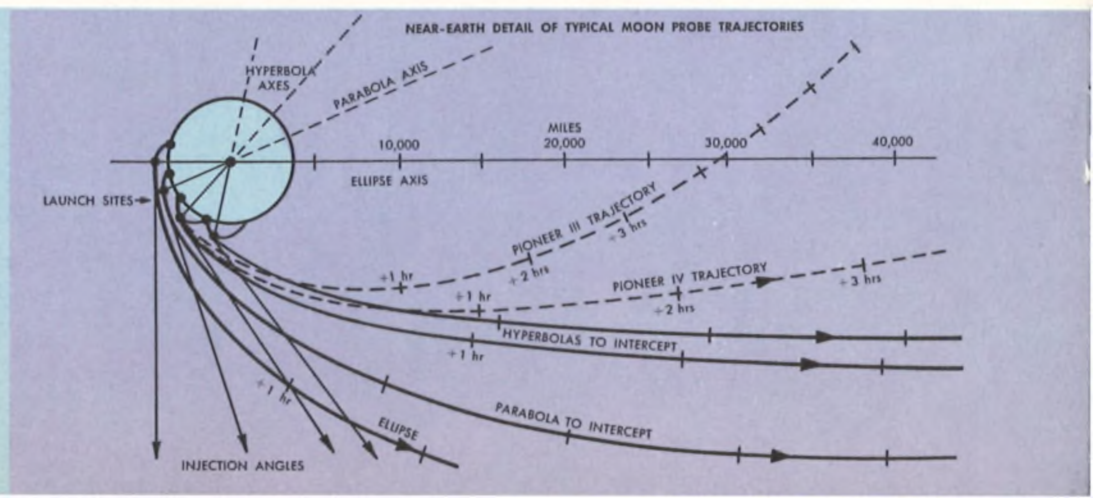
For every hour change in firing time on one particular day, a change of 7 degrees was made in both the azimuth heading and the elevation of the launching direction, and a change of 40 mph in the final speed. For each hour delay in firing time, the flight time was shortened by one hour. As a result, for all trajectories, the probe was scheduled to arrive at the Moon at the same time of day in order that the Goldstone tracking antenna should have the best chance of observing the probe during transit past the Moon.

The calculation of the final trajectory shows not only the proper settings for the *Jupiter* guidance system but also the predicted angles for tracking by all of the radio antennas which would be employed.

The simple scale model shown on the preceding page can be of great help in visualizing the moon probe launching problem. Besides the supporting base, this model has three functioning parts: (1) a small metal globe, (2) a thick plastic sheet on which are engraved several possible moon probe paths, and (3) a plastic dish target on which the moon's motion can be shown during the time from launch to intercept. By manipulating the flat plastic trajectory plane, practically any launch angle from any launch site on earth for any moon intercept condition can be duplicated. Any desired tilt of the probe trajectory can be maintained by inserting two supports in appropriate holes in the dish.

It can be seen that when an Earth satellite or a moon probe is injected horizontally due-east from the Atlantic Missile Range at 28° N, the great-circle plane of motion will always cross the equator 90° east of the injection point at a 28° angle.





TASK FOR THE FUTURE

Since its inception nearly 20 years ago, the Jet Propulsion Laboratory has given the free world its first tactical guided missile weapon system, its first earth satellite, and its first lunar probe.

In the future, under the direction of the National Aeronautics and Space Administration, pioneering on the space frontier will be advanced at an accelerated rate.

The preliminary instrument explorations that have already been made only serve to define how much there is yet to be learned. During the next few years, payloads will become larger, trajectories will become more precise, and distances covered will become greater. Inspections will be made of the moon and the planets and of the vast distances of interplanetary space; hard and soft landings will be made in preparation for the time when man at last sets foot on new worlds.

In this program, the task of the Jet Propulsion Laboratory is to gather new information for a better understanding of the World and the Universe.