NASA EP-38

# THE VIEW FROM RANGER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JET PROPULSION LABORATORY / CALIFORNIA INSTITUTE OF TECHNOLOGY

COVER: The region of Mare Cognitum surrounding the Ranger VII impact point (near upper right on back cover) at a scale of 1:10,000, as reconstructed from Ranger VII photographs by cartographers of the Aeronautical Chart and Information Center, USAF, as a portion of RLC 4 in the Ranger Lunar Chart Series, published for the National Aeronautics and Space Administration.

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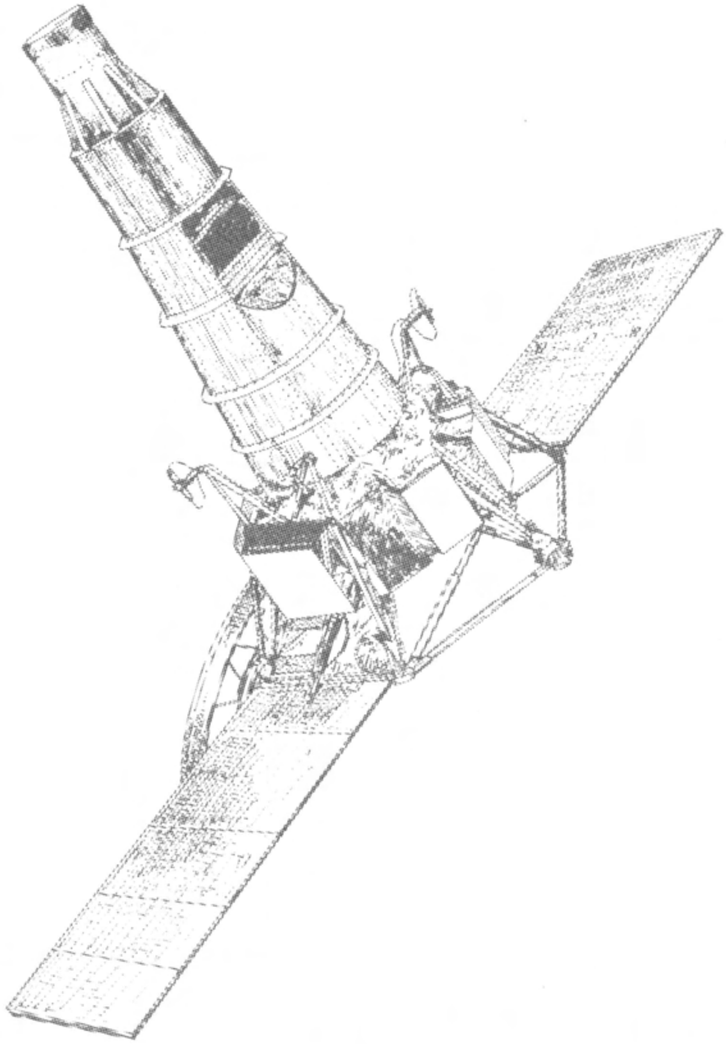

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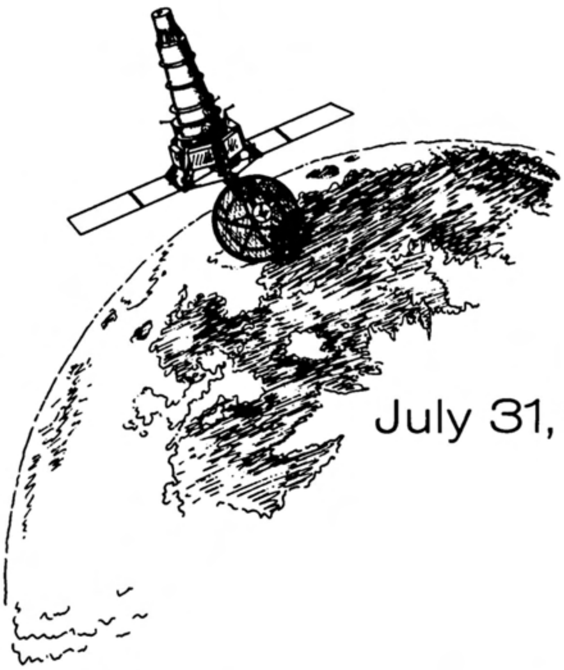
## FOREWORD

Ranger VII returned to Earth the first high-resolution pictures of the Moon's surface; it proved to be the first of three highly successful lunar photographic missions. The Ranger VIII and IX flights brought to more than 17,250 the total of Ranger pictures, extending the close-up coverage both in area and variety of terrain. Subsequent unmanned-spacecraft projects will further extend the coverage and bring the focus even closer. Project Apollo will place observers on the lunar surface. Still, some pride of position, as forerunner, must remain with Ranger VII.


Prepared by Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration. Writer: James H. Wilson. Art Director: Patricia A. Shutts. Production: John Kempton.



# July 31, 1964: "A Great Day"

As the Sun rose over the West Coast on the last day of July 1964, an air of expectancy grew in the space-exploration centers and news offices across the Nation. For two and a half days the scientists and engineers had tracked and calculated, and the newsmen and broadcasters had reported, the launch and satisfactory flight progress of an unmanned lunar photographic mission called Ranger VII.

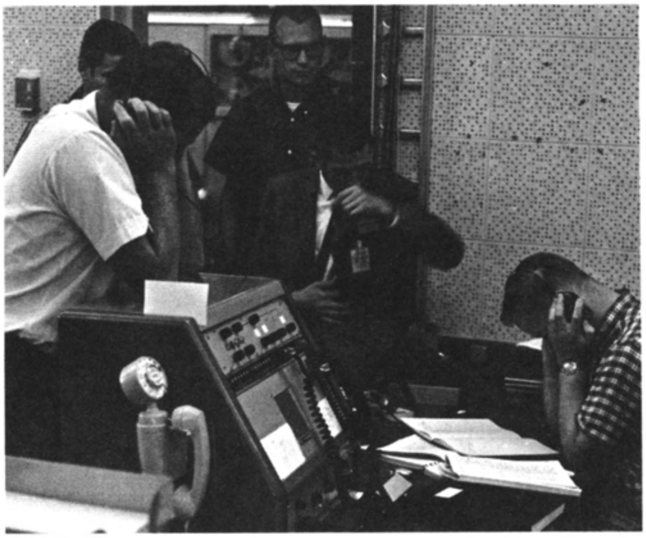
There had been six previous Ranger flights, spanning almost three years. They had had various objectives, representing in part the evolution of the mission now in progress. The sixth had attempted, and almost succeeded in attaining, the goal now facing Ranger VII: to send back to Earth a number of high-resolution pictures of the Moon's surface, showing objects at least one-tenth, and perhaps one-hundredth, the size of the smallest features discernible from the Earth.

Now, at sunrise, came the big question for the Ranger VII mission: would it succeed?

Officials and engineers and scientists from the National Aeronautics and Space Administration and their contractor, the Jet Propulsion Laboratory, thought it would. From the Laboratory's Space Flight Operations Facility in Pasadena, California, they monitored the spacecraft's performance as the minutes rolled by.

A few hundred feet away, a conference room had been equipped so that newsmen could observe the mission directly. By six in the morning the back of the room was crowded with employees — engineers, secretaries, carpenters — who had come to work two hours early just to share in the mission's climax.

In the Mojave Desert of Southern California, two giant reflector antennas were pointed at the waning Moon. They had been tracking since midnight. Operating crews and video data and recording specialists sat at their posts as the Sun rose. Here, they would be the first to hear the news — good or bad.



Around the world, in South Africa, at another tracking station, the crew had long since handed over operations to the Goldstone station in California. But they kept the lines of communication open. In Southern Australia, the Woomera tracking station had turned over communications with Ranger VII eleven hours before. But the Australians, too, stayed on the line — waiting.

A quarter of a million miles away, the Moon sailed serenely on her appointed course. Nearby coasted the 800-pound spacecraft; its outspread solar panels and polished structure glittering in the Sunlight. It also traveled serenely on its appointed course.

Presently a tiny electric clock ran out; a relay clicked over. Eighty seconds later, a stream of television pictures of the approaching lunar surface began to radiate back to Earth. Within minutes, another clock ran out, another relay closed, and a second stream of lunar pictures was on its way to Earth.

After some 17 minutes of TV operation, which produced more than 4300 pictures, Ranger VII crashed into the lunar surface while transmitting the last picture. On Earth, the monitor screens went gray; meter readings dropped to zero. The news was already going out, by television and radio. Some of the onlookers were cheering; some

were laughing; some wept. Every lunar picture had been recorded on film and on magnetic tape.

In the conference room, newsmen and employees looked up as Dr. Homer Newell, Director

of NASA's Office of Space Sciences and Applications, led JPL's Director, Dr. William Pickering, Ranger Project Manager Harris Schurmeier, and Ranger Spacecraft Manager Allen Wolfe, to the stage. They discussed the mission and its conclusion briefly, answered questions, were applauded. With an attempt at proper scientific reserve and conservative engineering practice, they insisted the mission could not be fully evaluated until the data were processed, in 24 to 48 hours. They were mistaken.

Fifteen hours later, after a brief but intensive examination of the photographs, the eminent lunar astronomer, Dr. Gerard Kuiper, stood before a televised press conference and said:

> "This is a great day for science, and a great day for the United States. What has been achieved is truly remarkable . . . the Moon, which to the unaided eye is seen at a distance of about 240,000 miles, and which, with a good telescope, can be brought to an equivalent distance of 500 miles, has been brought by this Ranger VII experiment to a distance of half a mile."

That was July 31, 1964.

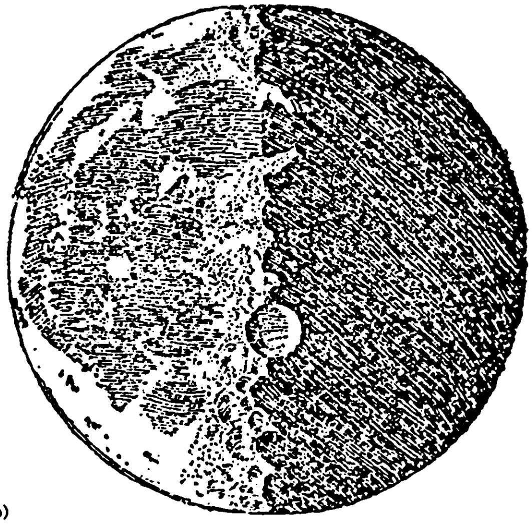
# The Moon: Known and Unknown

Earth's natural satellite, which has a little more than a quarter of the Earth's diameter and 1/81 of its mass, is unique in the solar system as a solitary, large satellite of a moderately small planet. As the second most prominent object visible in the sky, it has been the subject of direct observation and mythical speculation for as long as there has been anyone to observe it and compose myths. It has also been known as the mover of tides and considered the patron of romance and insanity.

## 355 YEARS OF STUDY

The Moon was naturally the first subject to which Galileo Galilei, the first astronomer to use a telescope, addressed himself. In 1610, after a survey with his primitive 32-power instrument, Galileo wrote in the *Siderius Nuncius* that the Moon appears "... full of inequalities ... similar to our most rugged and steepest mountains .... There are certain ridges ... which surround and enclose plains ... for the most part circular .... There are a very great number of smaller ones, almost all of them circular."

Visual observations of the Moon were made with instruments of increasing resolving power, visible features were mapped and named, and their nature and formation were the subject of much speculation. In 1667 the British scientist, Robert Hooke, gave the impact-crater theory an early boost by dropping bullets into a mixture of pipe-clay and water and observing the resulting formations. Giving the internal-convulsion or volcanic theory equal time, he then boiled a muddy mix of powdered alabaster and water, and found similar phenomena.



1610 (Galileo)

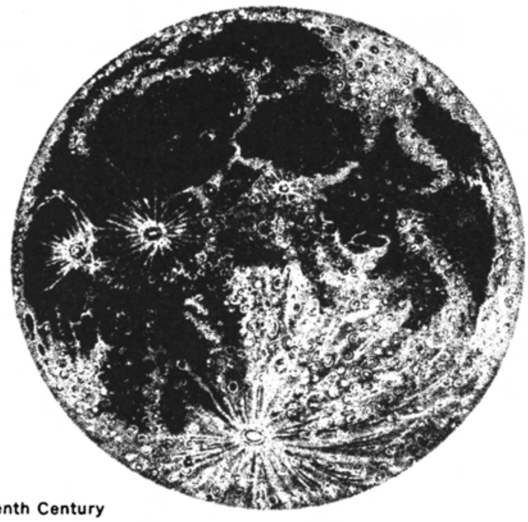
Galileo had noted a resemblance of the great dark lunar plains to oceans or seas, and by 1651 Riccioli in his *Almagestrum Novum* was applying such names as Mare Imbrium and Oceanus Procellarum. He also began the custom of naming the craters after eminent astronomers and philosophers. The present-day convention is to immortalize deceased scientists thus (though a number of mythological characters and ancient rulers are in the list), while the maria are generally named for states of mind, with the exception of Mare Smythii and Mare Humboldtianum on the western limb and, perhaps, the Sea of Moscow on the far side.

The first photograph of the Moon was a daguerrotype made in 1840 by Dr. J. W. Draper. As the photographic art improved, hand-in-hand with telescope technology, a new tool and technique moved in on the Moon. The Lick Observatory (opened in 1888), Mount Wilson (1904) in California, and the Harvard (1839) in Massachusetts, were among the first American institutions applying the new tools to the study of the Moon and the planets. It was one miraculous night of "good seeing" in 1963 at Lick Observatory, according to Dr. Kuiper, which produced the best photographic resolution of lunar detail—1,000 feet—ever achieved prior to the magnificent morning of July 31.

Around the turn of the twentieth century, the great photographic lunar atlases began to appear. These were the *Atlas Photographique de la Lune* of Maurice Loewy and Pierre Poiseux, published in Paris between 1895 and 1908, and *The Moon, from Photographs* (1904), by the American astronomer W. H. Pickering. A more recent lunar atlas is the *Photographic Lunar Atlas*, edited by G. P. Kuiper and published by the University of Arizona Press in 1960-63. This includes, as a supplement, the *Rectified Lunar Atlas*, based on the system of E. A. Whitaker. The USAF Aeronautical Chart and Information Center has prepared (and is continuing to prepare) a series of lunar maps based on photographs. A special series of five maps, based on Ranger VII photographs, has just been issued.

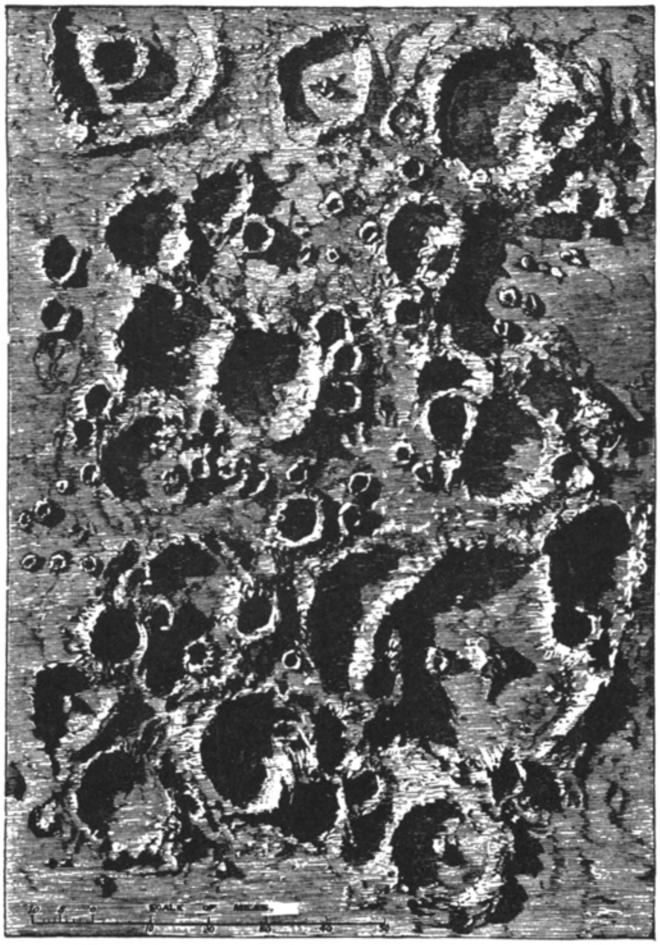
## FACE OF AN OLD FRIEND

Two types of lunar terrain could be distinguished with the naked eye: the light and the dark. The telescope revealed these to be, respectively, the comparatively rugged and mountainous lunar highlands and the seemingly smooth maria. Even the ancients, who believed the latter to be seas in fact, could note a striking difference from our planet: Earth's surface is only about one-fourth dry land, while the lunar highlands cover almost two-thirds of the visible surface. Pictures taken by the Russian spacecraft known as Lunik III appeared to suggest that this difference is even more extreme on the far side of the Moon.



Early Nineteenth Century

Twentieth Century
(Mt. Wilson Observatory)

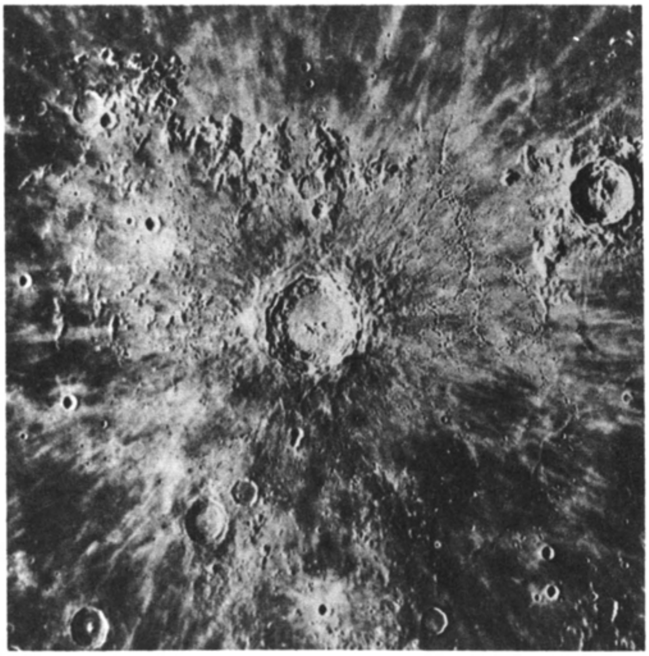


From Steele's Descriptive Astronomy (1869)

Another feature apparent to early observers such as Galileo—the circular ridges or "craters" —had very little parallel on Earth. Meteor Crater in Arizona, New Quebec Crater in Canada, and a number of volcanic cones (particularly in Hawaii) represent corresponding features on this planet — and by lunar standards they are very puny indeed. There are almost 40 lunar craters greater than 100 kilometers (about 62 miles) in diameter. Meteor Crater is 4000 feet across; New Quebec spans about 3 miles.

The lunar craters were originally compared with volcanic cones on Earth, and some scientists have suggested they were formed in the same way. However, the remarkable circular symmetry of the great majority of the lunar formations, over all sizes from 150 miles in diameter down to the limit of telescopic resolution, together with other evidence, brought most observers around to the hypothesis that these craters resulted from impacts of meteoritic material of various sizes and energies. Certain other lunar features of modest size, comparable with terrestrial volcanoes, appeared more likely to be lunar volcanic cones.

E. M. Shoemaker (a member of Ranger's scientific team, and a prominent lunar geologist) mapped the myriad small (1-mile) craters surrounding Copernicus, reasoning that these were secondary craters formed by the impact of material hurled out by the explosive impact which formed Copernicus itself. G. P. Kuiper (Ranger's Principal Investigator) argued from a general observation of marial features that the floors of the lunar maria consist of lava which flowed out of craters resulting from tremendous impacts

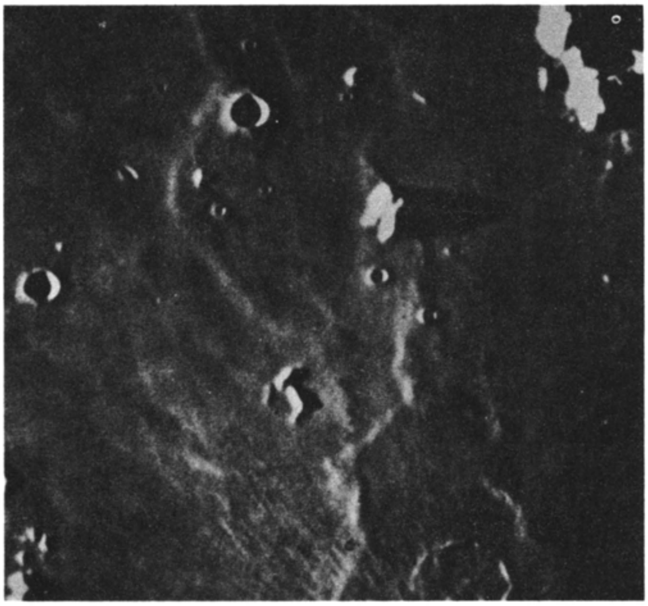


occurring early in lunar history. These were two of a number of major efforts to understand and explain various aspects of the lunar surface.

The mountains of the Moon are given a craggy, Alpine appearance by the fact that we can see these features best when the shadows are longest. Arguments could be made in favor of steep cliffs, towering peaks, and plunging chasms on the lunar surface, because of the lack of erosion and weathering which has smoothed the hills of Earth, or the low gravity (one-sixth Earth's) which would allow a mere sandpile to be steeper than on Earth.

However, the application of trigonometry to those long shadows reveals the actual height of the peaks that cast them, and the very breadth of the tall lunar features diminishes what height they have. Thus, one of the great solitary lunar peaks, Mt. Piton, rises 7500 feet on the western plains of Mare Imbrium, but it is about 18 miles across, North to South. The great crater Copernicus has 3200-foot walls, but it is 56 miles across. A larger crater, Clavius, rises about a mile above the plain surrounding it, and much higher above its inner floor; yet its diameter is so great—and the Moon is so small — that an observer could stand in the center of Clavius and not see any of the surrounding rim; it would be over the horizon.

Mighty mountains were observed in the lunar highlands. The Leibnitz range, near the lunar south pole, the nearby Doerfels, and the Rook mountains on the East limb are thought to be of Himalayan proportions. Slopes on the Moon, ranging up to about 50 degrees, however, were found to compare more closely to such American mountain ranges as the Rockies and the Sierra Nevada. Averaged over lengths of 1 kilometer (about 1000 yards), slopes have been figured to range up to about 10 degrees in the more rugged areas, as compared with a few tenths of a degree in the maria.

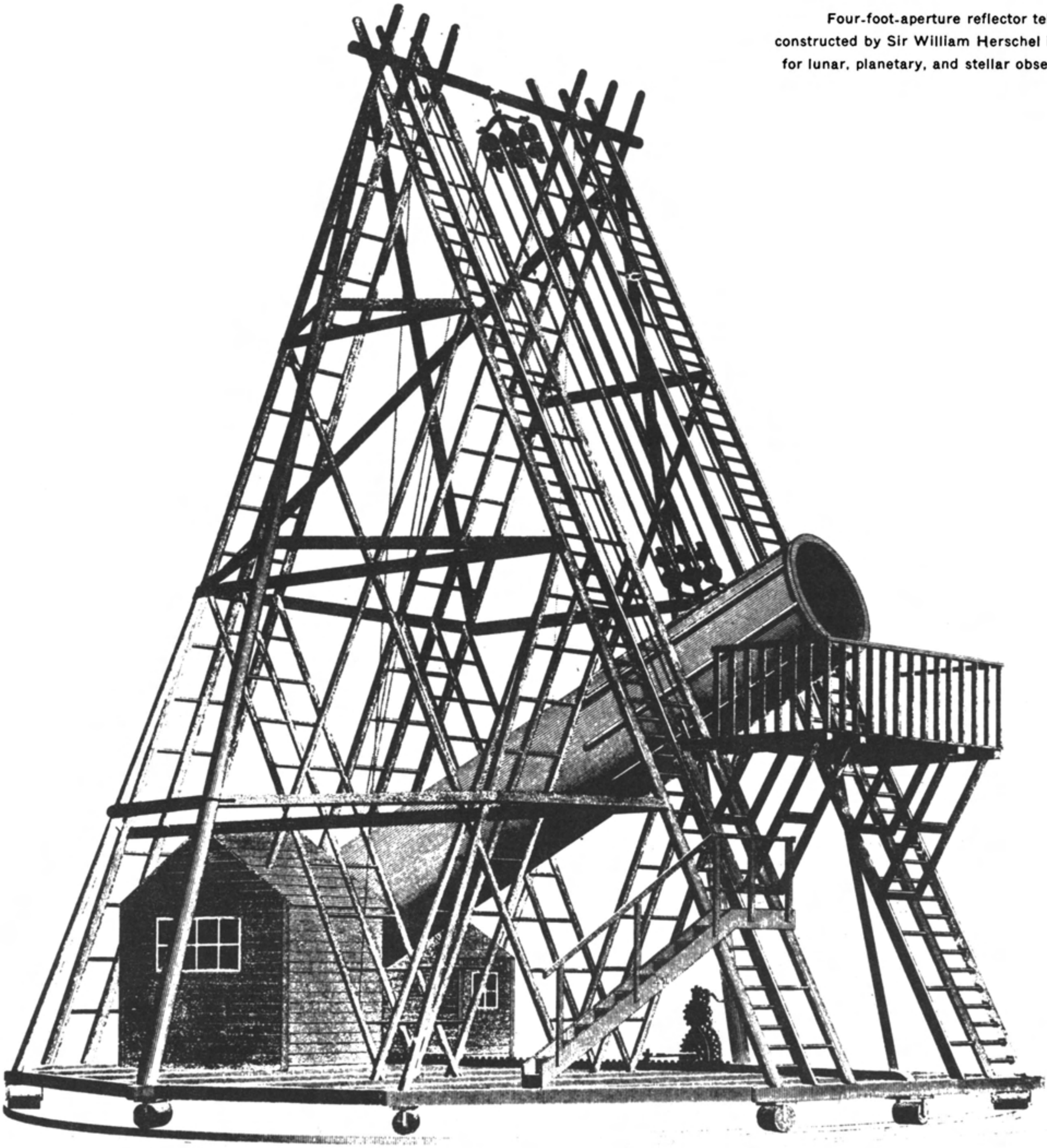


Mt. Piton, one of the solitary lunar peaks

Other features of the lunar surface are identified as crevasses, valleys, or rilles, wrinkle-like ridges, and geological faults. One type of feature whose nature was little known—if its origin and appearance were not—was the crater ray. A number of the larger craters — among them Tycho, Copernicus, Kepler, and Aristarchus — are surrounded by whitish radiating streaks. Seen through the telescope, they seem almost to have been painted on.

The study of the Moon's surface characteristics from Earth had become so intense and so generalized by the time of Ranger that, for instance, a Conference on Lunar Surface Materials held in mid-1963 brought forth almost twenty technical papers and involved many fields, from astronomy to physics and chemistry to geology to civil engineering.

Clavius, the largest lunar-highlands crater, with elevation profile (vertical scale X 2)



Four-foot-aperture reflector telescope constructed by Sir William Herschel in 1789 for lunar, planetary, and stellar observation

## THE WEATHER IS TERRIBLE

In 1780, the then-young William Herschel wrote enthusiastically that the Moon possessed "... in all appearances, a soil proper for habitation fully as good as ours, if not perhaps better — who can say that it is not extremely probable, nay, beyond doubt, that there must be inhabitants on the Moon of some kind or another.... For my part, were I to chuse between the Earth and Moon, I should not hesitate a moment to fix upon the Moon for my habitation."

It is now known that the lunar atmosphere — if any — is more tenuous than that of the Earth at an altitude of 21 miles. Lyot and Dollfus, two French astronomers, searched for evidence of a lunar atmosphere more dense than this in the polarization of light from the crescent Moon, and found none.

The temperature varies from about 230°F at midday in the lunar tropics to nearly −300°F at night. However, recent extensions of lunar observation beyond visible light — down past the infrared into microwave radiation—indicate, according to some observers, that at a depth of about 1 foot below the surface the temperature variation is less than a third of that on the surface, and at a depth of a yard the variation disappears entirely.

It is mainly the dense blanket of air which maintains temperatures on Earth within moderate limits. Our atmosphere extends many miles above Earth's surface, growing steadily thinner with increasing altitude. Half of the air is in the layers above 3½ miles; above 7 miles, a quarter; and so, higher and thinner. This air blanket screens out harmful ultraviolet rays and certain energetic particles coming from the Sun; it also protects Earth's surface and inhabitants from the rain of solid particles of all sizes, which fall unimpeded to the Moon's surface.

The numerical density of such particles in relation to their size—which ranges from thousands of tons to millionths or less of an ounce—has been calculated by astronomers and geologists. There are three sources of direct evidence of this material. One is the surviving fragments which reach the surface of the Earth. Most natural-history or geological museums have samples of nickel-iron, stony, and composite (both stone and metal) meteorites on display. An additional type of meteorite is theorized, but samples would be most difficult to find or keep here on Earth—the composition would be a mixture of frozen methane gas, dry ice, and ice. In addition to these large samples, fine dust-size meteorites have been collected using special surface equipment, balloons or aircraft, and rockets.

The second body of evidence — and the very newest — is the increasing fund of data from satellites and space probes instrumented to sense, measure, and count impacts from micrometeorites in space. Various types of microphones, wire networks, and other collection devices are used to measure the number, direction, and energy of impacting particles.

The third exhibit is the face of the Moon itself. Using Earth-based photographs, the craters associated with impact have been counted, measured, and variously classified.

No meteorite has ever been seen to hit the surface of the Moon. Observers have, on rare occasion, noted disturbances which they ascribed to meteorite impact events, but these phenomena are surrounded by controversy. However, meteor encounters with the Earth's outer atmosphere are observed frequently. They are called "shooting stars." One large surface impact, in Siberia in 1908, felled trees over a radius of 30 miles, though no iron or stony fragments are associated with this meteor.

On the basis of the calculations, the scientists estimate that the Earth and Moon sweep up many thousands of these particles—nearly all of microscopic size—each day. On Earth, they lose their energy and/or most of their substance in the upper atmosphere. On the Moon, they hit the surface.

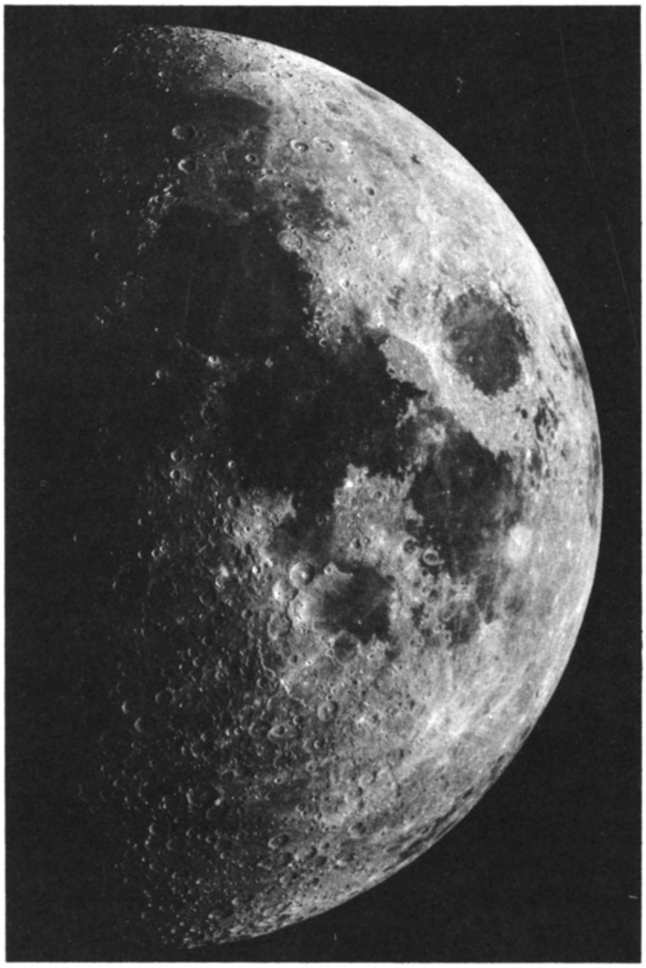
The velocity of this cosmic debris is as variable as the size of its particles. A rock falling on the Moon with no extra velocity would hit the surface at lunar escape velocity, 1½ miles per second or 5400 miles per hour. More often, these meteorites will be moving in comet-like orbits, with velocities up to 45 miles per second. At that speed, a particle as small as 1/30,000 ounce hits with the energy of a .45 automatic at close range.

High-velocity impacts may lead to a good deal of splashing. Laboratory experiments at 2.6 to 3.6 miles per second showed that the high-velocity impact could produce at least a hundred times the weight of the impacting particle in ejecta or flying debris. A particle impacting at 20 miles per second can give lunar escape velocity to more than its own weight of material, and it has even been suggested that more matter is thrown off the Moon by these impacts than falls into it. "Tektites," glassy, streamlined, meteorite-like rocks found on Earth, have been said to be such lunar debris.

Various types of electrically charged atomic particles, from the low- and medium-energy "solar plasma" or "solar wind" to the high-energy "cosmic rays," also impinge on the Moon. Cosmic rays, originating partly from the Sun and partly from far out in space, have such tremendous velocity as to penetrate Earth's atmosphere, human bodies, and various kinds of shields. On the Moon, they penetrate below the surface before all their energy is dissipated. Individual particle mass is insignificant, and the frequency of occurrence, as on Earth, is not high, except during solar flares.

The solar wind, on the other hand, streams out fairly densely from the Sun at velocities of 500 to several thousand miles per hour. During solar disturbances or storms, the intensity and velocity increase sharply. Earth's magnetic field tends to turn these particles aside and trap them in zones known as the Van Allen belts; they can expose unprotected astronauts to a lethal "radiation" dose. The Moon's magnetic field is at least 1000 times weaker than Earth's, and it has no apparent Van Allen belt.

Finally, the lunar surface sustains the full spectrum of the Sun's electromagnetic output — from above the ultraviolet, through visible light, down past the infrared into radio waves. Thus the lunar weather has included unseasonable daily temperature changes, a constant hailstorm of meteorites, atomic bombardment, and all forms of radiation, but no atmosphere, and of course, no water liquid or vapor.



## LUNAR MOTION AND THE HIDDEN SIDE

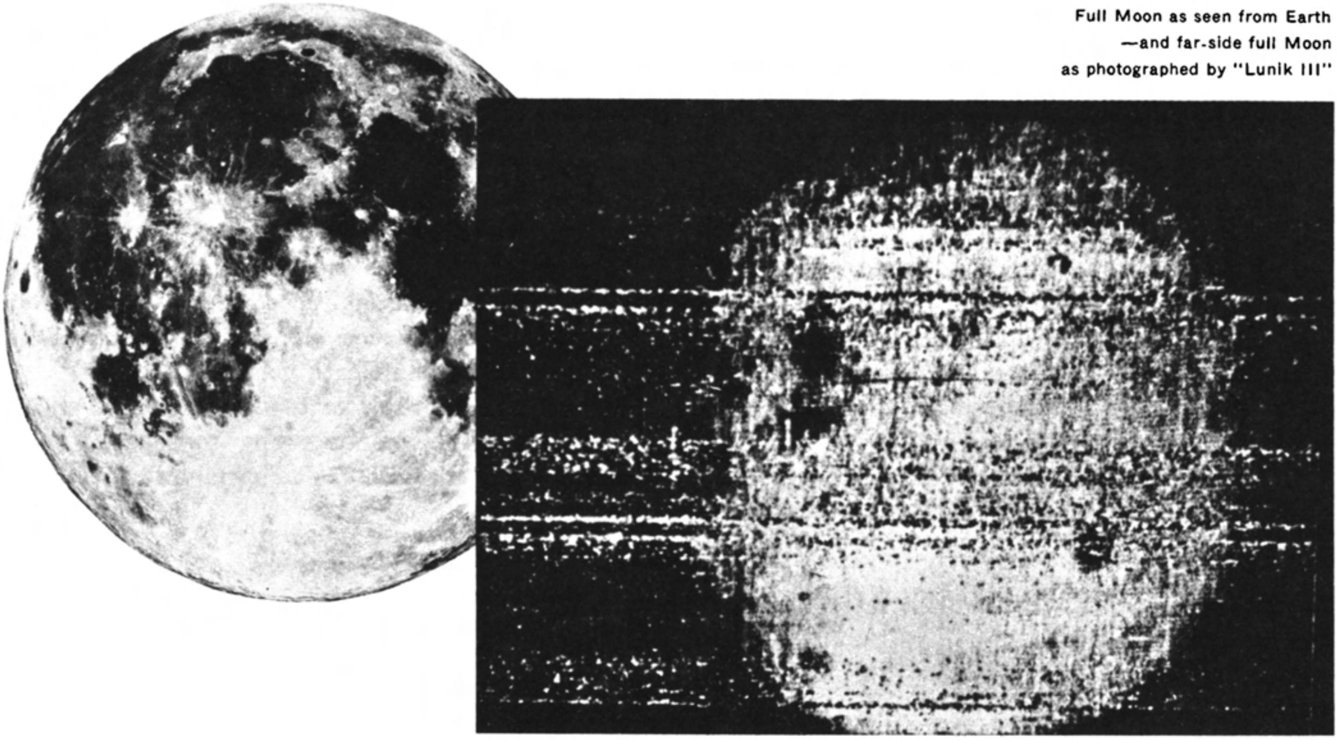
The solar system is often represented, and more often thought of, in terms of a simple, flat set of concentric circles which constitute the orbits of the nine planets. Actually, however, the planets and their moons move in ellipses, none of which is exactly aligned with the others. For example, our Moon's orbital plane is inclined more than 5 degrees from Earth's.

In addition — and more important to earthlings — the plane of Earth's equator is tipped about 23½ degrees from its orbit. This means that, in the course of a year, the Sun's position moves from the latitude of Rio de Janeiro to almost that of Key West and back, changing the seasons in the Northern Hemisphere from winter to summer and back. The Moon can range as much as 5 degrees above and below the Sun's latitude in a month, as it tours its tilted orbit. Thus, from a point on Earth, the Moon can be seen to move according to daily, monthly, and yearly cycles.

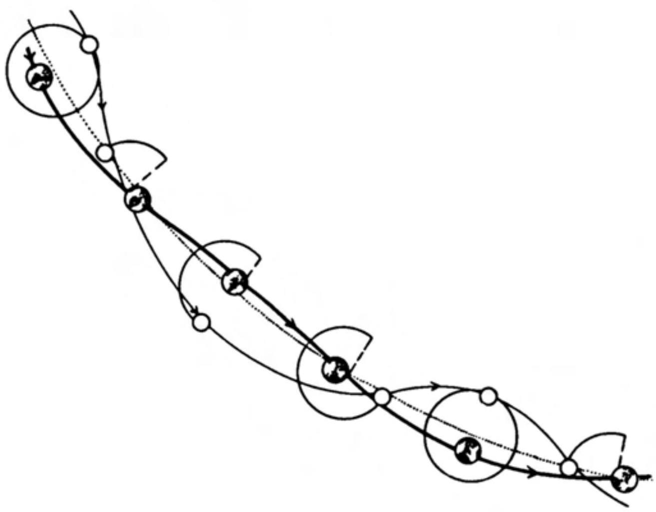
Incidentally, the Moon does not truly orbit around the Earth. Both objects have mass — the Moon has 1/82 of the total. They therefore rotate together about a common center, like a dumb bell with one very large and one very small weight and an extremely long handle. The center is within the Earth, nearer the surface than the middle. Observation of this phenomenon led to the first calculation of the Moon's mass.

Only the near hemisphere of the Moon—actually 59% of the sphere, because of libration—is visible from Earth.

Full Moon as seen from Earth
—and far-side full Moon
as photographed by "Lunik III"



The Moon's period of rotation — or day — is equal to its period of orbit—or year—so that we never see the other side. It rotates on its axis at a uniform rate of speed, but, being in an ellipse, it does not go around in orbit at a uniform rate of speed. Sometimes the "day" is ahead of the "year," and we can peek around the leading edge. Sometimes it is behind, and we see around the trailing edge. This leaves 41% of the surface permanently out of sight.



However, on October 4, 1959 a 950-pound Russian-built camera-carrying spacecraft was launched toward the Moon in a polar trajectory. It passed over Earth's north pole, then under the Moon's south pole. The closest approach was about 4000 miles. The pictures were not taken until the probe had moved past the Moon, and was between the Moon and Sun (looking at a "full Moon"), at a range of more than 40,000 miles. The exposures were recorded on film, developed in the spacecraft, and later relayed via TV to Earth. About 30 pictures were published, together with a map, in the USSR Academy of Science's *Atlas of the Moon's Far Side.*

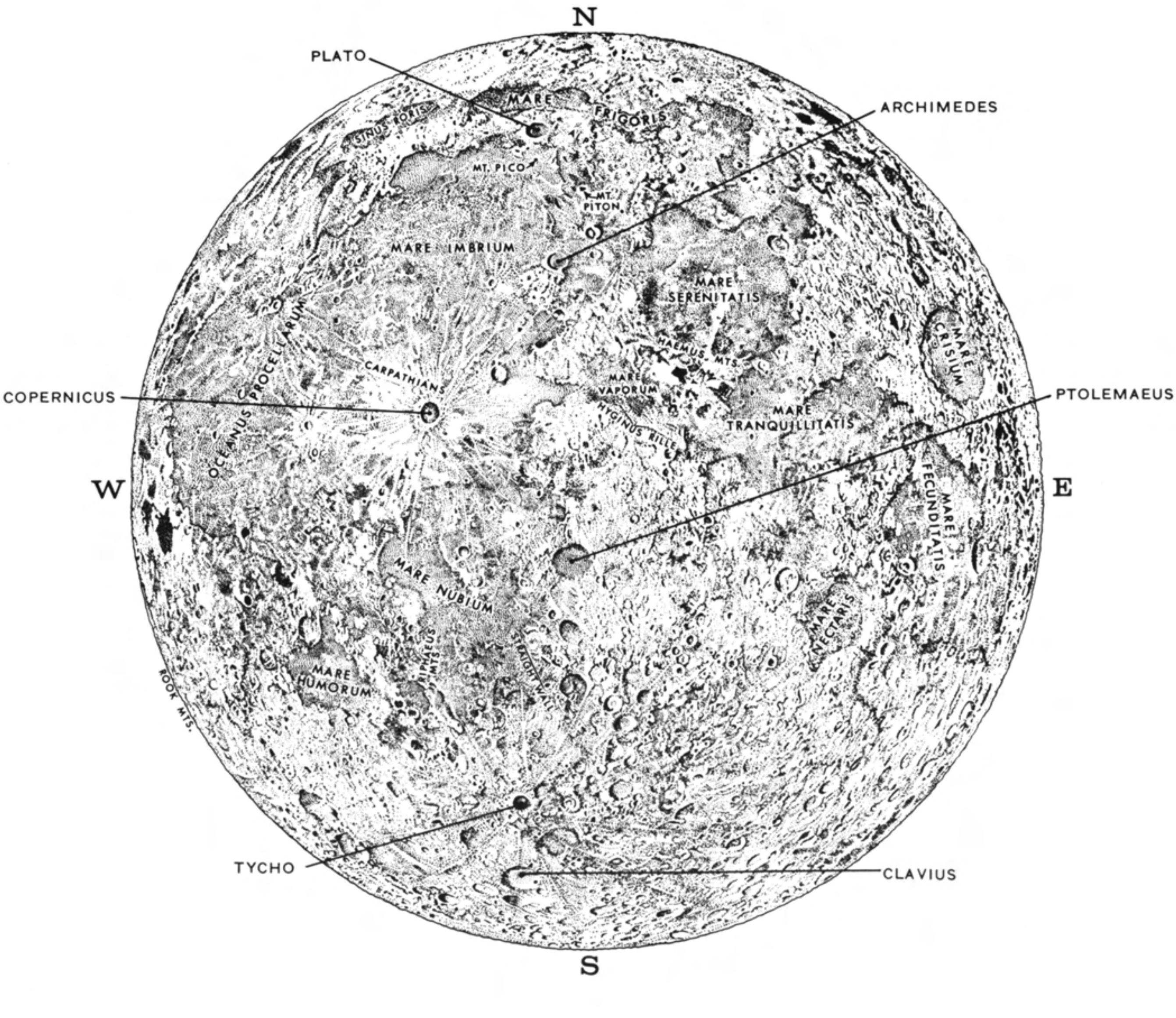
## MUSEUM OF THE SOLAR SYSTEM

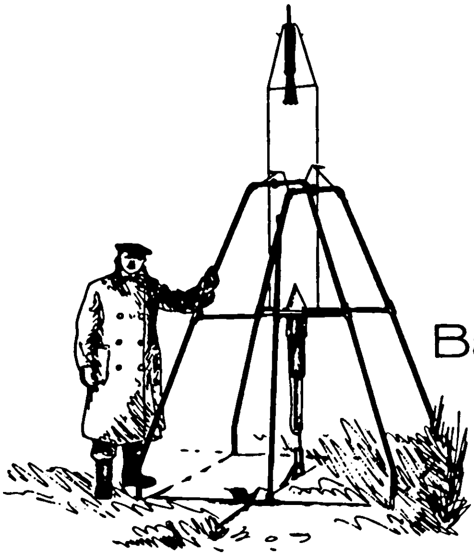
Though the history of the Moon has been one of constant bombardment by meteorites, irradiation by solar particles, light, and heat, and regular and extreme temperature changes, our satellite is, by comparison with the Earth a well-preserved relic of the early days of the solar system. For the seas, rivers, glaciers, forests, earthworms, and bulldozers of Earth have combined to level the mountains, carve the plains, fill the depressions, dissolve the minerals, and digest the fruits of the planet's surface not merely once but incessantly as long as they have existed. The original form and nature of Earth have been buried far deeper than the walled city of Troy. Terrestrial mountains have been thrust up again and again, to be sliced by glaciers, washed away by melting snow to the plains or to many-layered beds on sea-bottoms, until the accumulated weight thrust up new mountains.

Our Moon has never felt the kiss of clean snow, the tickling of spring rains, the agony of glaciers, or the gentle stirrings of a warm afternoon breeze. Its feeble gravity never had the strength to hold an atmosphere, and hence, the Moon has never had liquid water either. It has been packed in a vacuum for billions of years.

F. L. Whipple, in suggesting that direct lunar exploration will greatly advance mankind's knowledge of the Moon's evolution, adds: "Her ancient skin carries a 'fossil' record that predates any now left on Earth and her story reaches back to the days when the Earth was new."

On the Moon, the door to knowledge has always stood unlocked; we had only to reach for the handle. The Ranger VII mission was to be that reach.





# Background: Child of the Space Age

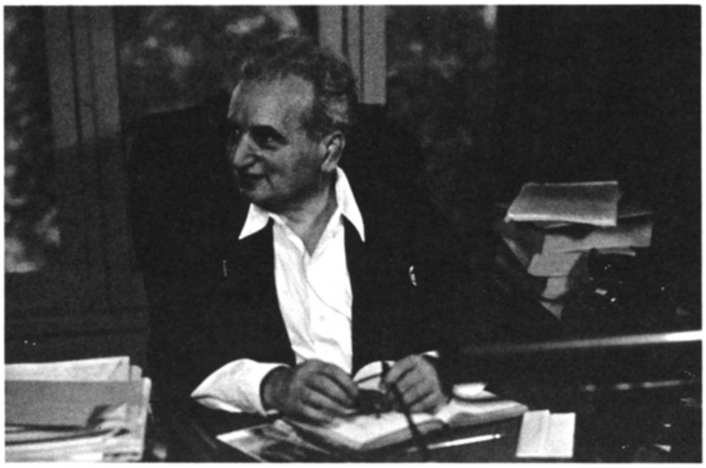
The origins of fanciful space flight and fictional journeys to the Moon are, like the origins of rocketry, buried in Man's past. The earliest literary Moon flight dates from the Roman age of the Antonines; war-rockets reached Europe from China late in the age of the Crusades.

Both reappeared in the Age of Enlightenment. Cyrano de Bergerac, Swift, and Edgar Allan Poe used fanciful space travel for satire and amazement, while Sir William Congreve developed black-powder rockets for use in the Napoleonic Wars and the American War of 1812.

## PIONEERS

At the turn of the twentieth century, a movie pioneer named George Melies took as his subject a fantastic trip to the Moon, and a Russian teacher, Konstantin Ziolkovsky, published a serious paper on the use of liquid-fueled rockets for space flight. In 1919, Professor Robert Goddard's paper on high-altitude research by rocket mentioned a possible lunar mission. Goddard coupled theory with experiment: after some powder-rocket flights, he experimented with liquid propulsion and on March 16, 1926, launched the world's first liquid-fueled rocket.

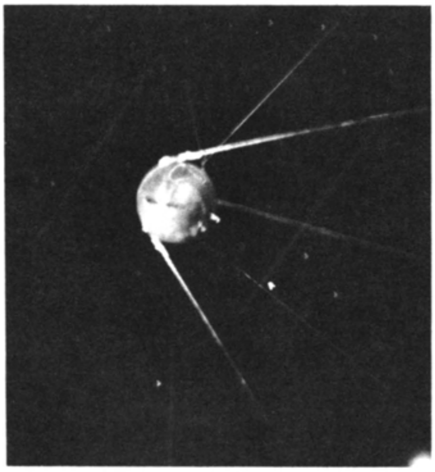
Goddard's experiments, papers, and patents were perused with interest by the members of the German Rocket Society, which had gathered around Professor Hermann Oberth after he published "The Rocket in Interplanetary Space" in 1923. This society, experimenting with rocket-driven automobiles as well as propulsion for space flight, became a major missile development group in World War II, producing, among other devices, the V-2 military rocket. Goddard, who had launched the first instrumented rocket payload in 1929, and had attained altitudes as high as 7500 feet by 1935, was, by 1939, at the head of the new profession he had helped create. At this time,



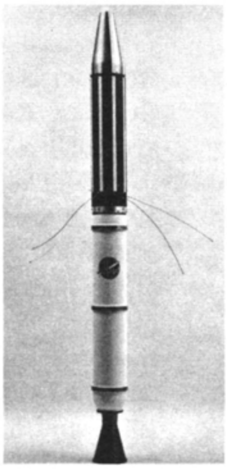
Dr. Theodore von Kármán of Caltech began a project to study rocket propulsion. Under Air Corps contract, von Kármán's Jet Propulsion Laboratory developed the wartime jet-assisted take-off rockets for aircraft and conducted broad research in this growing field.

At war's end American rocketry was augmented with a quantity of captured German equipment and a number of German engineers. Several instrumented V-2 rockets were launched; an American Wac-Corporal/V-2 two-stage combination extended Goddard's high-altitude work with a flight to an altitude of 250 miles and provided a new stimulus for space flight.

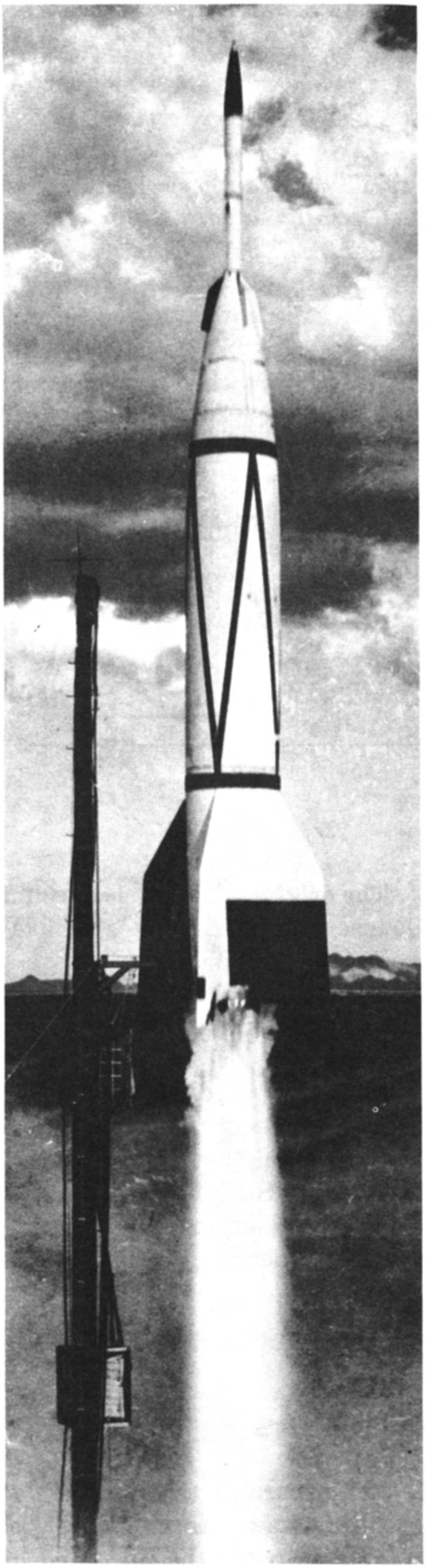
The combined field of research and exploration begun by Ziolkovsky, Goddard, and Oberth reached full flower in the International Geophysical Year of 1957-58 when Russian and American scientists opened (with Sputnik or Satellite I on October 4, 1957, and Explorer I, the following January) the Age of Space.



Sputnik I



Explorer I

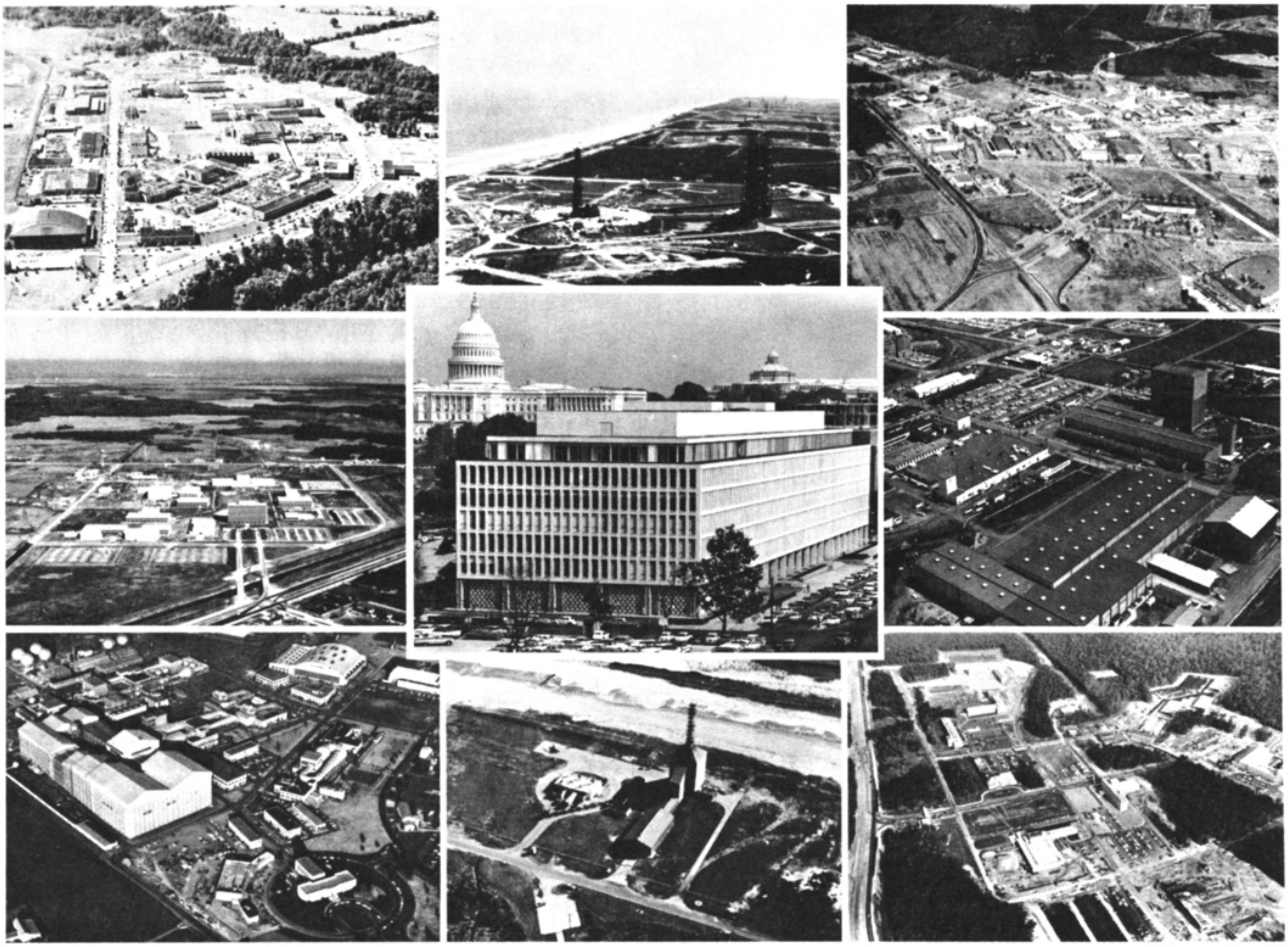


Wac Corporal and V-2

## A NATIONAL EFFORT

The National Aeronautics and Space Administration (NASA) was established on October 1, 1958, to conduct "aeronautical and space activities sponsored by the United States . . . to contribute materially to . . . the expansion of human knowledge . . .". Using the National Advisory Council for Aeronautics (which had conducted research in aeronautics and aerodynamics since 1915, and more recently, rocket-aircraft research leading to the X-15 rocket plane) as a nucleus, NASA began to draw together all American efforts toward the peaceful exploration of space. Project Vanguard, the U.S. non-military Earth-satellite effort; a number of Defense Department space projects; and the Caltech Jet Propulsion Laboratory, the first government-sponsored rocket research facility, which had developed the Wac Corporal, the Corporal and Sergeant missiles, and the spacecraft and upper rocket stages for Explorer, joined in 1958. Elements of the Army Ballistic Missile Agency, working under Dr. Wernher von Braun, which had developed the Explorer-boosting Redstone missile, and a launching facility at Cape Canaveral (now Cape Kennedy), joined in 1960.

At present, NASA maintains a headquarters in Washington, D.C., three Space Flight Centers, three Research Centers, a Manned Spacecraft Center, a Flight Research Center, and a Rocket Launch Facility; and it sponsors research in university laboratories and development by industrial



NASA Headquarters (center) with (clockwise from upper left) Lewis Research Center, Kennedy Space Flight Center, Langley Research Center, Marshall Space Flight Center, Goddard Space Flight Center, Wallops Launch Station, Ames Research Center, and Manned Spacecraft Center.



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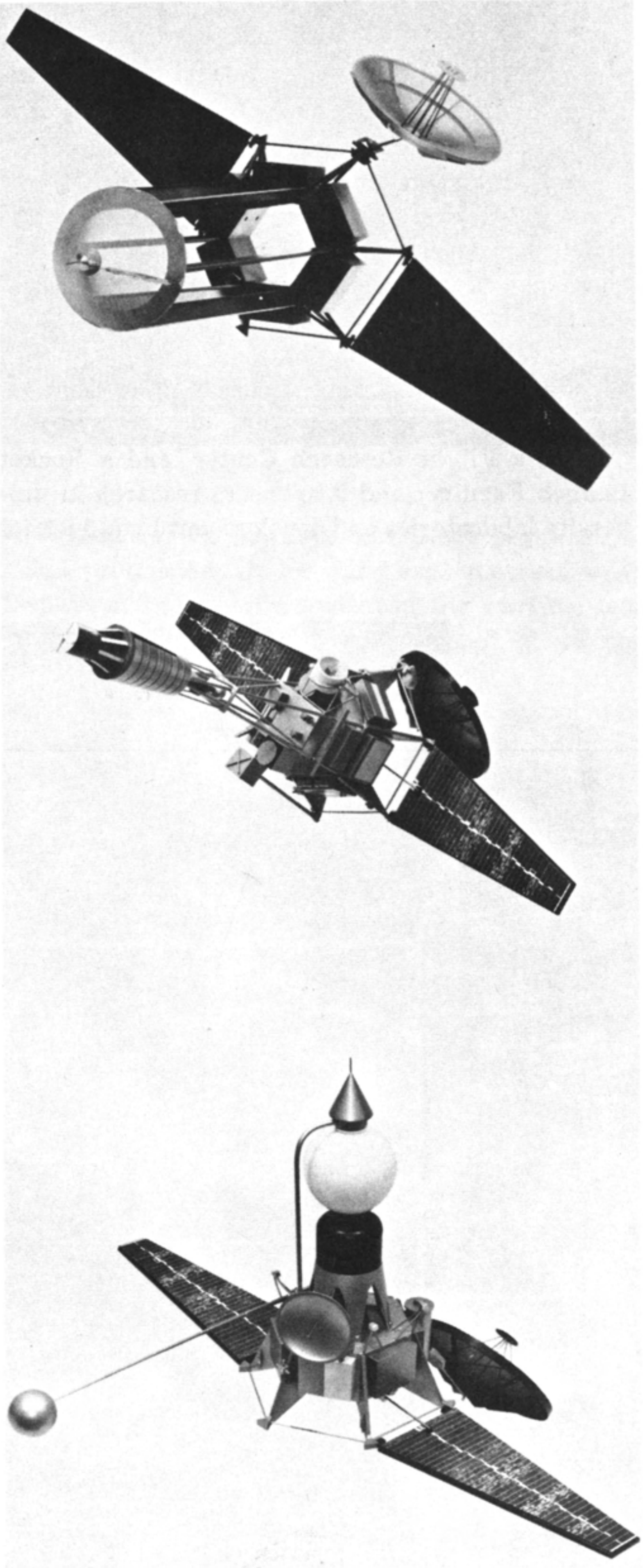


Top: Early spacecraft bus model without payload
Center: Ranger Block I model shows pre-lunar-mission instruments
Bottom: White sphere represents Block II survival package

contractors across the nation. The Jet Propulsion Laboratory is a contract research facility of NASA, operated by the California Institute of Technology, devoted to the exploration of the Moon and planets by unmanned space probes.

The establishment by President Kennedy in 1961 of manned lunar flight as a national goal gave a great impetus not only to manned spaceflight programs; projects devoted to the unmanned exploration of the Moon, assigned to JPL by NASA, were similarly highlighted. The first of these projects was named Ranger.

## A LONG HARD ROAD

The Ranger project began in 1959 as a multipurpose conceptual spacecraft design. The general format of a Ranger lunar mission was established as controlled approach to the Moon, ending in impact on the surface; scientific observations were to be made and radioed to Earth before impact destroyed the spacecraft. This design had seven fundamental novel characteristics, all of which appear in the finished system. They are:

1. Attitude stabilization: one side of the spacecraft always pointed at the Sun, another at a reference point such as Earth or a star.
2. Solar power from Sun-oriented panels (controlled by attitude stabilization), backed up by a spacecraft battery.
3. Combination of on-board automatic computing and sequencing with a small number of ground commands.
4. Communications and closed-loop tracking via high-gain directional antennas on the spacecraft (made possible by attitude stabilization) and the ground (the system which evolved into the Deep Space Network).
5. Launch by means of the parking orbit, in which the spacecraft is actually fired toward the Moon or planet from an Earth-orbiting rocket stage.
6. Midcourse trajectory correction: a small rocket motor aboard the spacecraft is used to increase the accuracy of the trajectory;

the position and velocity of the spacecraft are accurately known from ground-based tracking, and the correction is calculated and confirmed from tracking measurements before and after the maneuver.

7. The "bus" concept, where the same spaceframe design and common equipment such as electrical power subsystem, radio, antennas, and midcourse motor serve a variety of scientific payloads in diverse missions.

Each of these principles was new, undeveloped, and untried before Ranger. Each had to be carefully designed, painstakingly evolved, and repeatedly tested.

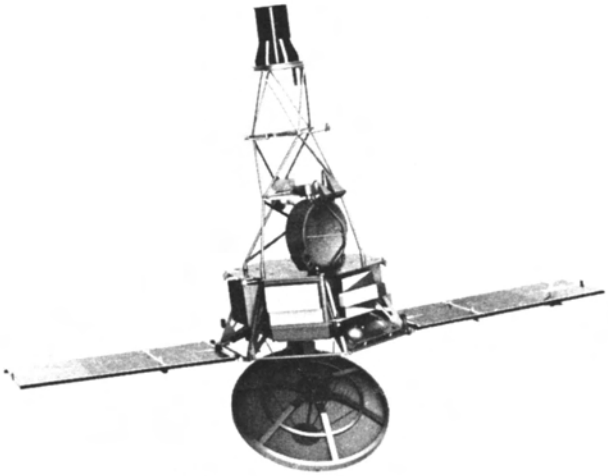
In addition to the spacecraft system, the launch vehicle, tracking network, and operational system had to be developed (or evolved from existing systems) and tested for the new complex type of mission. As expected — in fact somewhat more than expected—the process of evolution and testing proved tedious.

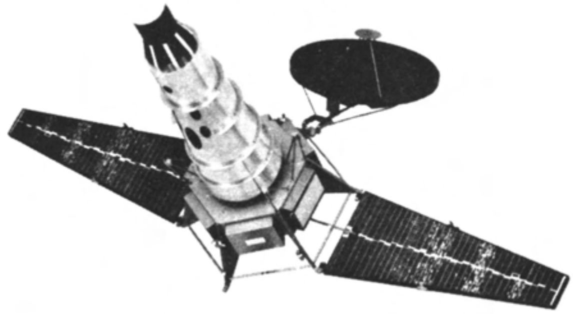
However, the work of designing and building the spacecraft, redesigning and adapting the Atlas/Agena launch vehicle for the parking-orbit mission, and expanding from the Goldstone deep-space tracking station to a world-wide Deep Space Instrumentation Facility, went on.

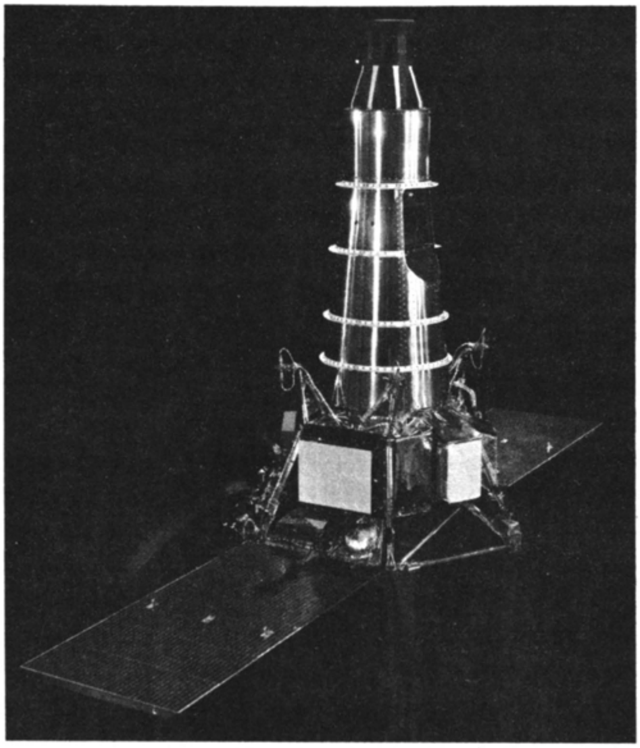
Ranger's first two flights, called Block I of the Project, were directed toward engineering test of spacecraft equipment and the system design, using a highly elliptical Earth orbit. A payload of environment-sampling scientific instruments was developed. The two missions, launched in the fall of 1961, experienced launch-vehicle failures which left the spacecraft in short-lived, low-altitude satellite orbits. Some scientific data were obtained and some spacecraft design elements were tested.

Three Block II flights were made in the year 1962. For these missions, a retromotor-slowed landing capsule containing a seismometer experiment and a radio system, to be separated from the spacecraft near the Moon, and two lunar-approach experiments, including approach television, were employed in conjunction with the Ranger basic bus.

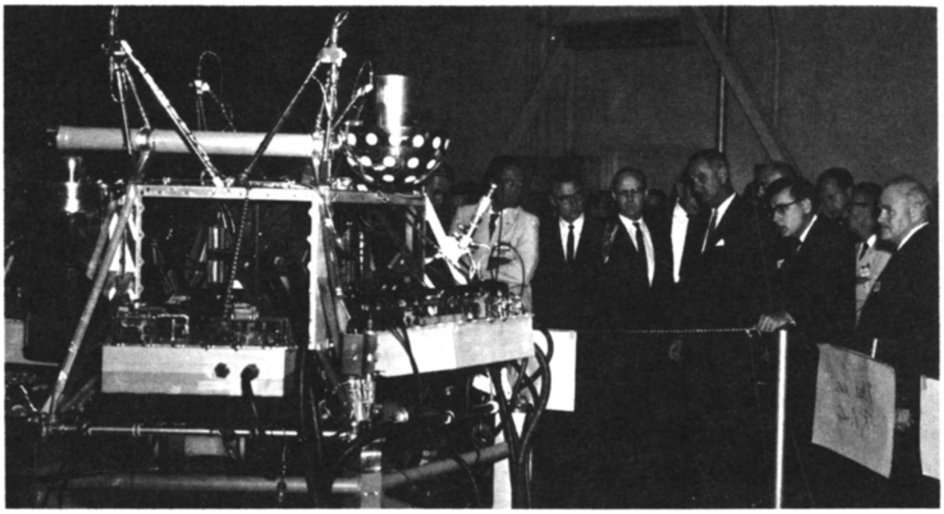
The missions collectively demonstrated launch vehicle performance and spacecraft design adequacy, but, unfortunately, not on the same at-







Top: Model of Ranger's cousin, Mariner II, the 1962 Venus probe
Center: Early Block III design shows TV tower, separate camera ports
Bottom: Ranger Block III design used in the Ranger VII mission



Vice President Lyndon B. Johnson, chairman of the National Aeronautics and Space Council, inspects Ranger IV in late 1961

tempt. Ranger III had the opportunity for a full exercise of cruise operations, but a launch inaccuracy made lunar impact impossible. Rangers IV and V suffered early disabling spacecraft failures; however, the capsule transmitters were tracked through the missions to impact in the case of Ranger IV and for eleven days in the case of Ranger V.

These missions, though disappointing from the point of view of their primary objective, were nevertheless highly productive. A full-length Ranger spacecraft mission was conducted for the first time, and emergency failure-mode procedures were exercised. The launch vehicle underwent three parking-orbit lunar-mission tests, and matured accordingly. And the tracking network had an opportunity to test and perfect its procedures and equipment in full-scale live operations. The fundamental design principles which Ranger had pioneered were also given a demonstration. These factors were even more dramatically confirmed late in 1962 with the successful flight to the planet Venus of Mariner II, a near relative of the Ranger design.

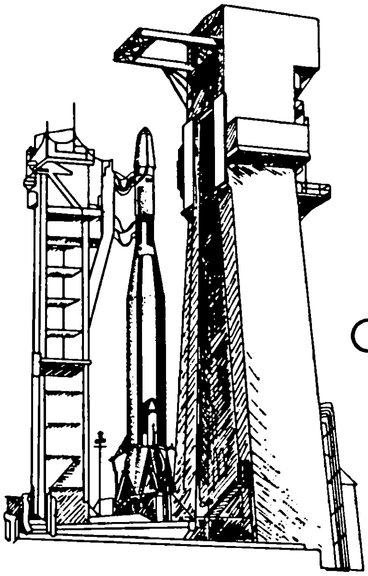
A group of four more flights, known as Block III, had been added to the Ranger series. Now, with a record of five flights marred by difficulties and devoid of any but partial success, a new look was taken at Ranger. Higher reliability became the prime goal. Reliability can be defined very simply as the probability of not failing. It can be enhanced in a number of ways: detecting and replacing unreliable parts; simplifying systems; duplicating critical elements so that if one fails, the other carries on; and isolating various systems so that a failure in one does not infect others.

The Ranger Block III system, shipped to Cape Kennedy at the end of 1963, incorporated many of these improvements. The new Block III payload was a single scientific experiment: a complex of six television cameras would take and transmit high-resolution pictures of the lunar surface as the spacecraft approached the Moon. At least ten-times-better pictures than could be obtained from Earth were hoped for.

But the rigors of space flight had one more surprise in store for Ranger engineers. As the Atlas/Agena/Ranger vehicle was lifting through the upper atmosphere, the high-voltage power supplies of the TV system apparently came on inadvertently during the brief interval when they could destroy themselves by high-voltage arcing. Ranger VI, precisely and almost without anomaly, delivered a dead, destroyed television package to the selected lunar location. The mission was a dramatic successful demonstration of the Ranger system, with the one exception.

Again there was a pause for investigation, research, and finally, the last redesign was completed. Though the exact cause of the accident was never pinpointed, preventive measures covered almost all possibilities.

The Ranger VII spacecraft was ready for launch.



# Cape Kennedy: Getting Off the Ground

The Ranger VII spacecraft was shipped to Cape Kennedy for prelaunch operations while the Ranger VI mission was underway. Its launch vehicle had preceded it to the Cape. After the Ranger VI flight, the Ranger VII spacecraft bus was sent to JPL in Pasadena for modification. Its television package was returned to RCA, where a number of preventive changes were made. After thorough laboratory testing, the spacecraft with its payload again travelled to Cape Kennedy, arriving on June 21.

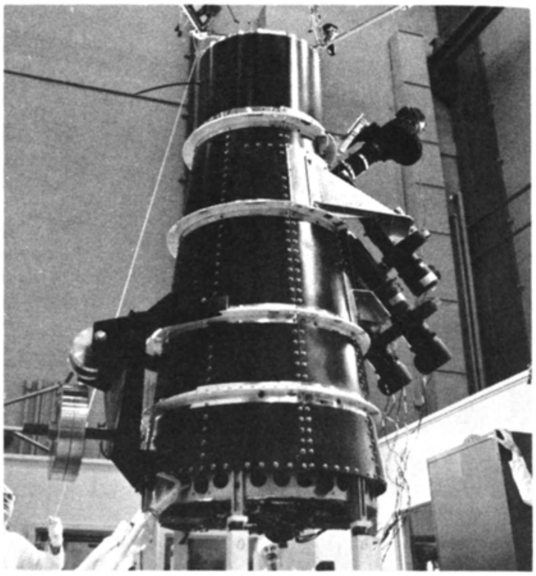
The launch vehicle was standing on the pad at Launch Complex 12 by this time. Ranger's "horse" consists of a stage-and-a-half Atlas space launch vehicle, based on the first U. S. ICBM, and a two-burn Agena stage. The engineering integration of this combined vehicle was performed by Lockheed Missiles and Space Company under the direction of NASA's Lewis Research Center, which is responsible for light and medium space launch vehicles in NASA unmanned programs.

## ATLAS AND AGENA

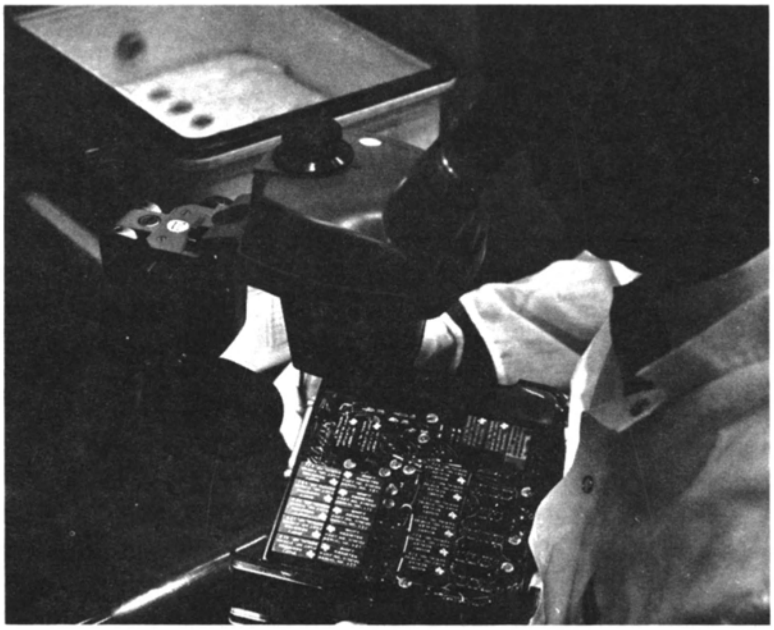
Developed in the mid-fifties by General Dynamics/ Astronautics, the Atlas stands about 66 feet high, weighs 130 tons when fueled, and has a maximum thrust at sea level of 370,000 pounds. Its "half stage" contains two large booster engines which are jettisoned some 2 minutes after liftoff, when their thrust is no longer necessary. The remaining stage is powered by a single large sustainer engine with 2000-pound vernier engines which provide fine tuning on the velocity. The engines are made by Rocketdyne Division of North American Aviation. The bulk of the vehicle is taken up with gigantic propellant tanks containing liquid oxygen and kerosene-like RP-1 fuel.

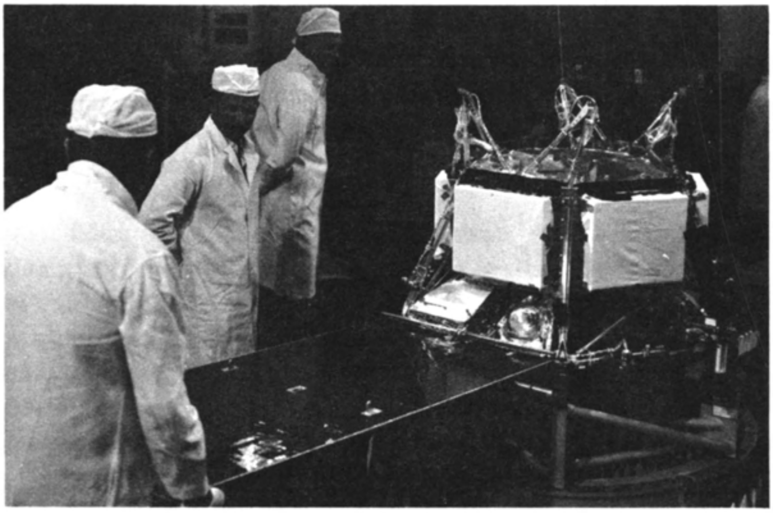
Atlas had behind it six previous Ranger launches, the six manned launches of Project Mercury, two launches for the 1962 Mariner Venus flight, the Project Score satellite mission, and countless military missile development and training launches. The vehicle assigned to Ranger VII was Atlas 250 D.

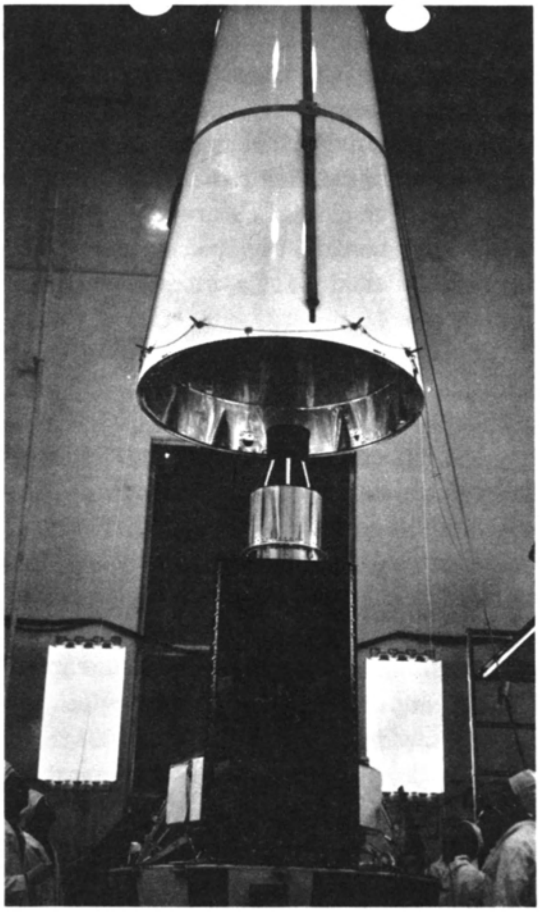
Agena, developed at the end of the 1950's by Lockheed as an Air Force satellite project, and modified for NASA space-mission launching, is powered by a 16,000-pound-thrust Bell engine. Its propellants are two unsavory chemicals known as unsymmetrical dimethyl hydrazine and inhibited red fuming nitric acid. Weighing 16,000 pounds, Agena is designed to operate at high speed in space.

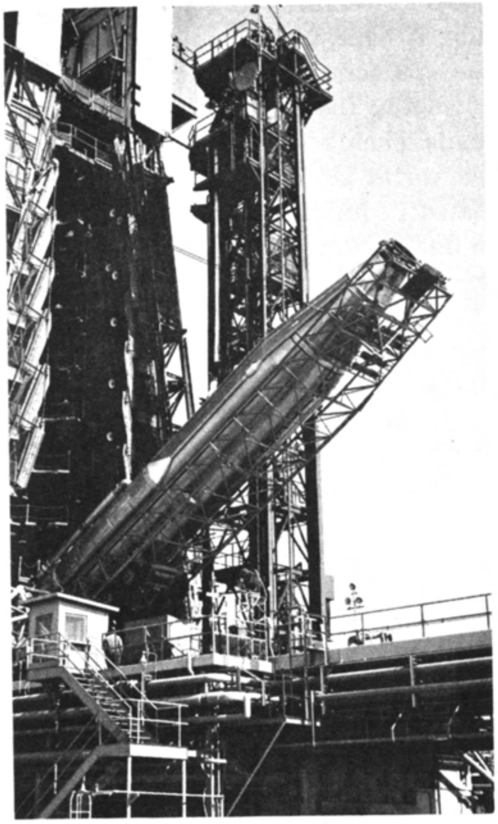


Spacecraft bus arrives at Cape (top left). Following checkout and inspection (left) assembly and test begin. TV subsystem is tested (above). After thorough testing and final assembly, Ranger VII is encapsulated for launch (below)

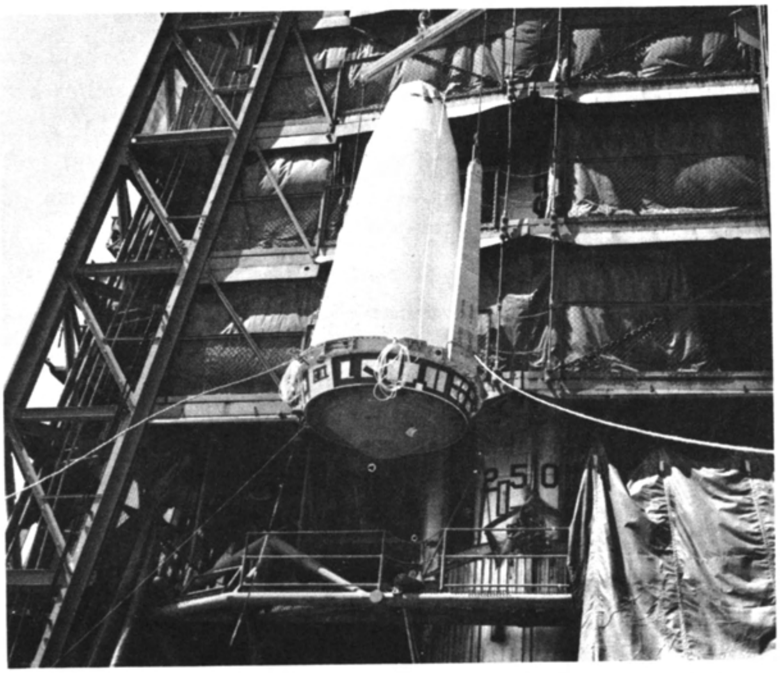


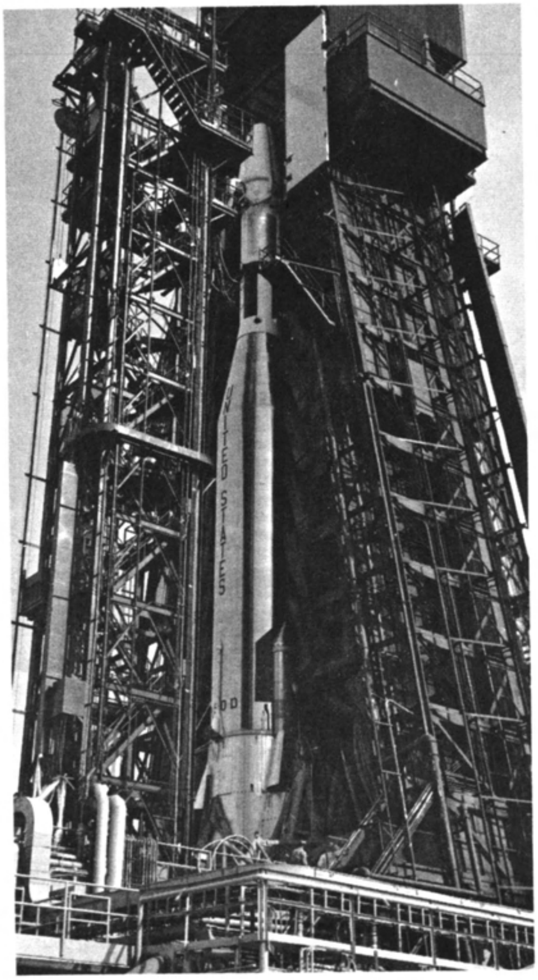






Meanwhile (above) Atlas and (above center) Agena have been installed on the pad. After a mechanical fit check and final tests back at the hangar, Ranger (below) is mounted on the launch vehicle. Final flight-acceptance test of complete space vehicle (right) involves all project engineers and managers

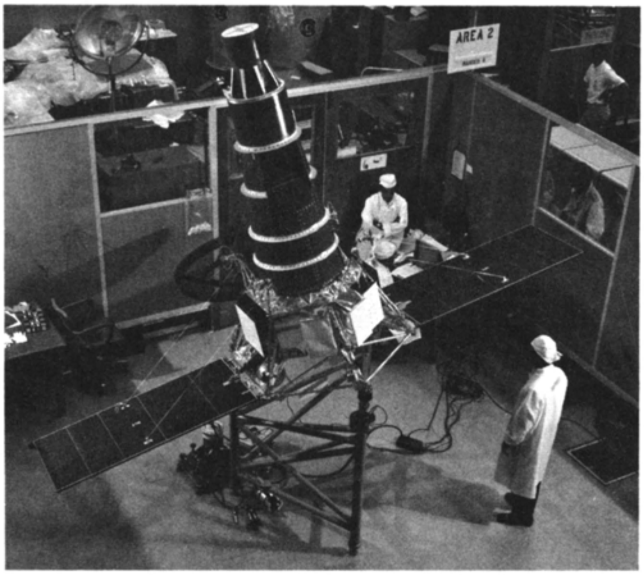




In its Ranger VII service, Agena B 6009 was expected to fire in two phases. First, taking over at about 12,000 mph, when the spent Atlas was jettisoned, it was to accelerate to 17,500 mph and achieve a satellite orbit. Then, after coasting into position for the launch, it had to fire again, accelerating to about 24,500 mph. Finally, after the spacecraft was separated, the Agena was to push itself out of the way with a small retro-rocket.

## A LAST MONTH OF TESTING

After a preliminary mating to the launch vehicle to ensure that everything matched, the Ranger VII spacecraft was returned to the hangar for another round of tests and for final calibration.




The ground equipment, TV system, midcourse motor, and spacecraft bus were given various separate tests and examinations. A joint flight acceptance compatibility test verified the ability of Atlas, Agena, spacecraft, and support equipment to function together. Tests involving the spacecraft rocket motor and the explosive squibs used for certain mechanical operations were run in the bunker-like explosive safe area; when these components were finally installed on the spacecraft, Ranger would go to the hangar no more.

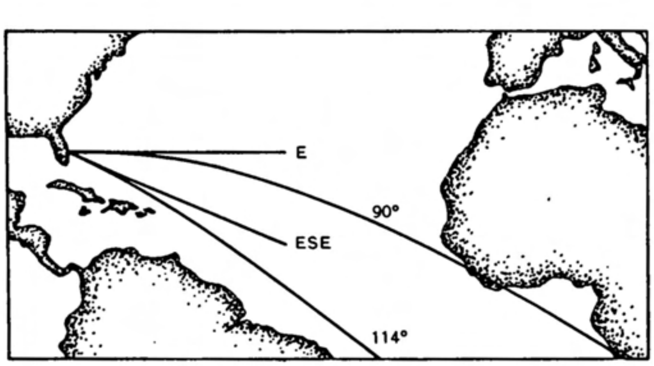
The assembled spacecraft was weighed and balanced carefully. A ballast of 3 pounds was added to balance the spacecraft around the midcourse motor axis, bringing the final spacecraft weight to 809.57 pounds. Then, mounted on the interstage adapter which would become part of the Agena stage, and sealed in its aerodynamic nose cover, Ranger had a final functional test. Meanwhile the Atlas and Agena had been going through their own series of tests, as had the Deep Space Network and all ground equipment.

On July 25, the assembled Atlas/Agena/Ranger went through a simulated launch operation. The countdown went to T−18 seconds before the test was concluded. Last-minute problems in ground equipment and launch vehicles were solved; the spacecraft was ready to go. The launch period would begin in two days.

## WHERE AND WHEN TO LAUNCH

The ideal base from which to shoot Rangers to the Moon would probably be a space station. Barring that, a well-equipped base on the equator, surrounded by several thousand miles of empty ocean for spent rocket stages to drop into, but easily accessible to most parts of the United States, would do. Cape Kennedy, Florida, is the practical solution.

However, to avoid dropping used rockets on the shipping lanes and land masses, launches are restricted to the corridor between 90 and 114° East of true North—approximately between East and East-Southeast. Eastward launches make use of the Earth's rotational velocity.



To understand the problem of hitting the Moon, it helps to imagine a long, gracefully curved pipeline running from Earth toward the Moon. This pipe is 10 miles in diameter, and its near end is at an altitude of 120 miles. If the spacecraft enters the pipeline with a velocity of 24,470 ±16 mph, the interaction of its speed and direction with the motions and gravities of Earth and the Moon and the corrective use of the spacecraft's midcourse rocket motor will place Ranger precisely on its lunar target. This pipeline has been calculated by a tremendous computerized operation, taking into account possible influences of the Sun and the planets Venus, Mars, and Jupiter. Specific trajectories for every minute of every possible launch opportunity have been designed.

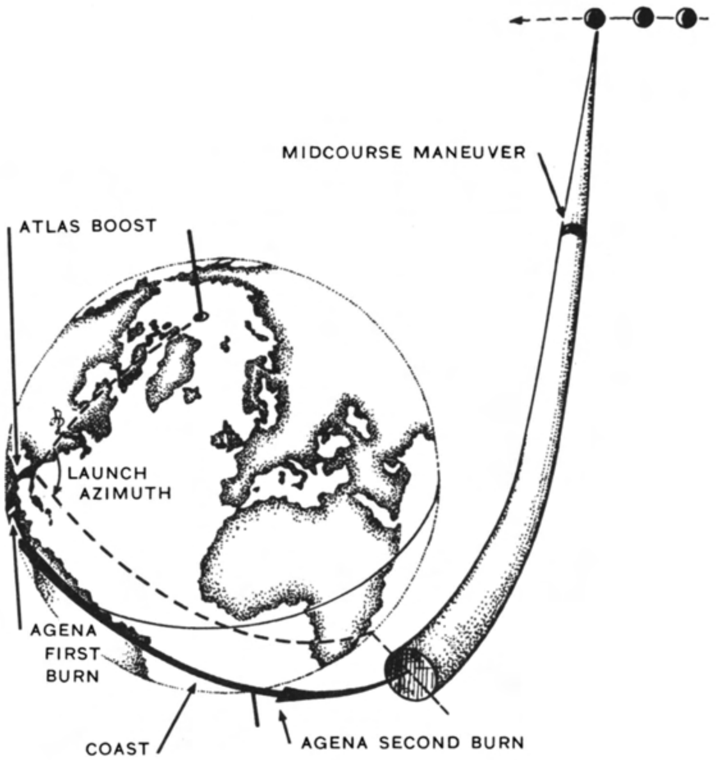
The Earth end of the lunar pipeline moves fairly slowly in space; however, the Earth, including Cape Kennedy and that East to East-Southeast angle, spins underneath it at nearly a thousand miles an hour at the equator. Consequently, the pipeline is within the launch angle for about 1 to 4 hours each day; this period is called the "launch window."

The third-quarter phase of the Moon had been selected for Ranger operations; this limited Ranger VII launches to July 27, 28, 29, 30, and 31 and August 1. The reasons for the restriction were twofold: scientific and engineering.

The television mission required that the Moon be lighted at an angle to provide clear contrast and shadow definition. Desirable impact sites, fairly near the center of the lunar disk as seen from Earth, would have such lighting at third quarter. The exact sites are selected on the basis of the day (and hence the location of the day/night boundary or terminator) of impact.

The spacecraft was stabilized along the direction to the Sun and the direction to the Earth. With these directions at a substantial angle, guidance would be accurate, but if they were nearly parallel (as at full Moon or new Moon) it would not.

These were the broad launch constraints: direction from the Cape, velocity, hour of the day, and day of the month. In addition, the time of transit to the Moon had to be around 60 to 70 hours, to ensure that the Goldstone Tracking Station, with all its video-recording facilities, would be in communication with the spacecraft at impact.




## COUNTDOWN AND LAUNCH

The first day's launch operations uncovered a few problems in the launch vehicle and ground equipment. These were solved to the satisfaction of the engineers, but the 2-hour launch window ran out, and launch was postponed to the next day, July 28.

The second day's countdown for the launch vehicle actually began before midnight on July 27. Three hours later, the spacecraft system joined the countdown, at T−215 minutes. Launch countdown is a combination of last-minute operations, such as fueling and certain system tests, with an orderly system of checks and tests of launch readiness. The Ranger countdown incorporates two built-in hold periods in which the countdown clock is stopped, at T−60 minutes and again at T−7 minutes, for evaluation and the adjustment of launch time. During the first hold, a recording device in the blockhouse which had failed was replaced with the unit borrowed from neighboring Launch Complex 13. Otherwise, the countdown was almost without incident.

Liftoff occurred at 10 minutes to noon, Cape time, 8 seconds after the earliest possible launch



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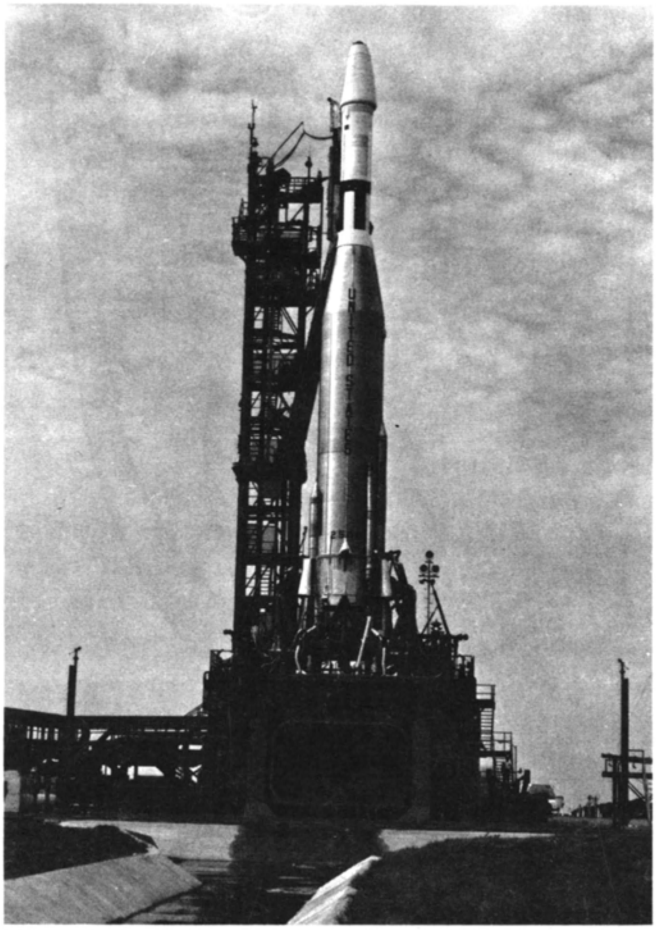
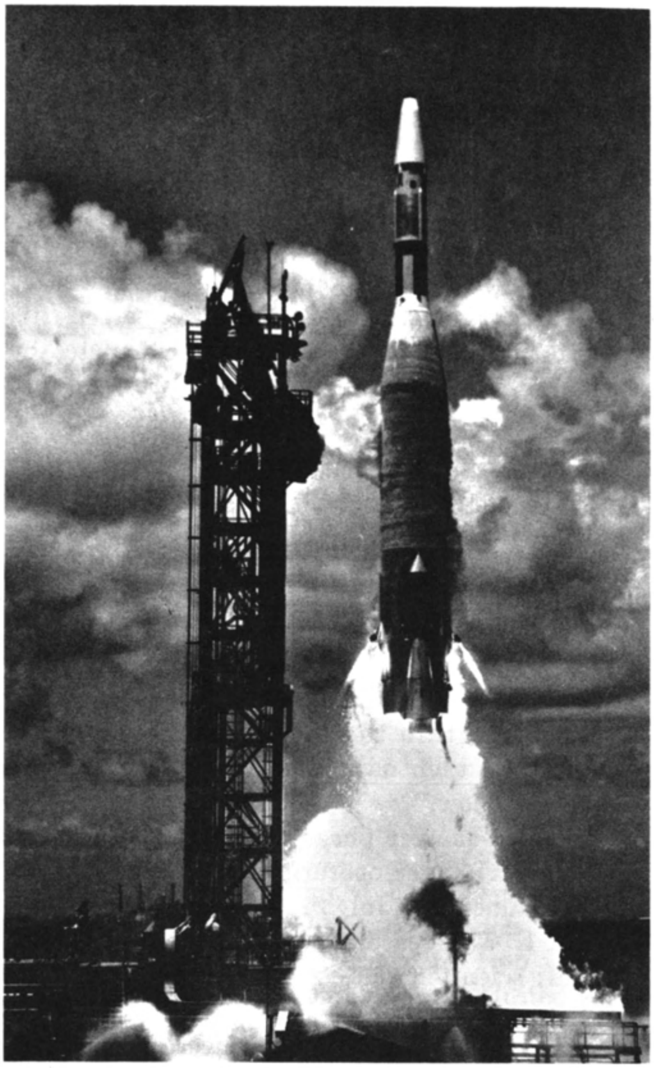
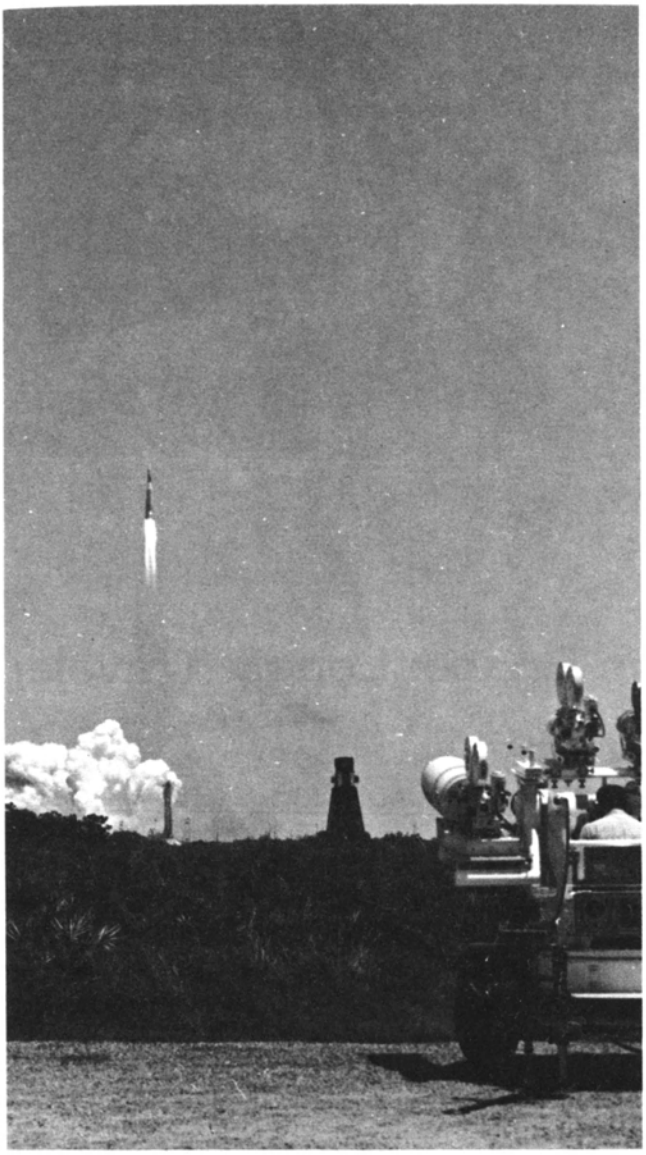




On launch day, the countdown is monitored at Spacecraft Control in the hangar (left) and conducted by Goddard Space Flight Center's launch operations team from the pad block house (below). After liftoff (above) Atlas/Agena/Ranger disappears into the blue as the mission director (Project Manager) waits for reports.



specified by the trajectory engineers. The weather was excellent — a 2000-foot ceiling, 3/10 cloud cover, and, at the surface, a balmy 86°F, 65% humidity, and a 10-knot wind.

## A PERFECT BOOST

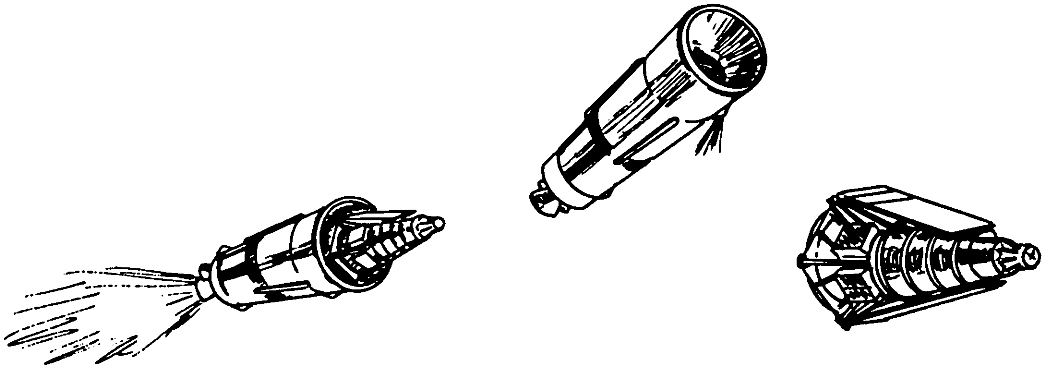
During powered flight, the three major elements of the space vehicle transmitted separate radio telemetry. As many as two hundred measurements —of temperatures, operating voltages and currents, and mechanical angles and positions, as well as the triggering of events—can be transmitted by broadcasting a number of channels simultaneously, and, on each channel, transmitting one measurement after another in sequence.

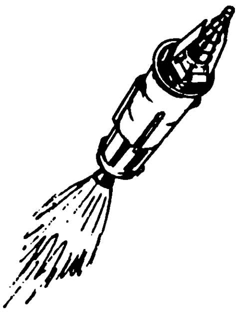
These signals were received by the downrange stations of the Air Force Eastern Test Range, Cape Kennedy. The first stations were actually on the Cape; then there were island stations in the Caribbean, ships in the Atlantic a few hundred miles off South America and Africa, a station on Ascension Island, one in South Africa, another ship in the Indian Ocean, and a station in Western Australia. In addition, the Cape station of the Deep Space Network, used primarily for spacecraft communications checkout, tracked Ranger VII's transponder to the horizon.

Data picked up by the downrange network showed that it was a good launch. Radar tracking data indicated a correct course, and telemetry demonstrated that all systems were performing within their design limits. The booster semi-stage was jettisoned on schedule, leaving the Atlas main stage to operate for nearly 3 minutes longer. Then Atlas shut down and dropped away, its mission successfully concluded.

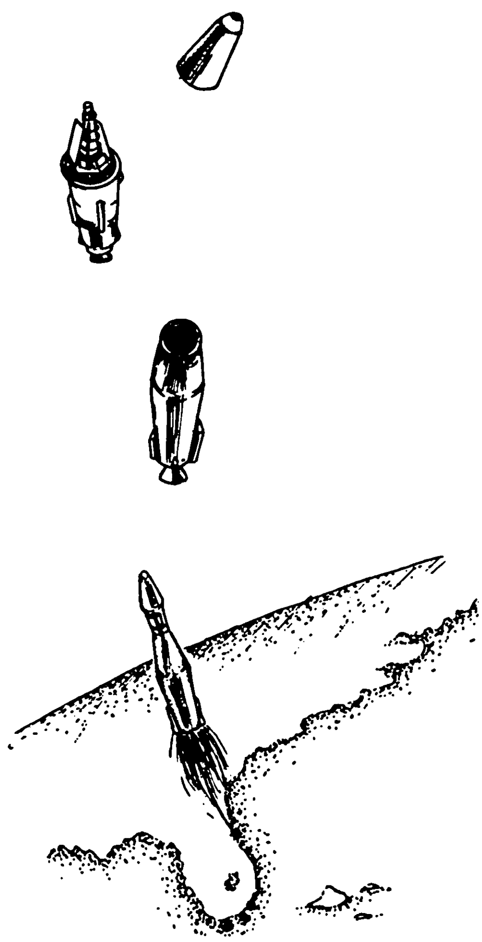
The Agena performed satisfactorily during its two thrusting and one coasting periods. It delivered the Ranger VII spacecraft to the beginning of its lunar trajectory under conditions which would have the spacecraft impact the far side of the Moon. The course was readily correctible by the spacecraft's motor to any desired impact point on the visible side.

It had been a successful launch.



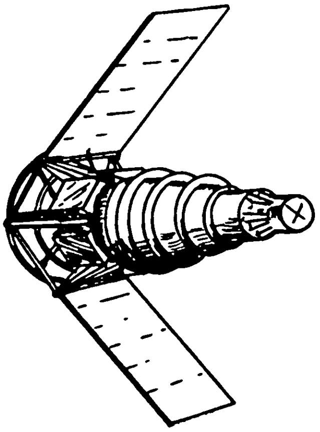


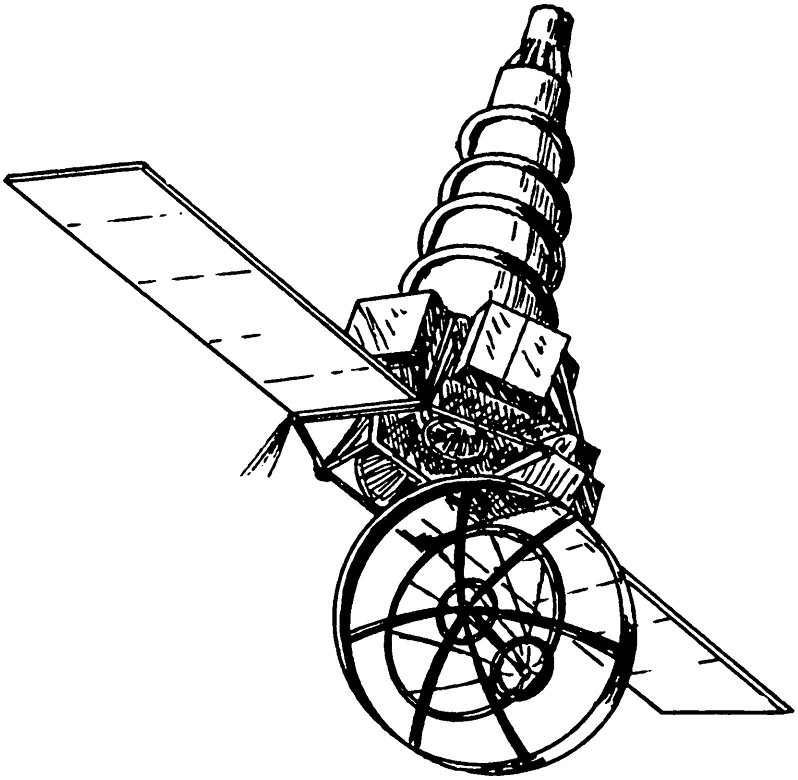
# Ranger VII in Space: Lonely Traveler



After separating from the Agena rocket, the Ranger spacecraft coasted toward the Moon, tumbling slowly, folded in upon itself as if still under the aerodynamic nose cone. It had just entered the Earth's shadow, and would be in it for some 40 minutes. After about half an hour (it was now 1 hour after liftoff) the spacecraft's central computer and sequencer or CC&S (something between a computer and a multiple alarm clock) commanded solar-panel extension.

A switch closed in the squib-firing assembly, and electrical current from the two spacecraft batteries was applied to four squibs located on the solar-panel support arms. A squib is an electrically fired detonating device, like a bomb, enclosed in a cylinder with a piston, so that its explosive force may be used to open or close a bolt or valve. These squibs withdrew the four pins locking the solar panels in the folded position; springs forced the panels to hinge outward like the wings of a butterfly, and lock in the outboard position.





Three minutes later, the CC&S commanded Sun acquisition. This meant that the circuits controlling the yaw and pitch attitude-control gas jets were placed under the control of the Sun sensors. With its photoelectric eyes, Ranger was looking for the Sun, trying to turn the top of its central tower toward the Sun by jetting nitrogen gas out of nozzles located in pairs out at the rim of the spaceframe.

However, the spacecraft was still in the dark of the Earth's shadow. When it emerged a few minutes later, it began turning toward the Sun, and "locked on" in 6½ minutes. Now the 9782 silicon solar cells on the panels were catching the Sun, and they immediately began supplying raw electrical power to the spacecraft, at a rate of about 200 watts.

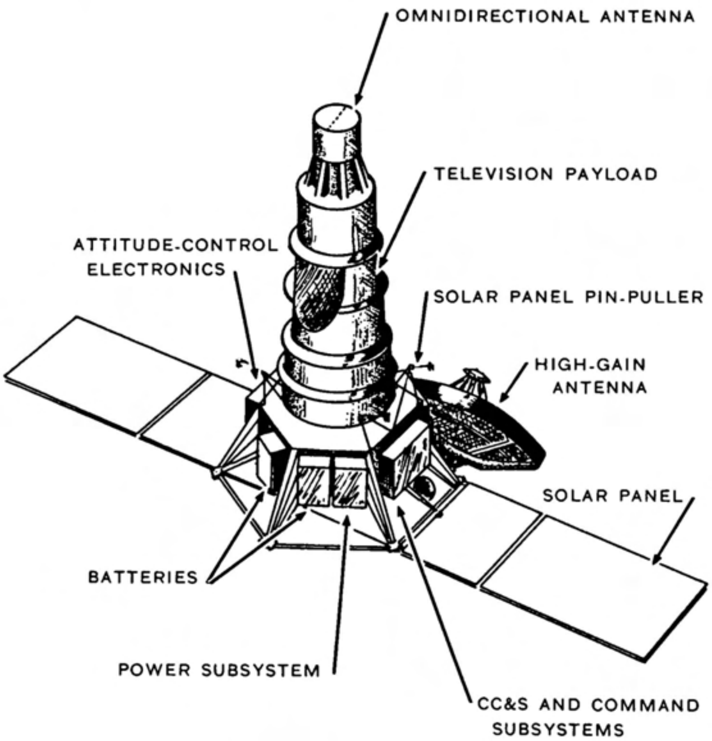
The spacecraft coasted without incident for 2¼ hours, and then the CC&S commanded Earth acquisition. The reflecting-dish antenna, to which a photoelectric sensor was attached, had been set out at a predetermined angle of 55 degrees during Sun acquisition; now the spacecraft rolled counterclockwise until the sensor detected the Earth. The spacecraft rolled 310 degrees—from a little past 10 o'clock back around to 12—in 23 minutes and locked on the Earth. The antenna was now pointed at the Earth.

The Australian Deep Space Station sent the Ranger spacecraft a command half an hour later. It was the first ground command Ranger VII received, and, incidentally, the first such command the station had ever sent to a spacecraft. The effect of this command was to have the spacecraft switch its radio transmission from the all-direction low-efficiency antenna to the high-gain directional dish pointed at the Earth. Within seconds, the radio signal from Ranger increased in strength by a factor of 10.

Ranger VII was now fully stabilized, operating on solar power, maintaining high-gain communications with the Earth. According to telemetered data, all systems were operating perfectly. Ranger was open for business. The mission was exactly 4½ hours old.

## RANGER SPACECRAFT ANATOMY

The Ranger spacecraft system is designed in twelve subsystems: structure and packaging, radio, command, spacecraft power, CC&S, telemetry, attitude control, pyrotechnics, cabling, midcourse propulsion, temperature control, and television. These subsystems may be grouped according to what sort of engineers designed and developed them—for example, sequencing and attitude control belong to the art of guidance and control, while structure, temperature control, pyrotechnic actuators, and the cables and connectors come from engineering mechanics. Or they may be grouped by the nature of their components—the CC&S and the telemetry system are electronic devices, the midcourse propulsion subsystem is a monopropellant hydrazine rocket motor, the temperature-control subsystem is a complex of paint and polished metal.



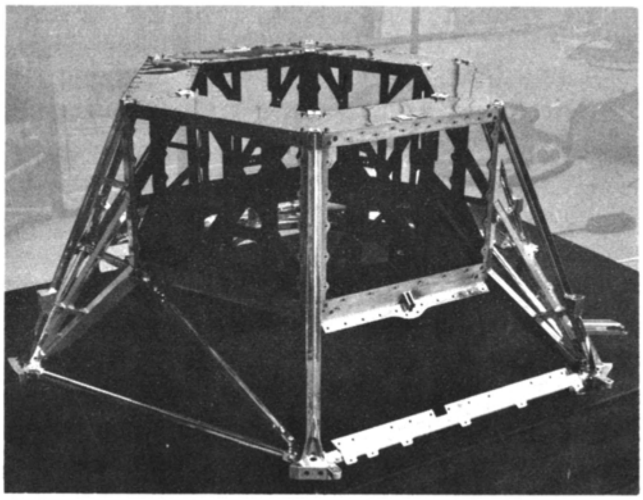

Functionally, the spacecraft may be viewed as a structure, a group of mission-service units (such as radio and attitude control), and a television payload. The structure and service units were originally designated the "bus" when it was planned to develop a common-carrier spacecraft adaptable to various flight missions with the application of various scientific-instrument "passengers". Design evolution and particular mission requirements brought about design differences from one "bus line" to the next, but the principle and the name are still used.

The basic spacecraft structure is a six-sided triple ring made of aluminum and magnesium alloys, braced together at each of the six corners. The lower outer ring has the solar panels attached at two opposite sides; the high-gain radio "dish" antenna is mounted on another corner. The spacecraft is joined at this ring to the Agena rocket and is about 5 feet across at the base.

The small rings make a short hexagonal tube or belt. The midcourse motor is mounted inside the tube; six electronic packages, containing most of the spacecraft housekeeping and communications equipment, are hung on the outside of the belt. The TV tower is mounted on the top ring. The spacecraft is 8 feet 3 inches tall with the dish antenna folded in. The Ranger VII structure weighed 91.15 pounds, and it supported a total of 809.57 pounds under about 7*g* acceleration during the launch phase.

## SERVICE IN SPACE

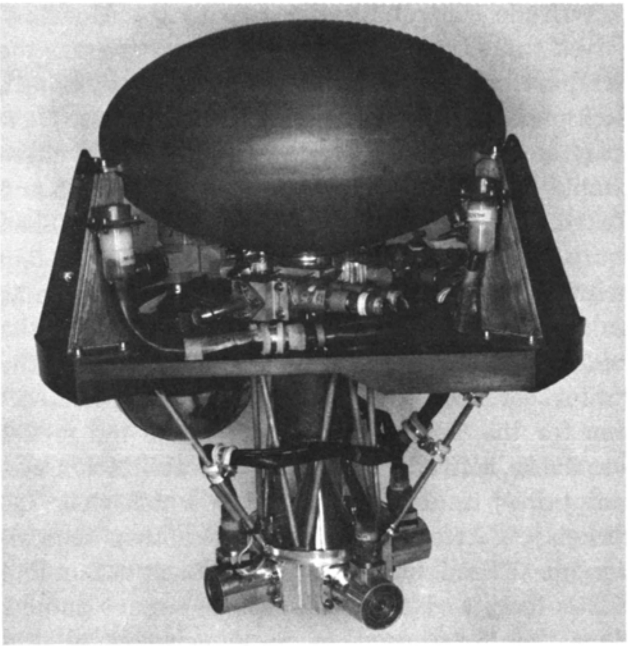
Spacecraft electric power, as mentioned previously, comes from either of two sources: solar panels (when the spacecraft is pointed at the Sun) or batteries (when it is not). Each of these sources is duplicated—two silver/zinc batteries, and two solar panels each wired in three sections—to reduce the effect of any failure and increase reliability. A power switching and logic device distributes power from the two sources according to how

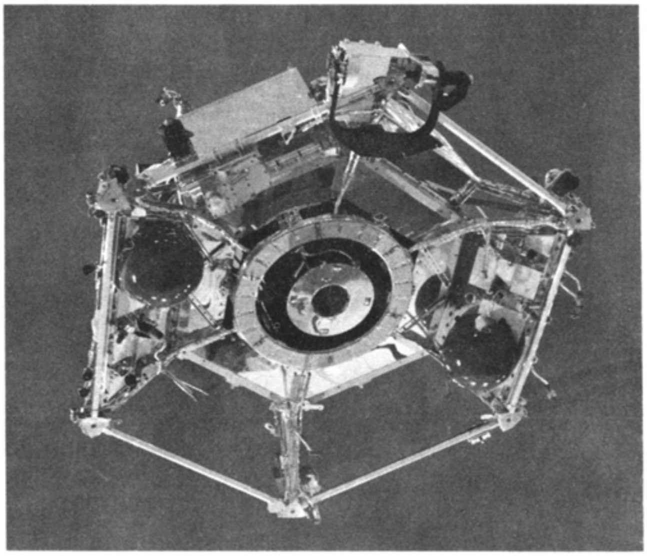


much the solar panels are generating. In the Ranger VII mission, the batteries supplied power for 5 minutes before launch, then for about an hour and a quarter until the spacecraft acquired the Sun, and for less than half an hour during the midcourse maneuver. The batteries alone could have powered the spacecraft for 18 to 20 hours.

Voltage regulators, power cables, and converters on devices to provide alternating current or particular voltages required by various subsystems make up the rest of the power equipment. The TV subsystem has its own independent power supplies fed by two separate batteries.

The midcourse propulsion system consists of a rocket motor, ignition cartridge, fuel tank with lines and valves, gas pressure system to force the fuel into the motor, and jet vanes at the mouth of the rocket nozzle for steering. The rocket motor is made of stainless steel, with a cylindrical chamber and a long flaring nozzle. Turned nozzle up, it looks like a modern vase for long-stemmed roses. It runs on hydrazine, which can be used as a rocket fuel in a bipropellant system with an oxidizer like





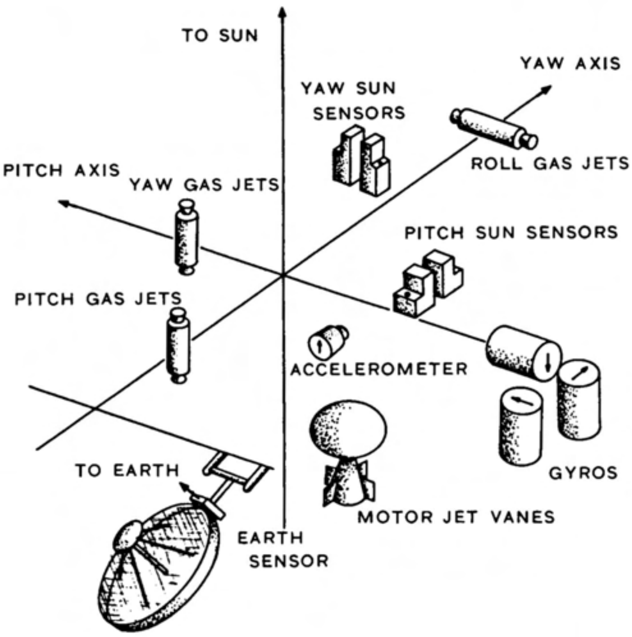
Lower deck of spacecraft bus mounts midcourse motor, spherical gas tanks for attitude-control jets

nitric acid (as in the Agena) or as a monopropellant, decomposing spontaneously in the presence of a catalyst. For the Ranger motor, aluminum oxide catalyst lines the rocket chamber walls, and a spoonful of nitrogen tetroxide oxidizer is injected into the chamber to start the hydrazine reaction. Ranger's midcourse motor was like those used on earlier Rangers and on Mariner II, the Venus probe. Its thrust is 50 pounds, and it can change spacecraft speed by as little as 1.2 inches per second or as much as 190 feet per second, depending on how long it is turned on. Its valves (releasing pressurizing gas, propellant, and ignition cartridge to start the motor, and turning pressure and propellant off to stop) are actuated by squibs like those which released the solar panels. The steering vanes are driven by an autopilot which is part of the attitude-control system.

The pyrotechnics subsystem consists of the various squibs already described, and their master squib-firing assembly, which, on command from the CC&S, applies battery current to the appropriate squibs. On ground command, this assembly can ignore certain CC&S orders.

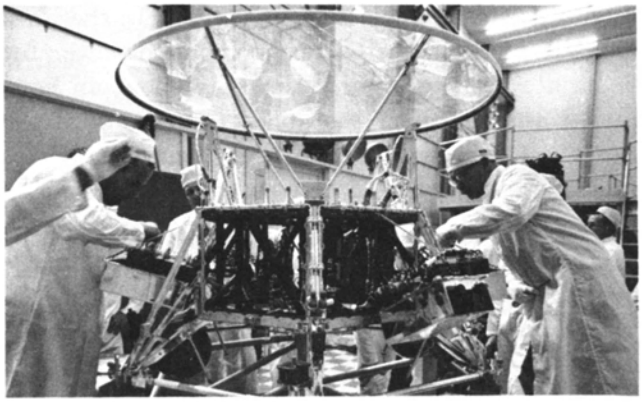
The attitude-control subsystem is very complicated. It includes electronic devices such as the autopilot, the command switch and logic, control amplifiers for the gas jets and antenna pointer; sensors such as the photoelectric Sun and Earth sensors, the accelerometer, and three gyros (one for each axis); and "muscles" in the form of the gas-jet system.

Attitude control for the trip to the Moon involved three types of activity. First, there was the two-part acquisition phase, already described, each part taking about half an hour or less. Next was the "cruise" phase, in which the subsystem simply kept the spacecraft lined up on the Sun and Earth. This went on for most of the voyage. Then there was the maneuver in which the subsystem pointed the spacecraft in a particular direction as ordered from Earth. This was done during the midcourse maneuver, so that the impulse from the rocket motor would be pointed in the proper direction for the trajectory change. While the rocket was firing, attitude or directional stabilization was maintained by driving the vanes which steer the rocket jet. After the maneuver, another acquisition phase brought the spacecraft back to Sun and Earth lock, and the cruise phase was resumed. Near the Moon, another maneuver can be performed to point the TV cameras at their target; this was not necessary on Ranger VII.




Active elements of attitude-control system

The twin gas-jet systems (duplicated down to gas tanks and pressure regulators for extra reliability) used between two and four ounces of nitrogen gas in the whole 244,000-mile flight—an inspiring example of gas economy. The entire system performed well within expectations during the mission. However, the Earth appeared generally brighter to the Earth sensor than had been calculated from the flight path and estimated Earth brightness.



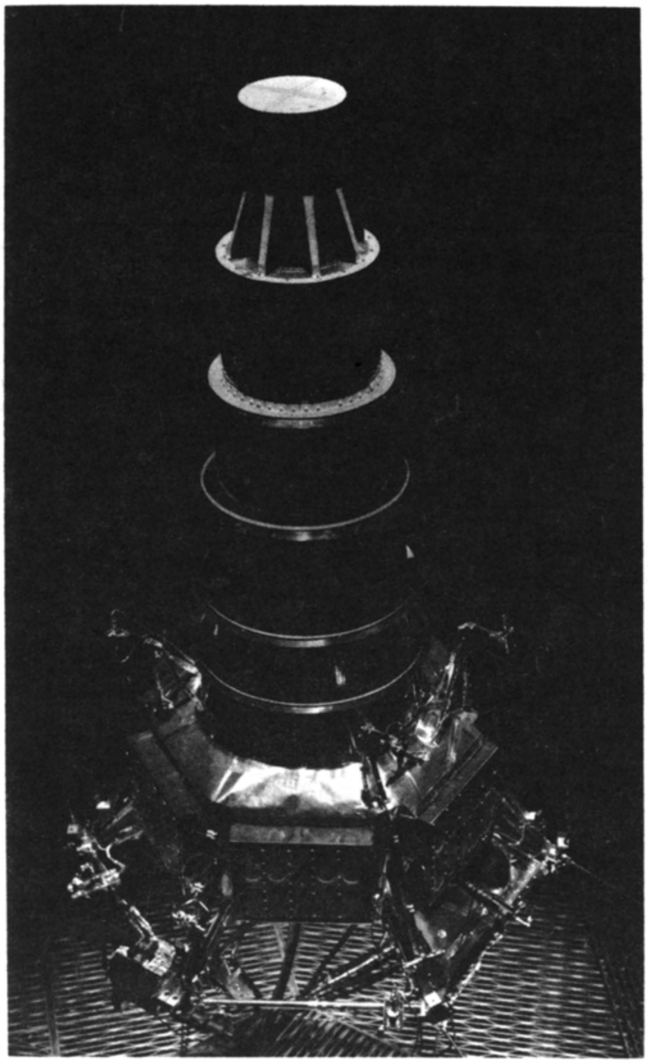
Electronic packages hinge open for assembly, inspection, test

The heart and brain of Ranger VII was the central computer and sequencer, or CC&S. It provided the master heartbeat to all subsystems which had to work in synchronization. All such automatic functions as solar-panel extension, initial Sun and Earth acquisition, and TV turn-on, got their cues from the CC&S. It also directed the maneuver operations, working from numbers and a "start" command sent by the engineers on Earth.

Weighing just over 9½ pounds, the CC&S consists of an input decoder which interprets the instructions on where to point the spacecraft and how long to run the midcourse motor, a maneuver-duration assembly which stores this information and reads it out when desired, a maneuver clock which schedules the various maneuver operations, a launch counter which schedules the initial spacecraft operations, and a central clock which provides the timing for these and all other elements of the spacecraft bus. Without exception, the CC&S operated perfectly throughout the Ranger VII mission.

Temperature control of Ranger VII was entirely passive: that is, paint, black cloth, and plated or polished surfaces were used to control the heat-radiating characteristics of outside surfaces in order to balance the heat input from the Sun and some spacecraft components against the heat output as radiation to space. Heat shields were used on large areas of the spacecraft to cut down heat absorption from the Sun. Surfaces which were likely to reflect heat to other parts of the spacecraft —too complex an arrangement to control—were painted or covered in black. Finally, since the engineers knew the spacecraft would be in the chilling shadow of the Earth for nearly 40 minutes, they warmed it slightly before launch.

Spacecraft temperatures stayed within predicted bands at all times. The solar panels remained at about 115°F through most of the flight, warming up to 130° just before impact in the heat reflected from the Moon. Most spacecraft subsystems were in the 70's to 90's range; the Earth sensor was in the low 60's, and some of the power-distributing equipment heated to over 100°F.



Temperature-control design test in solar simulator

## THE LONG CONVERSATION

From about 45 minutes after launch, when the Australian Deep Space Station established two-way lock, until lunar impact, Ranger VII carried on a continuous two-way conversation with the Deep Space Network Stations in South Africa, Australia, and Southern California. Earth had by far the stronger voice—200-watt transmitters radiating from 85-foot dish antennas as against 3-watt spacecraft transmitters using either an omnidirectional antenna or a 4-foot dish—but Ranger had the most to say.

Two-way lock is maintained as a part of spacecraft tracking. Here is how it is done during the "cruise mode." The ground station sends a signal to the spacecraft at approximately 890 megacycles. The spacecraft picks up this signal on its omnidirectional antenna and separates any command information from it in the receiver. The 890-megacycle carrier wave goes to the transponder section, where its frequency is multiplied to approximately 960 megacycles; a 10-channel telemetry subcarrier is added; and this signal passes through the transmitter amplifiers and the high-gain dish antenna. Back on the ground, comparing the carrier frequency received from the spacecraft with the frequency sent (and knowing exactly the effect of the frequency multiplier) enables the engineers to calculate how fast the spacecraft is moving away from the ground station.

Switching antennas affects only transmission by the spacecraft, not reception; further, the outgoing signal is not actually switched from one antenna to another. There are two chains of transmitting amplifiers, one terminating in each antenna. The transponder feeds them both at all times. To change antennas one amplifier chain is turned on and the other off.

Twenty-four commands—twelve of them merely "clear" commands—were sent up to Ranger VII. They took the form of 18-digit binary words imposed on a frequency-shift-keyed subcarrier on the 890-megacycle signal sent constantly to the spacecraft. These "words" were recovered in the spacecraft receiver and passed along to the command subsystem, where they were detected and decoded. "Clear" commands went no further. "Real-time" commands for immediate action, such as antenna switching, maneuver start or interrupt, were sent to their "action" addresses. "Stored" commands, containing numbers to be used by the CC&S in directing maneuvers, were sent to the CC&S for storage.

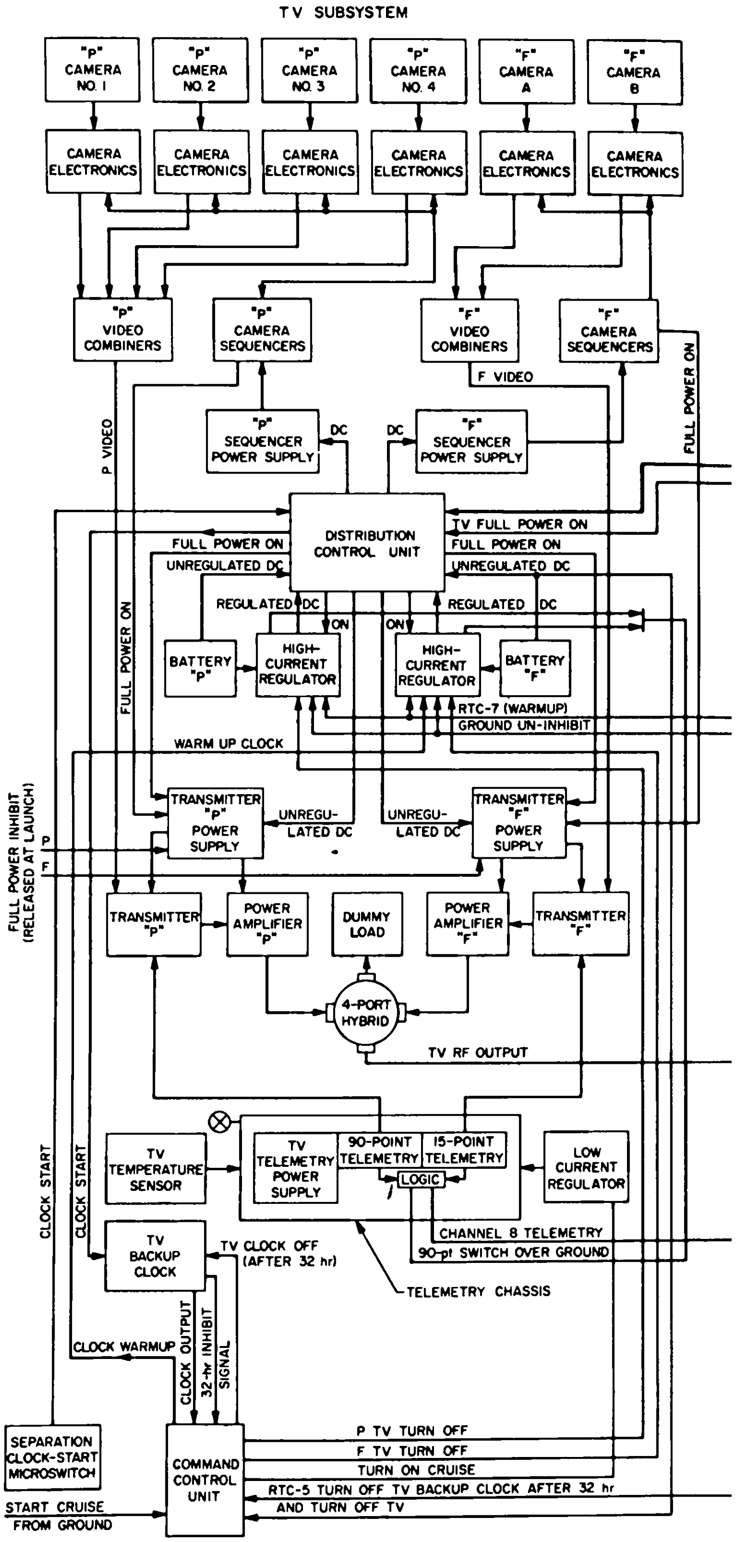
The following commands were sent to Ranger VII:

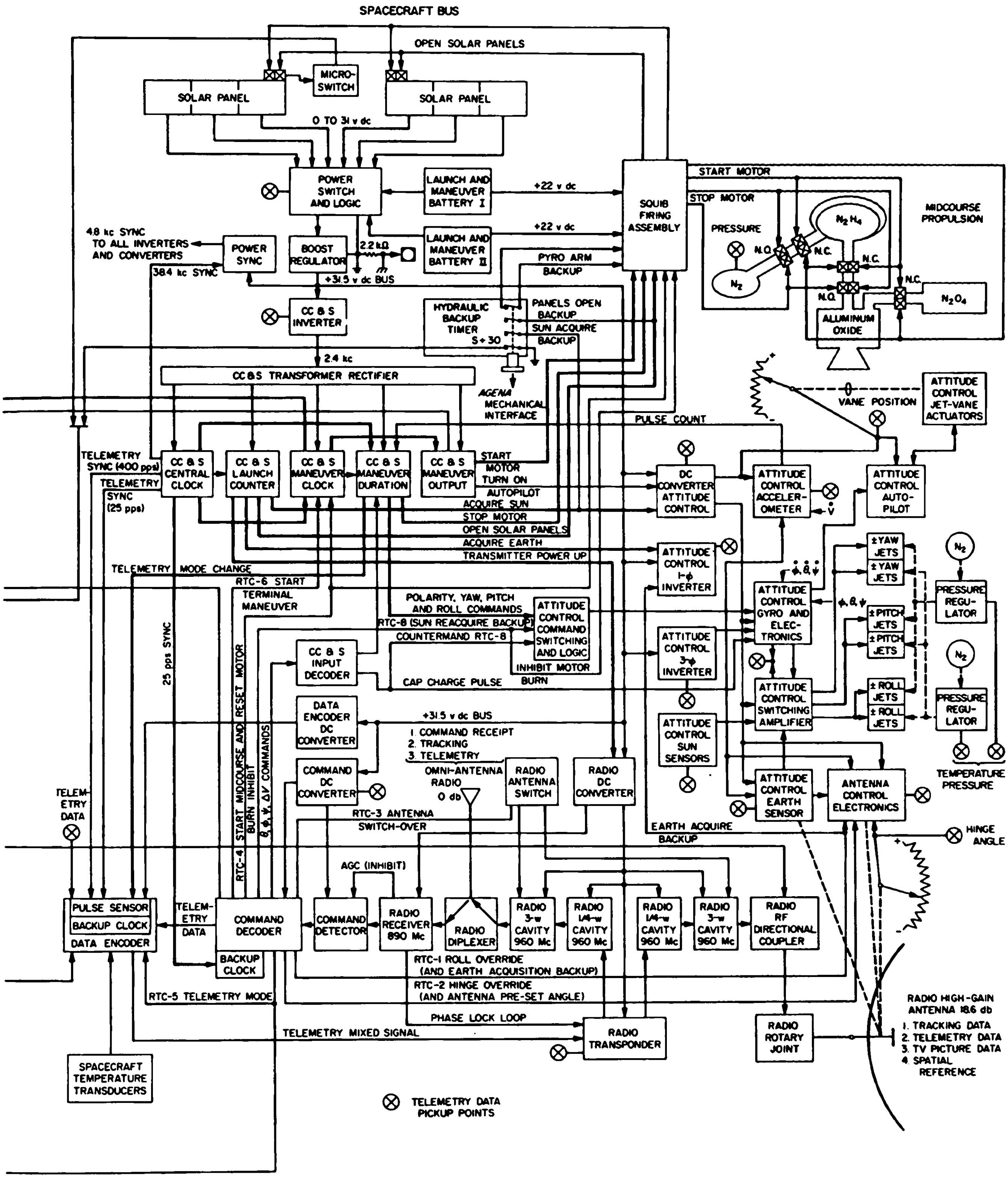
1. At 4½ hours after launch, antenna switchover (to the high-gain dish).
2. At 17 hours after launch, the three stored commands specifying the midcourse maneuver turns and velocity change desired.
3. Three-quarters of an hour later, antenna switchover (back to the omnidirectional antenna).
4. At 18 hours after launch, midcourse maneuver execution.
5. One hour and 20 minutes later, antenna switchover (to the dish again).
6. At 66 hours 20 minutes after launch, stored commands specifying a minimum (1-degree) terminal maneuver.
7. Half an hour later, a maneuver override command (telling the attitude control to ignore the maneuver commands when they come from the CC&S).
8. Half an hour after the override, the maneuver command. The purpose of this "ignored" maneuver was to start a clock in the CC&S which, in turn, started the second channel of the TV system 45 minutes later.

Each of these commands was acknowledged, routed to its addressee, and executed faithfully by Ranger VII.

Spacecraft diagnostic telemetry, like a medical checkup, is useful immediately only if something goes wrong. If all is well, as in the case of Ranger VII, the details are for the record, where they are stored for further spacecraft development.

The Ranger VII spacecraft telemetry record consists of a total of 7½ million individual measurements (exclusive of TV pictures), compiled and sent back to Earth by the 27-pound data encoder. Almost 75 voltage and current sensors, temperature transducers, pressure gauges, and the like were installed in all parts of the spacecraft to gather these measurements. In the data encoder, the measurements were gathered in






Simplified block diagram of Ranger spacecraft shows relation of subsystems, isolation of TV payload (left) "decks" of seven to nine and sampled in order, usually with a calibration voltage in case of drift in the data system. Where data were subject to rapid change, as in the midcourse maneuver, they were monitored frequently; other fairly steady conditions were sampled less often.

A number of measurements were lost during the midcourse maneuver, when a weak spot or "null" in the low-gain antenna had to be pointed at the Earth. This effect of the maneuver had been anticipated, and the resulting loss of data was considered negligible. There were no failures or anomalies in the three spacecraft subsystems which contributed to Ranger VII's 68-hour conversation with the Earth.

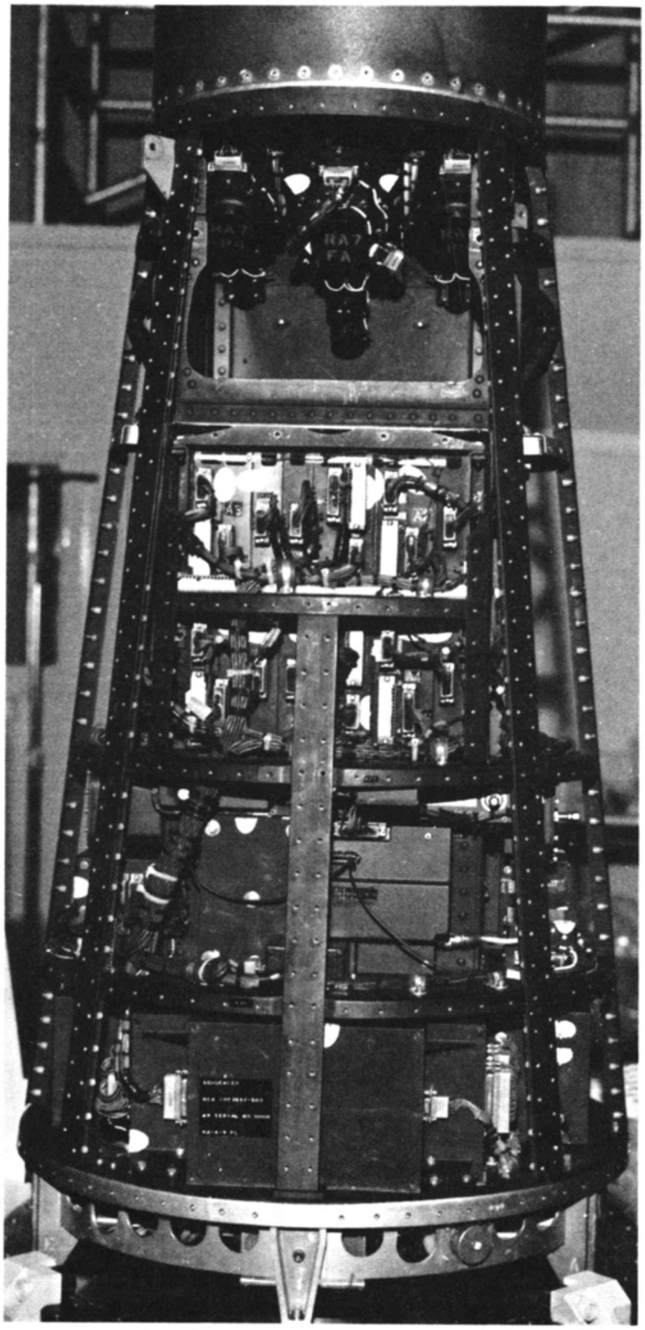
## THE PAYLOAD

At 381½ pounds, Ranger VII's TV system was almost as heavy as the entire spacecraft bus. In design complexity, too, it was nearly a match for the Ranger bus.

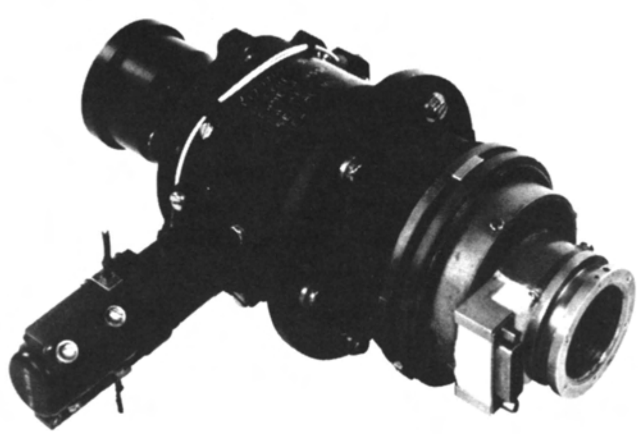
Ranger Block III's design carried the bus-passenger principle further than any previous unmanned spacecraft project. The TV payload and spacecraft bus were as nearly independent of one another as possible. There were five command lines running from the spacecraft to the TV, and two outputs—telemetry and radio-frequency video—coming back from the TV.

The TV subsystem had its own electrical power supply based on two silver/zinc batteries, its own diagnostic telemetry encoder, its own control and sequencing electronics, its own passive temperature-control system, and its own high-power radio transmitters which fed the spacecraft's high-gain directional dish antenna.

The subsystem was organized in two chains: two fully scanned cameras transmitted on channel F, and four partially scanned cameras on channel P. Each camera used a vidicon (an extremely compact type of TV camera tube) with a 1-inch screen. Two different focal lengths (1 and 3 inches) and two different apertures (f/1 and f/2) were used in the optics to provide varying fields of view and magnification, and to cover a wide range of possible brightness of the lunar scene.



Before each image was exposed on the vidicon faceplate by the shutter, the faceplate was electrically charged by the tube's electron beam. The faceplate is made of photoconductive material, so that when a light-and-dark image is focused on it, an electric-charge pattern corresponding to the image is formed. The beam again scans the plate, recharging it; the changing current on the beam denotes light or dark areas of the image, and will

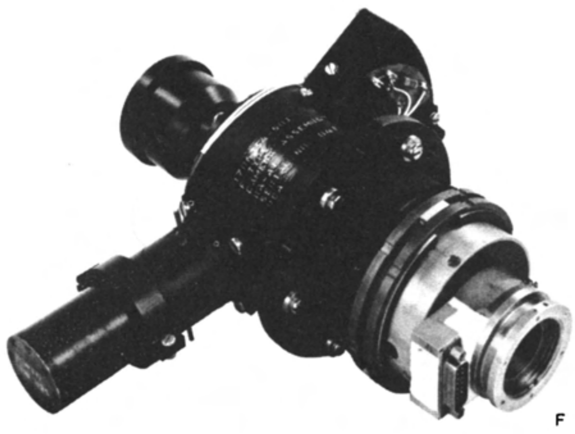


P camera

reproduce the picture when amplified and applied to the scanning beam of a TV picture tube.

The images on the F-camera vidicon tubes were 0.44 inch square and were scanned in 1152 lines. The images on the P-camera vidicons were 0.11 inch square and were scanned in 300 lines. Exposure time of the F cameras was 0.005 second; this, together with scanning time, erase time, blanking, and preparation for the next exposure, adds up to 5.12 seconds for the production of each full-scan picture. On the P cameras, the exposure time is 0.002 second, and the complete frame time was 0.84 second.

The two F cameras were scanned alternately, and the video output went through a combiner to the channel F transmitter and amplifier. The 15-point TV cruise telemetry was transmitted with the F-camera video. Channel F had its own battery and power supplies.



F camera

The four P cameras were scanned in turn, and their video output, combined with the 90-point TV operating telemetry, went to the P-channel transmitter and amplifier.

Thus during the picture-taking phase of the Ranger VII mission, the high-gain antenna was transmitting two wideband TV channels, each at 60 watts, and a 3-watt spacecraft transponder signal between them.

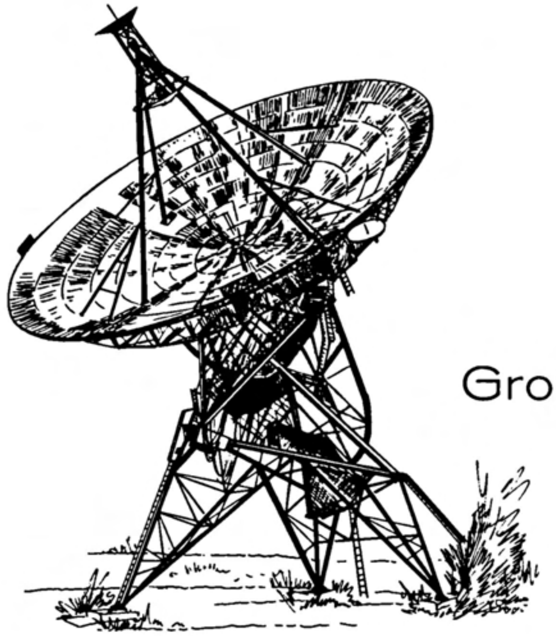
## A ROUTINE FLIGHT

After the spacecraft had entered its cruise mode at launch plus 4½ hours, business was routine. The TV backup clock, which had started at spacecraft separation and would turn on channel F in 67¾ hours, ticked off the time. The CC&S did the same. The telemetry system sent a steady stream of information back to Earth. The radio transponder remained in two-way lock with the tracking stations on Earth.

Sixteen hours after launch, the midcourse trajectory-refining maneuver, calculated on Earth to bring the spacecraft down at 21°W, 11°S, was flawlessly executed by the spacecraft. It rolled 5½ degrees in a clockwise direction, pitched negatively (bowing the TV tower over toward the high-gain antenna) almost 87 degrees, and then fired its rocket motor to produce a velocity change of just under 100 feet per second or about half the velocity-change capacity of the motor.

Following this maneuver, the spacecraft resumed the cruise mode for about 50 hours. Then, about an hour before impact was due, the truncated terminal maneuver was performed. If the TV cameras had not already been aligned for picture-taking, the terminal maneuver would have turned the spacecraft to align them. As it was, only the 45-minute TV timer in the CC&S was activated.

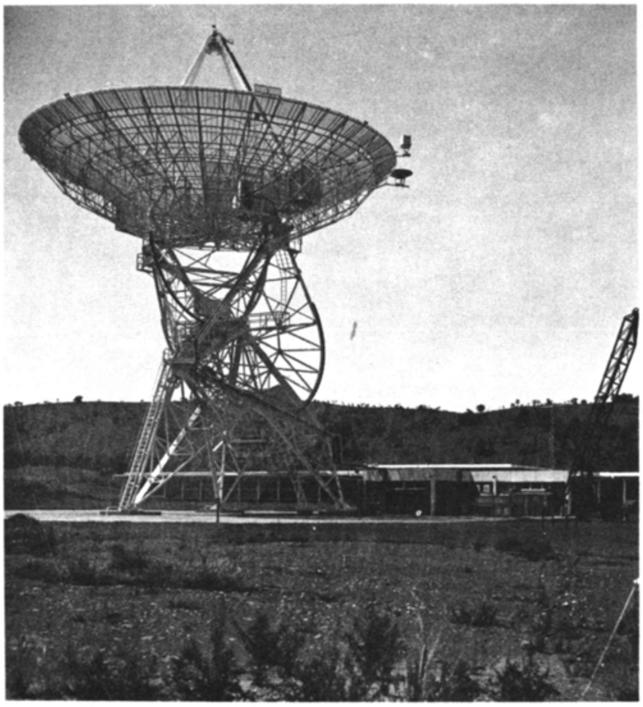
At last, at 67¾ hours after spacecraft separation (68¼ hours after launch) TV channel F was activated. Three and a half minutes later, the CC&S activated channel P. Television operations continued until, at 13:25:49 Greenwich Mean Time, Ranger VII retired from business after the shortest, most perfect career in TV history.



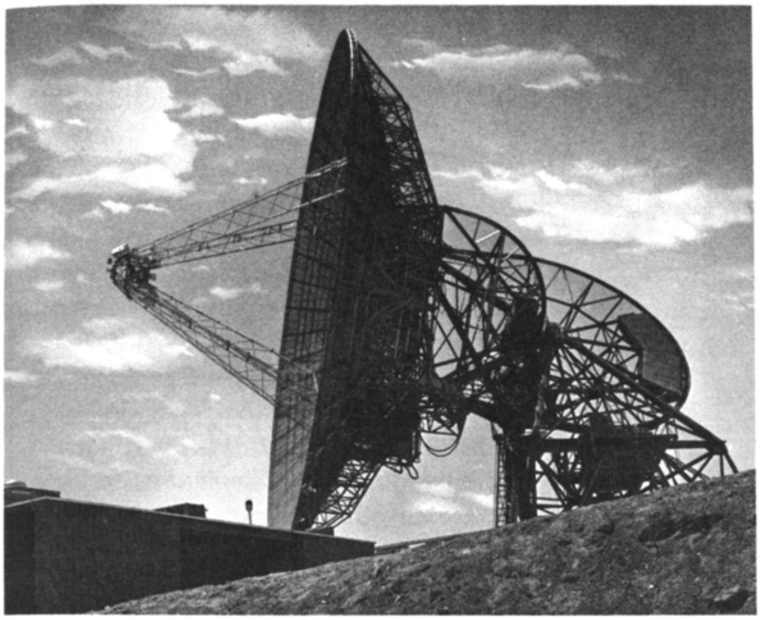
# Ground Operations: The Long Wait

For Ranger VII (or the other Rangers and Mariners) to maintain constant two-way contact with its human colleagues, while the Earth turns under it, the Earth must be effectively covered with antennas. This coverage is provided by a Deep Space Station near Johannesburg, South Africa, operated by an agency of the South African Government, and a station at Woomera, Australia, operated by the Australian Government, in addition to the Goldstone Station in Southern California, which is operated by the Bendix Corp. but often throngs with JPL telecommunications and spacecraft engineers doing antenna research or setting up tests or experiments.

The path which Ranger VII flew meant that it would pass rapidly over the South African station at relatively low altitude, being "in sight" for only about 10 minutes, then rise over the western horizon of the Australian station. During this portion of its flight the spacecraft appeared to move from West to East as viewed from the ground; it was going around the Earth's axis more rapidly than the Earth itself, but as it rose farther away from Earth and began moving more nearly straight up, it seemed to turn back and move from East to West. This occurred over Woomera, and the spacecraft appeared to set in the West less than 8 hours after it had risen in the West. Thereafter, Africa, Goldstone, and Woomera again had Ranger "in view" for 11 to 12 hours at a stretch;



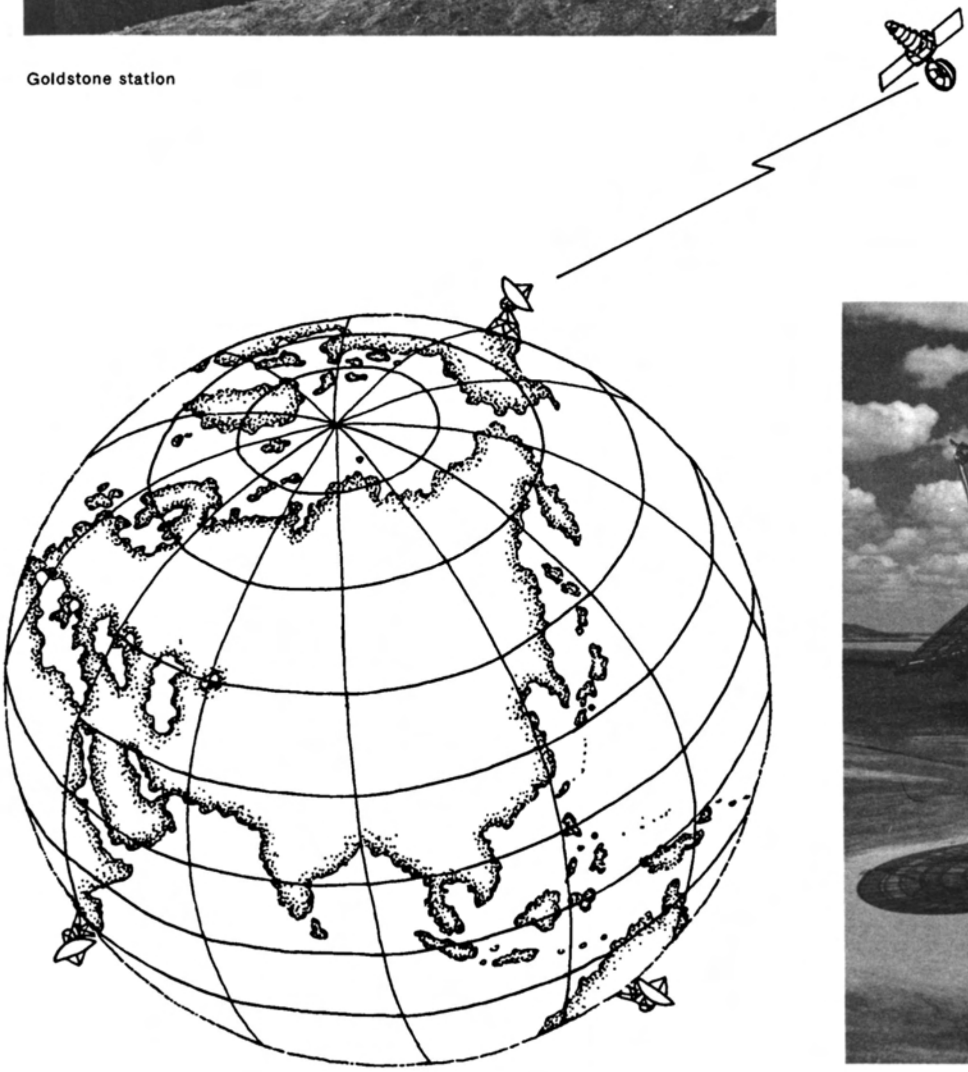
Johannesburg station



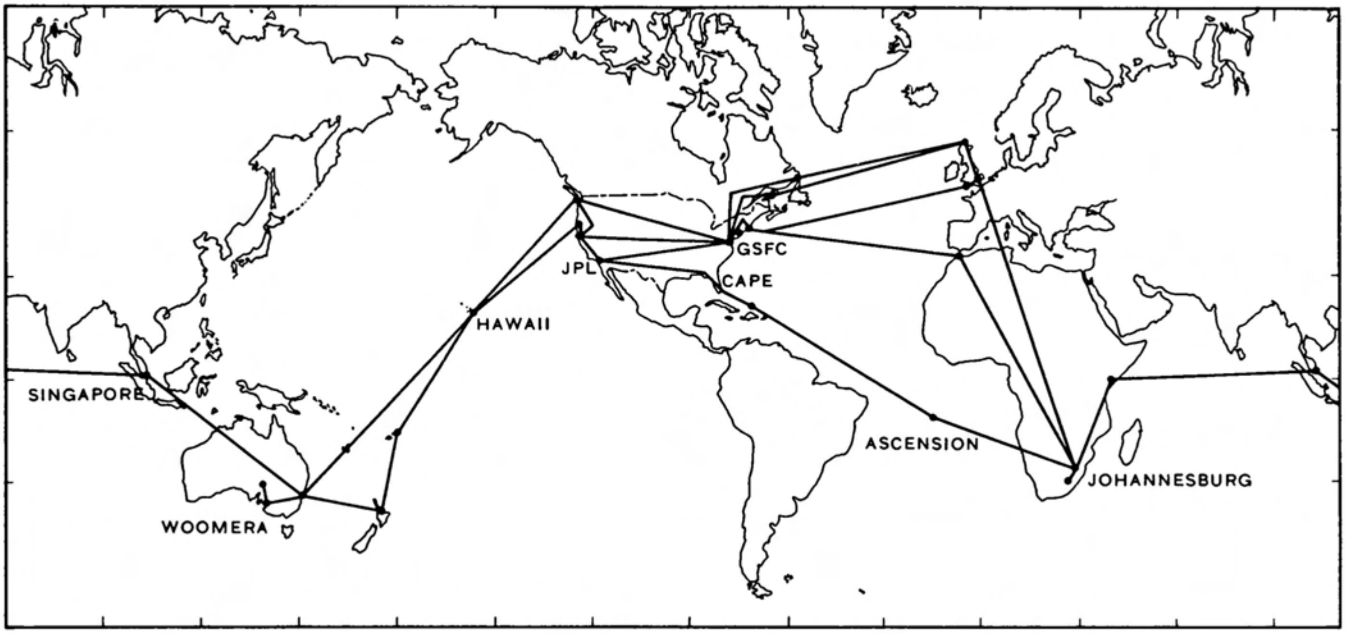
Goldstone station

counting Woomera's first short shift and Goldstone's last, 6½-hour viewing period, each station had three long shifts of communicating with Ranger VII.

During the first brief high-speed pass over the African site the "two-way lock" was interrupted sporadically but without affecting telemetry reception; only eight tracking points were obtained. Two-way lock must normally be interrupted three times a day as each station hands over the "talking" function to the next; any number can listen, if the spacecraft is in view.



Woomera Station




The three stations are tied together and to the central control facility by an intricate, redundant web of undersea and ground cables, many of them commercial facilities leased by NASA, and high-frequency radio links. The ground communications network also ties in the Cape, so that JPL's Space Flight Operations Facility was in touch with Ranger VII from before launch until lunar impact.

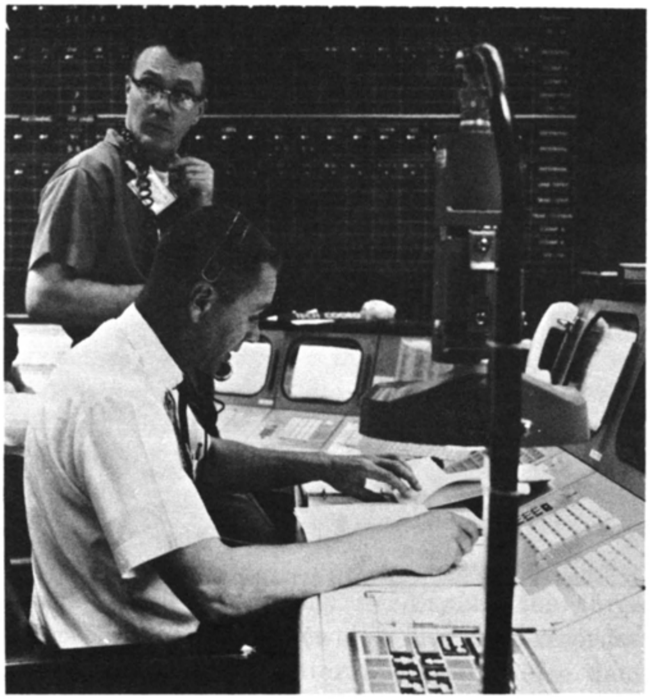
The SFOF is a large windowless three-story structure with one floor of offices, one of computing equipment (including two IBM 7094's, one IBM 1401, and a number of other devices), one of operational and control rooms, and a basement full of such things as an electrical power generating station. The operational desks resemble the control stations of a modern ship or aircraft; the SFOF is, after all, the bridge or cockpit of the

Space Flight Operations Director

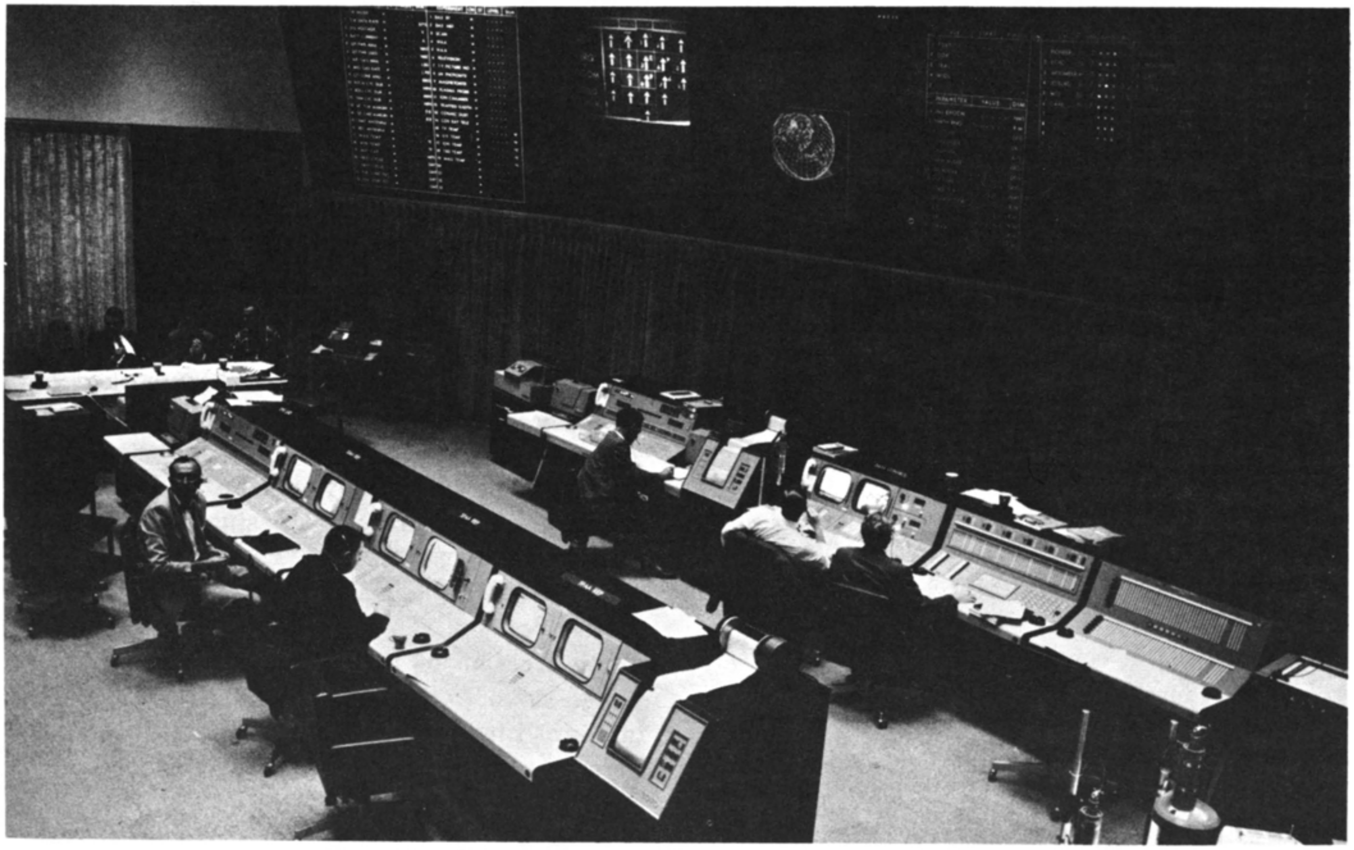
spaceship Ranger VII. The operators are linked together by intercom and closed-circuit TV; computer printouts and graphs are available to all who need them simultaneously.

There is a dual mission control center (two missions occasionally occur at one time), with displays and console positions for the Space Flight Operations Director and his crew; special operations areas for flight path, spacecraft performance, and space science teams; and special devices such as a spacecraft-and-Moon model set with which various possible maneuvers are demonstrated.

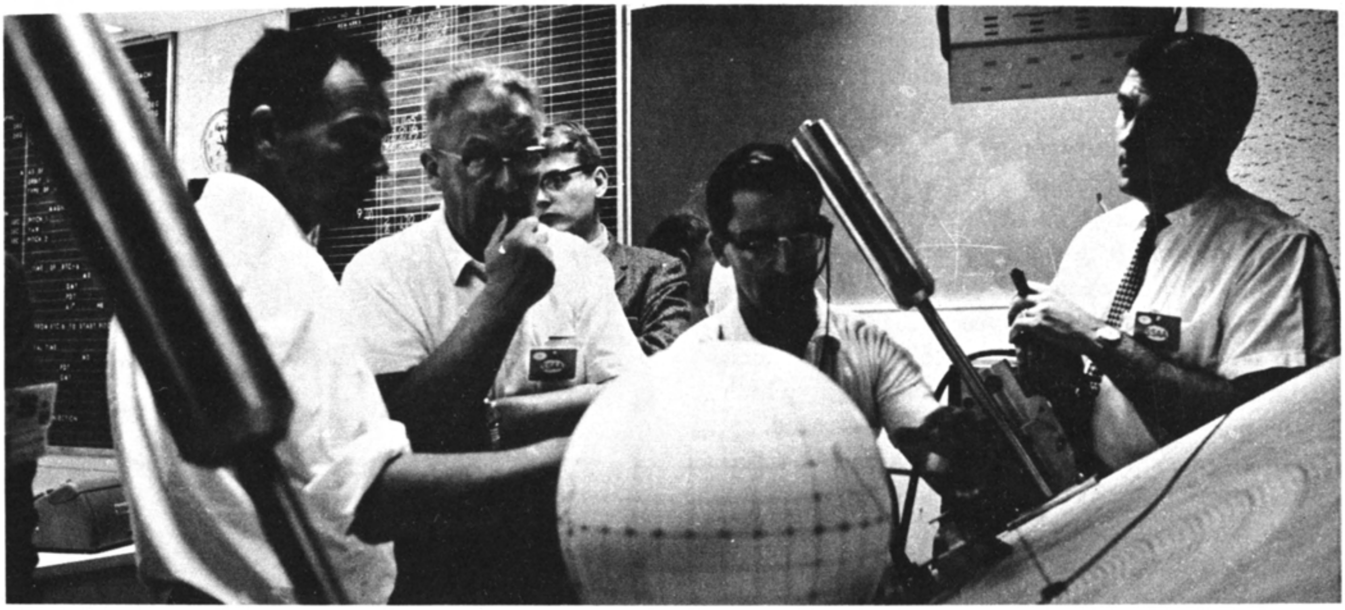
With a few exceptions, including a brief partial power failure, the SFOF equipment turned in a perfect performance. The operating teams also performed well. The spacecraft data analysis team, which is by nature a troubleshooting organization, was restricted to very limited exercise of its talents by the near-perfect spacecraft performance.



Communications Center

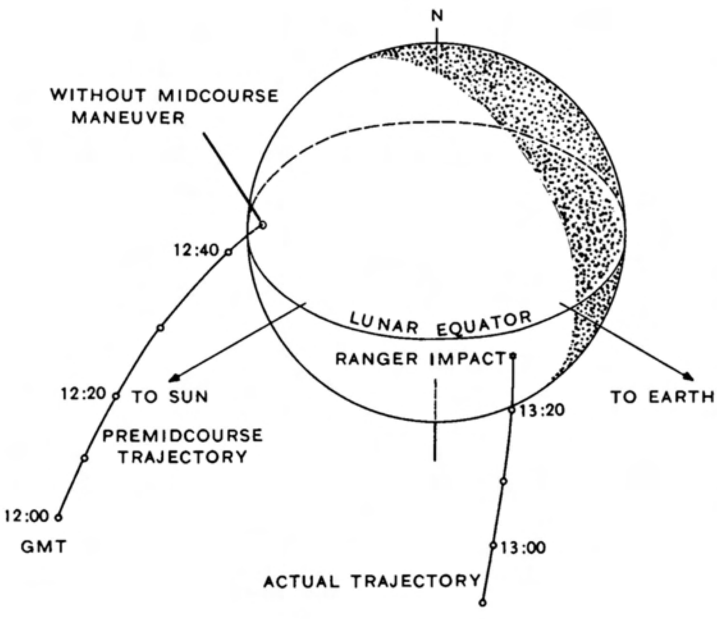


SFOF operations area



Flight path analysis area: midcourse maneuver discussed with experimenters

The flight path analysis and command group began determining the trajectory of the spacecraft with the receipt of the first position and velocity from the African tracking station. Early determinations showed that Ranger VII would impact the Moon at 12.3°N, 204°E (on the far side), 67.391 hours after the launch vehicle had given it lunar-transit velocity. The TV camera's backup clock had been preset to turn on the full-scan cameras at 67.793 hours, and turn-on should occur 10 to 30 minutes before impact. Therefore, to use this valuable backup switch, as well as impacting in the desired area, both the time to impact and the location had to be adjusted.




A number of alternative adjustment maneuvers were calculated, and the spacecraft, scientific, and flight path teams joined to consider them. All the maneuvers entailed pointing the "up" direction of the spacecraft at the Earth (instead of at the Sun) for the maneuver. The low-gain antenna happened to have the lowest gain in this direction. The earlier the TV was to turn on, the longer would be the possible loss of data because of this antenna-pattern "null." A compromise was worked out, resulting in approximately 17 minutes of full-scan TV operation. A modest number of the early TV pictures thus obtained would be no better than Earth-based pictures; increasing the TV time would only increase this proportion, though it would widen Ranger VII's coverage on the lunar surface.

The location of the target had never been in serious doubt—it was to be at about 11°S, 21°W, in a small mare almost due south of Copernicus. This was the prime target recommended for a July 31 impact by the Experimenter Team and selected in consultation with various interested parties.

Space Science analysis area

After the midcourse maneuver had been agreed upon—and executed by the spacecraft, at about 3:30 a.m. PST on July 29—there was little for the operators and experts to do but monitor an almost perfect operation. Subsequent flight path determinations confirmed that the spacecraft was going where it was supposed to go; continuing telemetry data confirmed that all conditions and activities were normal.

The spacecraft had been designed with the ability to make one more maneuver—a change of orientation only—to point its cameras in the best possible direction for getting lunar pictures. However, spacecraft and mission design made the maneuver unnecessary under most conditions. It proved to be unnecessary for the conditions of the Ranger VII flight.

However, the terminal maneuver had been designed for a double purpose. Starting the maneuver starts a 45-minute timer which, when it runs out, turns on both TV channels. The time of starting the maneuver, therefore, controls the time of TV turn-on. Assuming that the long-term TV backup clock started channel F, this shorter timer could be used to start channel P, or, by jumping the gun on the clock, it could start both. In addition to the two timers, a real-time command could be sent from Earth to start both channels.

A "zero" maneuver, which would start the timer but not turn the spacecraft, was the answer. First, a series of instructions for minimum turns was sent to the spacecraft. Then a command was transmitted which made the attitude-control subsystem deaf to even these mild changes. Finally, an hour before impact, the terminal maneuver was ordered. As planned, nothing happened except starting the timer.

Although the diagnostic spacecraft and TV telemetry and tracking data were piped to the Space Flight Operations Facility by the three Deep Space Stations (which also tape-recorded the information for later analysis), video data were too complex and precious for such routing. The pictures were being filmed and taped at Goldstone. It was frustrating, indeed, for the experimenters, the spacecraft and trajectory engineers, the Space Flight Operations Director, and all the Ranger Project staff to know, in the early morning of July 31, that Ranger VII was taking thousands of pictures of the Moon, but to be unable to see even one of them. Over the intercom they could hear the shouts of delight from Goldstone as one channel, then another, flickered into life; the quotations of signal strength; and the electrifying report: "We can see craters!" For hours that had to be enough. They knew, at least, that the operation had been successful; it was finished before they found out how well they and their flight equipment had actually done.

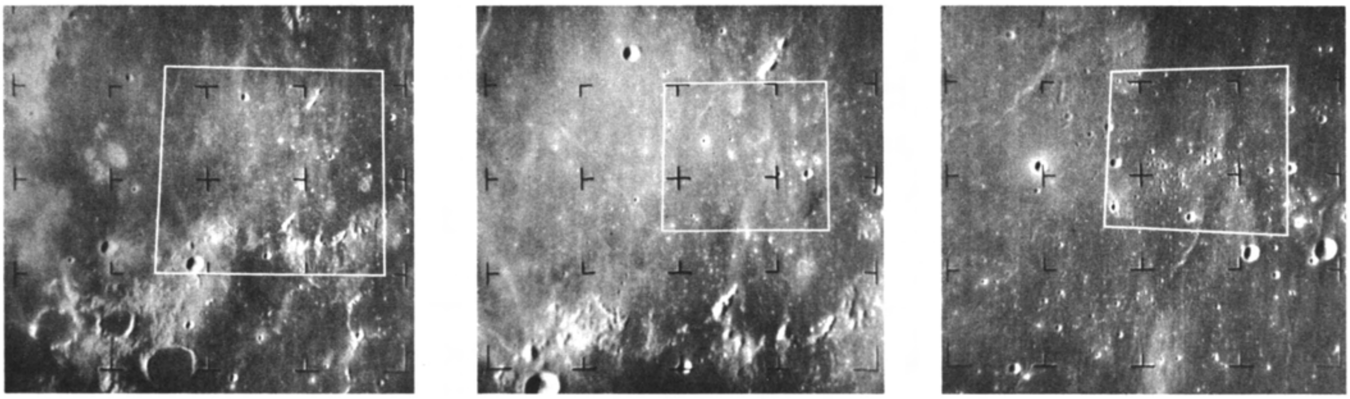
Spacecraft data analysis team area

# Journey's End: The Results

The successful conclusion of the Ranger VII mission had many diverse effects on the technology of which it was a product, as well as on the sciences of which it was the servant.

First, it demonstrated fully the operation and efficacy of a powerful and useful tool for space exploration. Considering the improvement in lunar photographic resolution, the mission has been compared with the sudden invention of a powerful microscope in medical research. All of the equipment and techniques which contributed to Ranger VII received a new validation, and much was added to the growing fund of knowledge of spacecraft design and mission behavior.

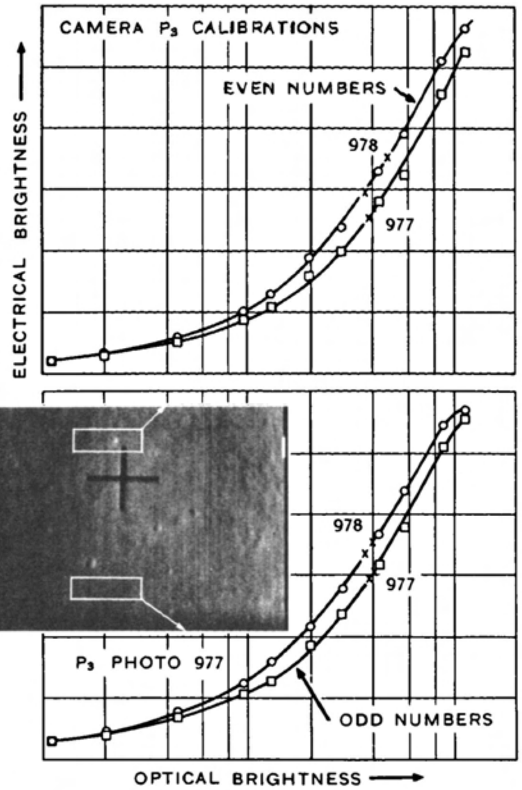
Second, another installment of information was added to the tracking and navigation background. Spacecraft like Ranger are tracked so accurately that their positions can be used to correct the map of the world. Many tracking stations are now fixed on the map more precisely than they ever could be by ordinary means. In addition, the accurately known flight path of any space probe is useful in deducing the mass of celestial bodies which influence it. Before this technique came into use,



Camera-A photographs 195, 198, and 199 show photographic nesting and impact site during last quarter-minute of operations the mass of Earth was known to within 7.5 parts per million; tracking data from Ranger VI alone have reduced this uncertainty by almost 75%. In the case of the Moon, the dispersion had gone from 600 to about 20 parts per million.

However, the unique and most dramatic contribution of Ranger VII has been pictures of the Moon. There are more than four thousand of these, and they form six continuous series.

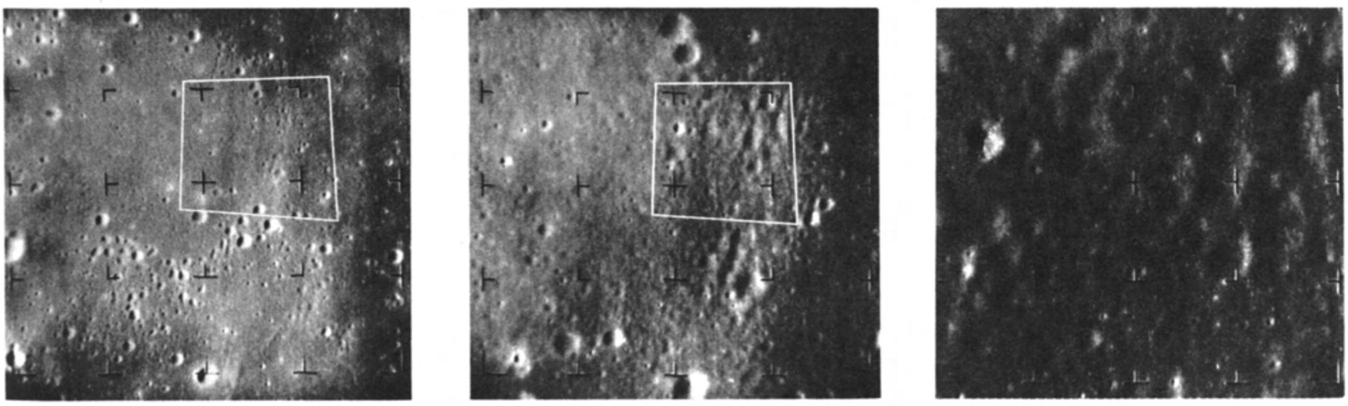
As the pictures were received, they were recorded on film and tape in the Goldstone television room and the signal was metered as a check on the video communication link. Polaroid cameras had been set up to make partial records for immediate engineering evaluation of TV performance. These small pictures served primarily to confirm that Ranger was truly shooting the Moon, and gave rough indications of lighting quality.




## MEASURING MOONLIGHT

The technique of determining the response of a new instrument by measuring known quantities, so that its readings may be correctly interpreted, is known as calibration. Ranger VII's TV cameras were calibrated for shape distortion of the scenes they viewed by placing a square gunsight-like pattern or reticle in front of them; all pictures were taken through this pattern, and it shows undistorted in the reproduction of the pictures.

A more delicate calibration was undertaken for brightness. A TV camera turns visible brightness into an electrical brightness. Since the part of the system which does this is the coating on the face of the vidicon tube, and it may not be uniform, many parts of the picture area must be calibrated. As an example, two rectangular areas in the $P_3$ camera were calibrated by exposing the camera to scenes of steady, uniform brightness (in eleven levels) and noting the video amplitude or electrical brightness in those areas. The results were plotted in a graph. It was found that, because the camera shutter worked back and forth at slightly different speeds each way, two calibration graphs



Photographs 132, 167, and 188 (left to right) from full-scan camera A show nesting as Ranger approaches the surface from 485 miles had to be made—even and odd. Then the video amplitudes encountered on the lunar scene could be measured from the video tape recordings, and the accurate, absolute brightness of lunar features observed by Ranger VII could be read off the graphs.

## A COMPUTER LOOKS AT THE MOON

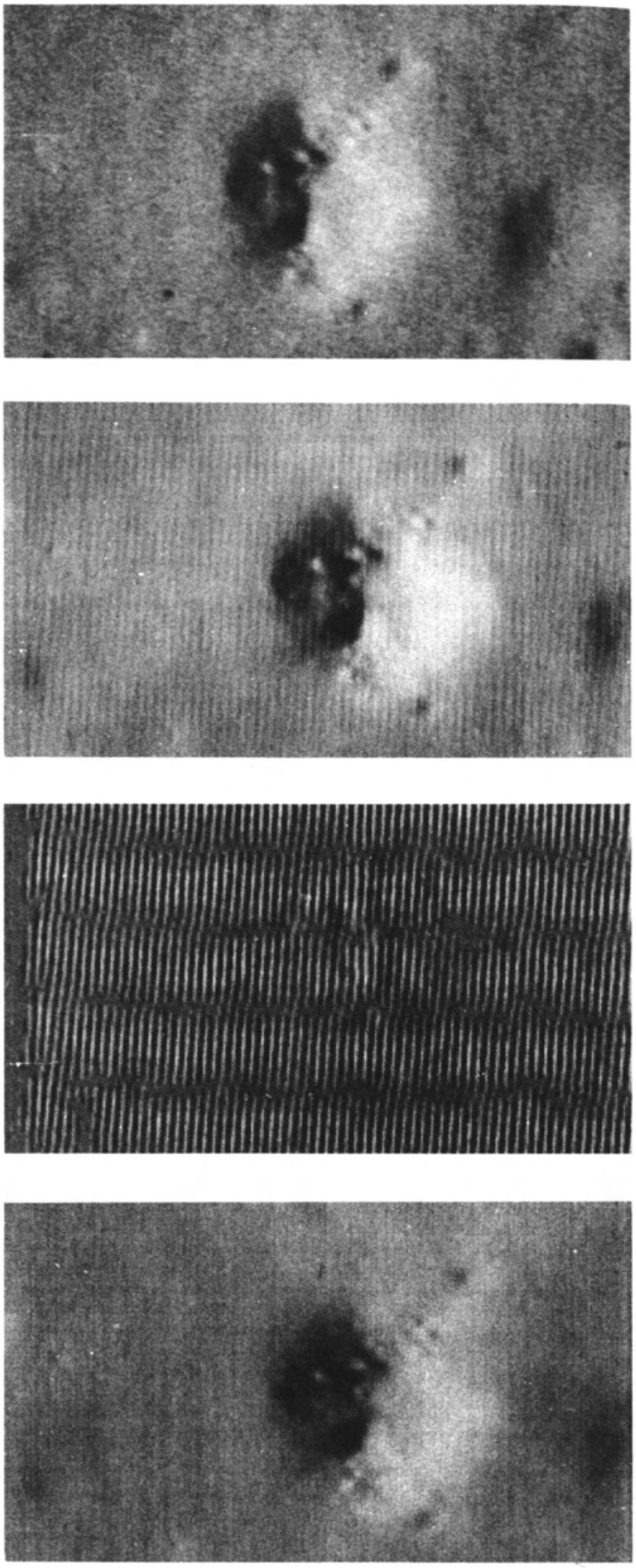
Noise is everywhere. The difference between what is there and what you see or hear, whether you are listening to the record player, working your amateur radio equipment, watching television—or conducting a space mission—is defined as noise. It may be caused by the transmitter, the receiver, or something in between; it may be a scratchy hiss, a warbling squeal, TV "snow," or a herringbone pattern.

The Ranger VII pictures were remarkably clear and clean as received and as released. Still, there was noise, some of it from within the TV system, and in order to achieve the best results from them a process for cleaning them up by the use of a computer was devised by a JPL mathematician.

First, the pictures were "digitized"—translated into the computer language in which something is either exactly something or exactly something else. The TV images, formerly a row of lines, were converted to a fine checkerboard—like the photographs reproduced in newspapers or most books. At the same time, the smooth spectrum of grey was reduced to 64 shades between black and white. Incidentally, the square reticle pattern was removed at this stage. Then the computer searched for recognizable noise patterns, and removed them. The contrast could also be enhanced by the computer.

## FIVE TO EXPLORE THE MOON

Long before Ranger VII sent home its pictures, it had been established by NASA that scientific results of space missions were to be given to the scientific community and to the people. However, particular scientists or teams were to be appointed for each experiment on the various space



Example of computer processing of Ranger picture: top, enlargement from last camera-A picture; digitized version; detected noise pattern; processed picture

First-look Ranger results conference: left to right, Heacock, Newell, Schurmeier, Kuiper, Pickering, Shoemaker, Whitaker

projects, to assist in the planning and development of the experiment, advise in its use, organize the resulting data, and make the first analysis and release of the data.

The Experimenter Team appointed for the TV experiment of Ranger VII was a very eminent one: two astronomers, Gerard Kuiper and Ewen Whitaker, both of the University of Arizona team which produced the Photographic Lunar Atlas; geologist Eugene Shoemaker, of the United States Geological Survey; Nobel Laureate Harold Urey, a geochemist and professor at the University of California at La Jolla; and spacecraft engineer Raymond Heacock, Chief of JPL's Lunar and Planetary Instruments Section. Dr. Kuiper was appointed Principal Investigator.

This team recommended impact sites for Ranger VII (the actual site selected was the best of the five recommended for that particular day), and, after the mission, conducted a great deal of analysis of the new lunar data. Whitaker personally prepared a number of the negatives from which the published Ranger VII photographs were made, and, with Kuiper, supervised the photographic printing of the Ranger VII Atlas.

After participating in preliminary conferences in the United States, the Experimenters and other members of the Ranger team presented initial scientific and engineering results of the mission to the International Astronomical Union at a special session of their Twelfth International Federation in Hamburg, Germany, on August 31, a month after the mission. By a formal act of the Union, the previously unnamed, small lunar sea into which Ranger VII had plunged was named Mare Cognitum—the sea which has become known.

The first series of photographs—the camera A pictures—was released at about this time. The second series (from camera B) and a further analysis of results were released at the fifteenth Western Congress of the American Geophysical Union in Seattle, Washington, in December. One of the experimenters estimated at a press conference that there is a good three years' work left to do on the Ranger VII photographs of the Moon.


IAU Conference, Hamburg

# The Meaning

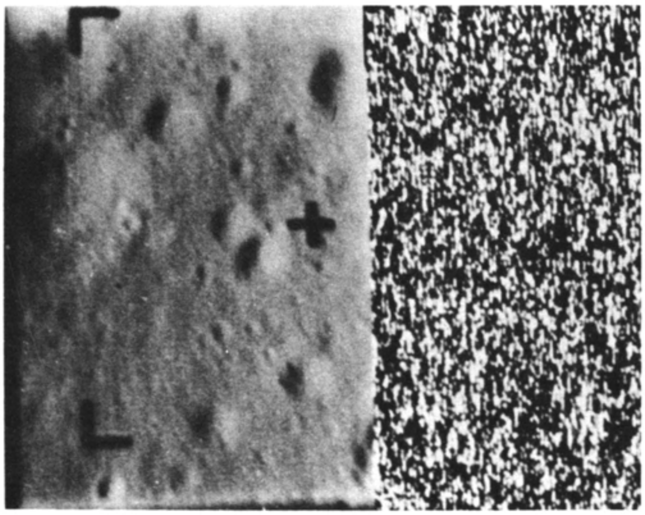
One of the most obvious new facts about the lunar surface is that craters at all scales down to less than a yard across are the dominant features of Mare Cognitum. The number of craters increases with decreasing size (from the largest ones visible from Earth). Within the portion of the Tycho ray on which the spacecraft impacted, the last photographs show more than 50% of the surface covered by craters; between rays, and in another part of the same ray, only about 20% of the area is visibly cratered. Small craters are distributed over and between large craters; below the resolution of the last Ranger VII picture the crater and debris coverage of the surface is believed to approach 100%.

## PRIMARY AND SECONDARY CRATERS

Some of the small craters are shallow and elongated; others are deeper and more circular. Most of the smaller craters—less than 1000 feet across—have a soft, smoothed appearance when compared with the large lunar craters. Their walls appear rounded over.

Steep, sharp-rimmed craters, too, are found down to sizes a few feet across; they appear to be perfect miniatures of the craters seen with the telescope. Some of them—as small as about 100 feet in diameter—have bright halos and ray systems like their big brothers.

The sharp-edged symmetrical craters, which fit in size distribution as well as appearance into the family of the majority of large craters observed before Ranger VII, are believed to be "primary"

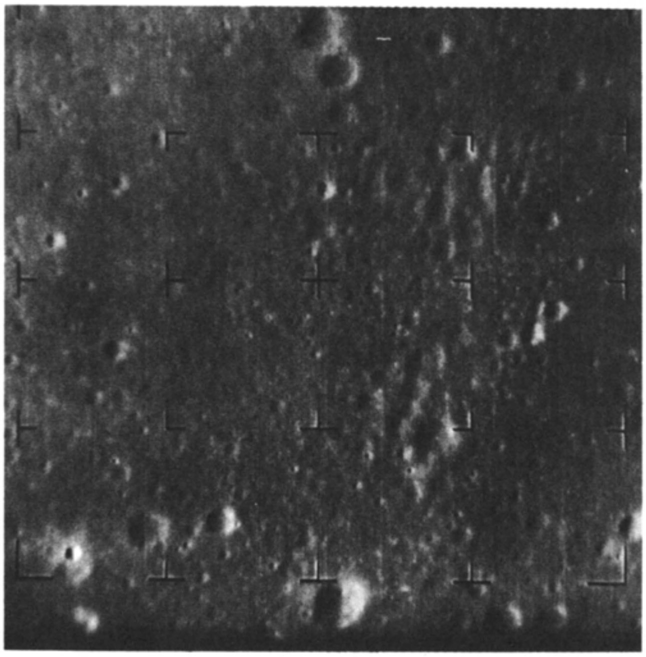


craters caused by the impact of meteoritic particles. The shallower, more irregular craters, many of which show their dependent status by their arrangement in rays of the Tycho or Copernicus system, are believed to have been caused by particles ejected during primary impacts. Craters of this type, grouped in clusters, pepper the ray areas. Each cluster consists of a nucleus of larger craters, with a fan of smaller craters stretching away from Tycho, the origin of the ray. Solitary secondary craters similar to these ray-cluster craters were also observed. "Tertiary" craters, resulting from the splashing of material when secondary particles or ejecta hit the lunar surface, may also be present.

Whitaker postulated that rayed craters might have been formed by small comets, whose gaseous residue could serve as the propellant to transport secondary particles to produce the impact patterns observed.

At least one small crater appeared to have a rock-like mass protruding from it. Several explanations of this — for example, a large particle impacting at low velocity — were considered, but the result was more puzzle than conclusion.

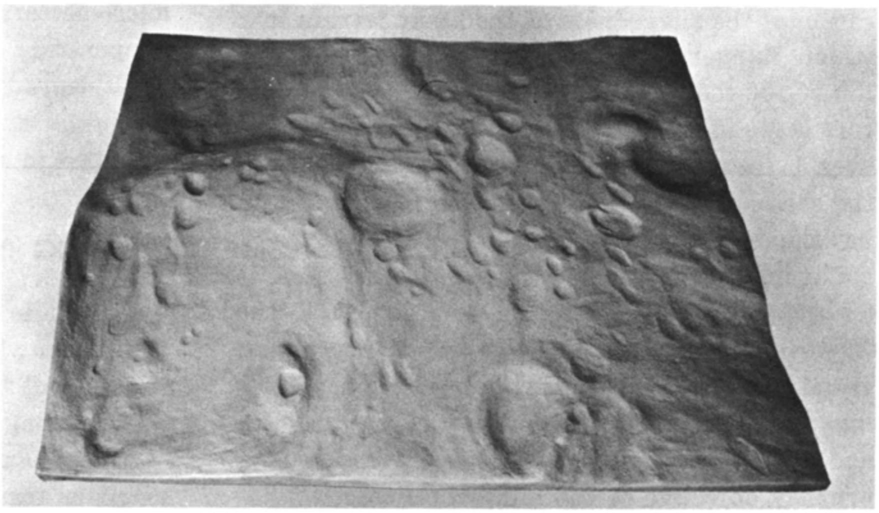
Urey speculates that slumping of the surface into subsurface cavities may be the cause of some of the shallow, rimless craters which have a dimpled appearance. It is probably not maintained by any scientist that all the lunar craters were formed by the same mechanism; most incline to the theory that the great majority result from impacts, with volcanic or other activity accounting for the remainder.



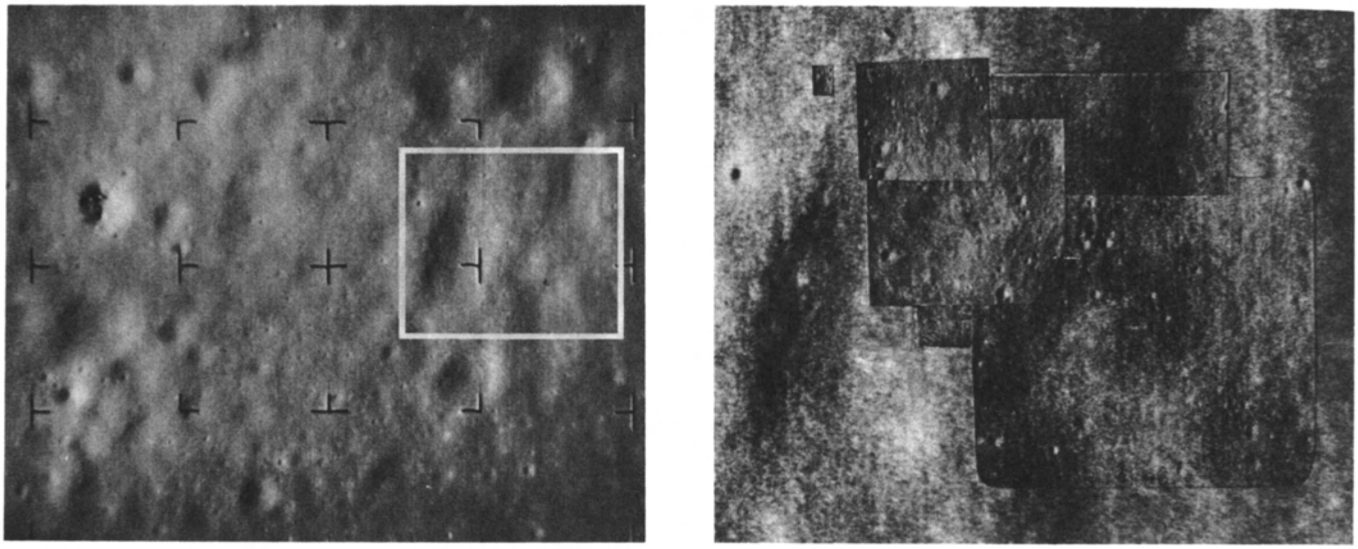
Next-to-last wide-angle camera-A picture of 4-mile-square area

## THE MISSING BOULDERS

The rarity of positive marial relief features other than crater rims was one of the surprises revealed by Ranger VII's extension of lunar visibility to the small scale, according to Shoemaker. The extension of the families of primary and secondary craters beyond the sizes previously visible was contrasted with the lack of positive-relief rubble. Crevasses also failed to appear in small scale.



Lunar-surface model constructed by Shoemaker from last partial-scan picture at left, showing dishpan-size craters. Model corresponds to upper two-thirds of photograph, which was terminated at right by lunar impact during transmission.



On a portion of the last camera-A photograph (left) a mosaic has been constructed (right) using partial-scan photographs. Final Ranger photograph (p. 46) is at upper left corner of mosaic.

A few details in known marial ridges were seen in the last A-camera pictures, and an interesting branching and cross-ridging effect was noted, as well as a striking sharpness of form. In addition, a number of small, low mounds, pocked with craters, were detected in the Tycho ray near the impact site. Kuiper noted the resemblance of the mounded surface to the bark of the Ponderosa pine. The mounds are narrow, 5 to 15 yards across, and only a foot or two high.

## THE LUNAR LANDING FIELD

Photometric measurements have given an indication of the ruggedness of the lunar terrain into which Ranger VII crashed. Ten percent of the 160 × 100-foot area seen in the last P-camera picture is found to slope less than 1 degree, measured over 1 meter (about 3¼ feet) lengths; 50% of the area has slopes less than 5 degrees, and 90% has slopes less than 15 degrees.

Concluding that a large part of this area is topographically suitable for soft landings, the Experimenters emphatically agree that more than visual inspection is required before manned landings are carried out. Measurement of the strength and other properties of the lunar surface is a primary objective of the Surveyor Project.

## THE PLOUGHED FIELDS

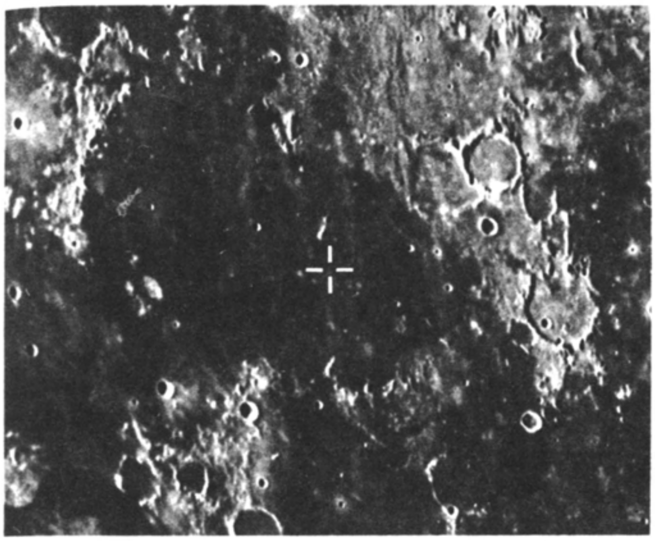
The visible evidence of craters covered in turn with craters suggests strongly the churning up of the lunar surface by repeated impacts. Urey remarks that small craters must have been produced and destroyed many times in the life of the Moon, and suggests that the surface may have been "gardened" to a depth of some 10 meters (32 feet). Kuiper puts the average depth of the disturbance at 1 meter or less.

In addition to meteoritic bombardment, whose catering effect may be seen in the Ranger records, the Moon has withstood the erosive attacks of micrometeorites, solar protons, and rapid and vast temperature changes. The Experimenters deduced some degradation from observation of the high-resolution photographs, but Ranger VII was not equipped to study fine-scale lunar erosion.

## FISHING IN THE LUNAR SEAS

The origin of the Moon and its surface—like any subject on which there are facts enough to tantalize but not to convince—is the object of controversy among scientists.

Kuiper and other observers view the lunar maria as resulting from flows of lava, sometimes



Ranger VII impact site in Mare Cognitum, seen from Earth

in many layers, each as much as 1000 feet thick. They see Mare Cognitum as an impact mare—a large, old crater most of whose walls were destroyed before its basin was flooded with lava.

Apparently, according to Kuiper, lunar material is scattered or spread over the surface only during the course of impacts; crater rays and independent secondary-crater projectiles constitute all of the "lunar dust" and there is no general dust layer.

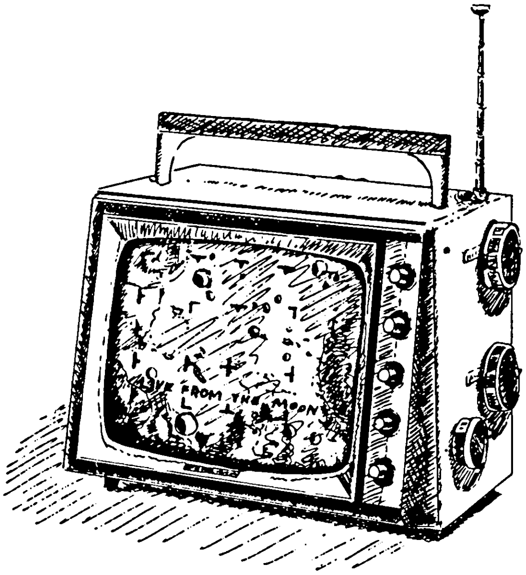
Urey, on the other hand, inclines to the belief that the outer layer of Mare Cognitum consists of highly fragmented material or debris. Whatever "original" lunar features there may have been, they have been obliterated or covered by this 10-meter-thick debris layer.

But Urey effectively places Ranger VII at the dawn of the Age of Lunar Exploration—where it belongs—when he states that its evidence is not conclusive.

"The evidence from the Ranger VII pictures is most interesting," he says, "but these pictures raise more questions than they answer unequivocally."

Ranger VII was no conqueror, but rather a pathfinder. It left much for those who come after to discover. They would be not long in coming: two flight missions still remained within the Ranger Project.

Presentation of Ranger VII data to President Johnson by Dr. Pickering



# Sequel: The Double Feature

Seven full months elapsed between the triumphant conclusion of Ranger VII's flight to the Moon and the launch of its successor — an interval longer than that between the Ranger VI failure and the Ranger VII success. Possibly a part of the reason was that the step from success to perfection may be greater than the step from failure to success — and the Ranger team wanted perfection.

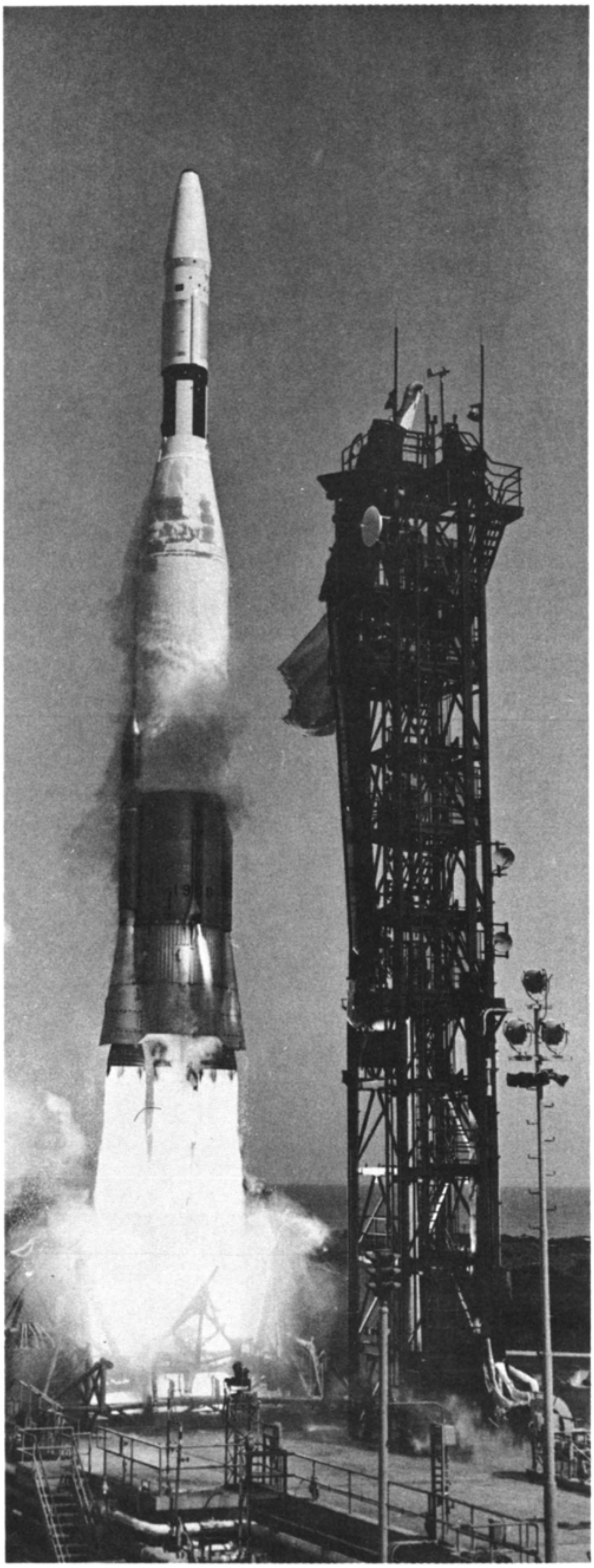
There were practical reasons. Launch schedule: the launch pad was committed to a series of other launches, and test and launch facilities at JPL and the Cape were needed for Mariner/Mars, scheduled for a November launch; then tracking and operational facilities were assigned to the Mariner IV mission until it was well underway. In addition, as indicated earlier, Ranger scientists and engineers were much in demand to report their accomplishments to scientific convocations, technical symposia, and the people of the world — at least one engineer noted facetiously that, in this regard, success was tougher than failure. In the science area, the lunar experts had to consider what region of the Moon to observe next in the light of the Ranger VII results — how to extend and verify the extremely detailed but still puzzling knowledge of a tiny portion of the lunar surface. For the engineers, there would be time to feed back flight performance data, especially on the television cameras, into a general quality improvement.

Thus the Ranger VIII launch was scheduled for February 17–23 and Ranger IX for March 19–25. The work of assembly and testing went on, and by the turn of the year Ranger VIII was being prepared for shipment to Cape Kennedy, and Ranger IX was almost ready for vibration testing.

The two Ranger spacecraft moving toward launch were barely different in design from the one which had surveyed Mare Cognitum. A gain change in three of the television-camera circuits increased the sensitivity by reducing the "white" level from 2700 to 1500 foot-lamberts; a more sophisticated circuit in the attitude-control electronics, developed for a subsequent block of Ranger flights, now cancelled, was introduced. The Atlas/Agena launch vehicles were like the one which had boosted Ranger VII to its lunar path.

The Deep Space Network, however, had been converted since July to the frequency employed for the Mariner IV mission, and was presently participating in Mariner flight operations — as it would be for six months after the Ranger flights were over. The Johannesburg and Woomera tracking stations would have to convert back to Ranger's 890/960 megacycles, while Goldstone Pioneer and the new Australian station at Tidbinbilla carried on with Mariner. There being no substitute for Johannesburg, the Africans were kept busy before and after each of the two Ranger flights, converting back and forth to cover both Projects. The SFOF had been designed with this two-mission problem in mind, and could maintain tracking coverage of a planetary and a lunar flight at the same time.

As the ground crews carried out their conversions, checkouts, and rehearsals, the Ranger VIII spacecraft and its launch vehicle arrived at the Cape, were tested, assembled on the pad, and readied for launch. Five minutes past noon on February 17, the preparations were over, and Ranger VIII lifted off for the Moon.



## VOYAGE TO A TRANQUIL SEA

Ranger VIII's target area, in the southwestern portion of Mare Tranquillitatis, had been chosen to complement the area photographed by Ranger VII. Lunar maria have been classified as "red" or "blue," according to slight differences in their reflected sunlight; the reddish regions were thought to be older than the bluish. Mare Cognitum is, by this criterion, a red area; Tranquillitatis is blue. Valuable comparisons and common characteristics could be obtained by a mission to the latter; the unsuccessful Ranger VI mission had ended in Mare Tranquillitatis.

The trajectory on which it was launched would have taken Ranger VIII past the Moon's trailing edge and on into space, coming within about 1200 miles of the eastern edge of Mare Crisium about 66½ hours after launch. This flight path could readily be corrected to an impact in the target area, about 250 miles north of the crater Theophilus. The correction maneuver involved rolling the spacecraft about 12 degrees, pitching about 150 degrees, and then turning its rocket motor on for just under a minute. (At 50 pounds of thrust, this would increase the spacecraft velocity toward the Moon by about 82 miles per hour.) Seventeen hours after launch, the spacecraft was commanded to carry out this maneuver. Two minutes later, trouble developed.

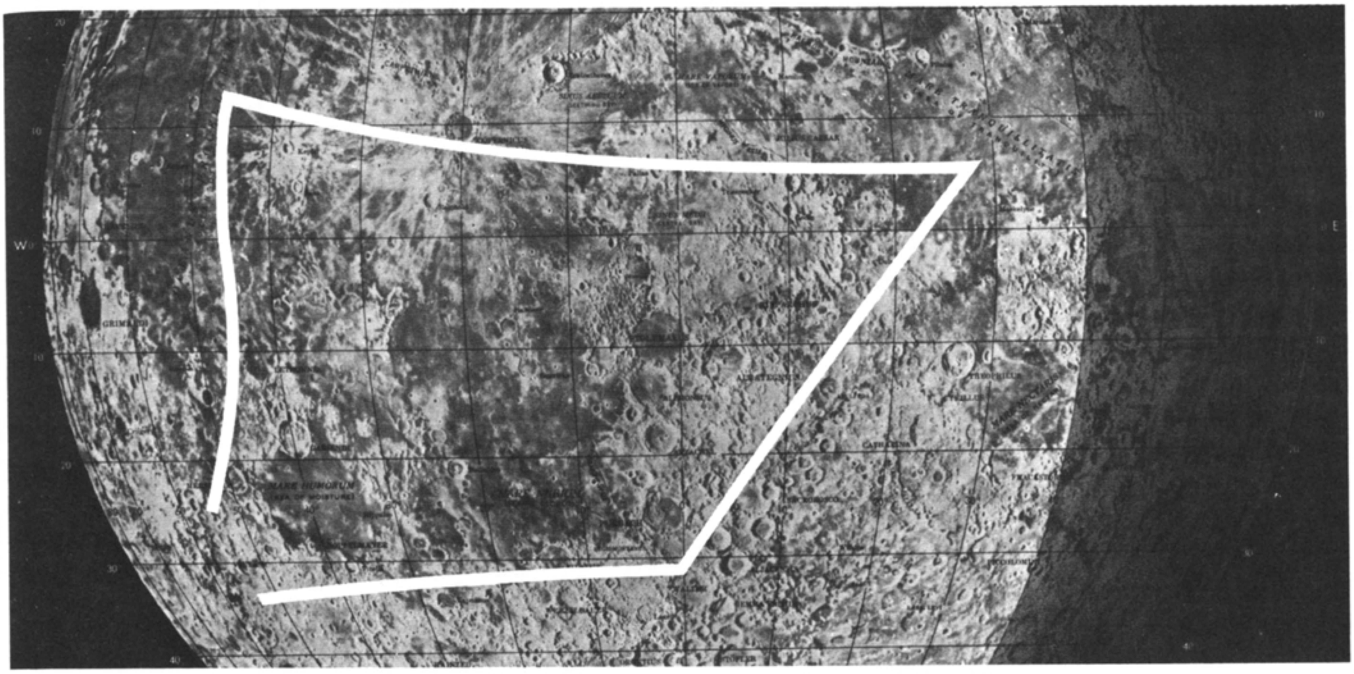
For the midcourse maneuver, when Ranger must be pointed away from its lock on the Sun and the Earth, spacecraft-to-Earth radio transmission is switched from the narrow-beam high-gain antenna to the omnidirectional antenna, which is mounted atop the television tower. Some loss of telemetry is expected during certain maneuvers, for there are "holes" in the pattern radiated by the omniantenna. However, there was no reason to expect the huge drop in signal strength that occurred after Ranger VIII's roll turn.

The signal fluctuated about the telemetry threshold, delivering an occasional measurement and then plunging below intelligibility, for 25 minutes, as the engineers moved into action, trying to analyze the failure, predict its effect on the mission, and formulate a command decision. The long hours of training and practice for this kind of problem paid off. The decision not to rescind the maneuver command was vindicated when, as soon as the midcourse motor ignited, full telemetry was restored. It was postulated that a tiny loose particle in the spacecraft radio had drifted into a position where it could drain off part of the radio power into a short circuit, until the motor's thrust moved it out of harm's way. It caused no further excitement.

Ranger VIII approached the Moon at a lower angle (42 degrees above the horizontal at impact) than Ranger VII, with its cameras pointed down, sweeping the surface in the manner of a mapping-survey aircraft on Earth. The experimenters chose to keep this arrangement, trading off increased resolution just before impact for broad overlapping coverage, and the terminal sequence was used, as in Ranger VII, only to set a spacecraft timer to turn on the TV cameras.

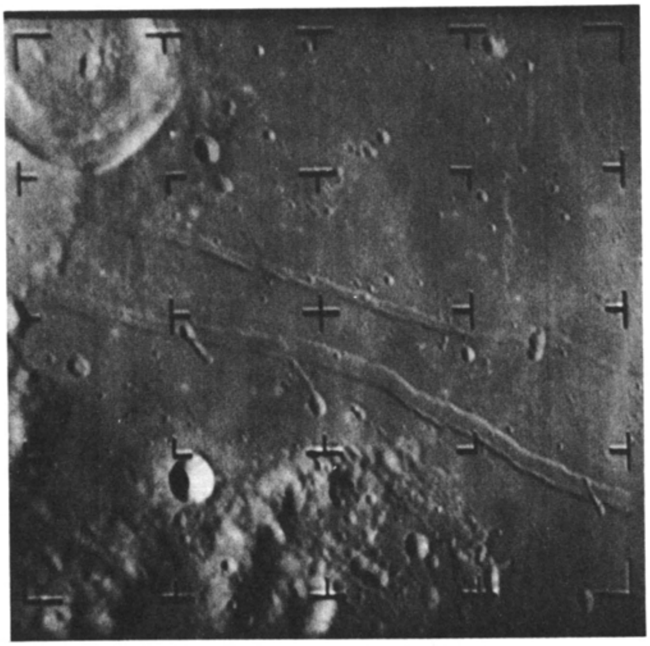
Once again, scientists and engineers in the Space Flight Operations Facility — this time at 1:34 a.m. PST — cheered the news that pictures were being received at Goldstone from a Ranger spacecraft near the Moon. For nearly 24 minutes the pictures continued to stream in — a total of 7137 from all six cameras. Then Ranger VIII hit the lunar surface, about 16 miles from its intended target. The mission had accomplished all its objectives, mapping a large swath of the visible lunar disk and showing the southwestern shore and portions of Mare Tranquillitatis in detail, with a terminal resolution of about 5 feet.

As the pictures became available, the experimenters began evaluating and interpreting them. The detailed measurements from the flight engi-



Ranger VIII photographic coverage of the Moon's surface

Crater Delambre (center), shore of Tranquillitatis (top right), as seen from Ranger VIII at 470-mile altitude



Rilles in Mare Tranquillitatis, photographed from 270 miles by Ranger VIII, 4 minutes before impact; North at top

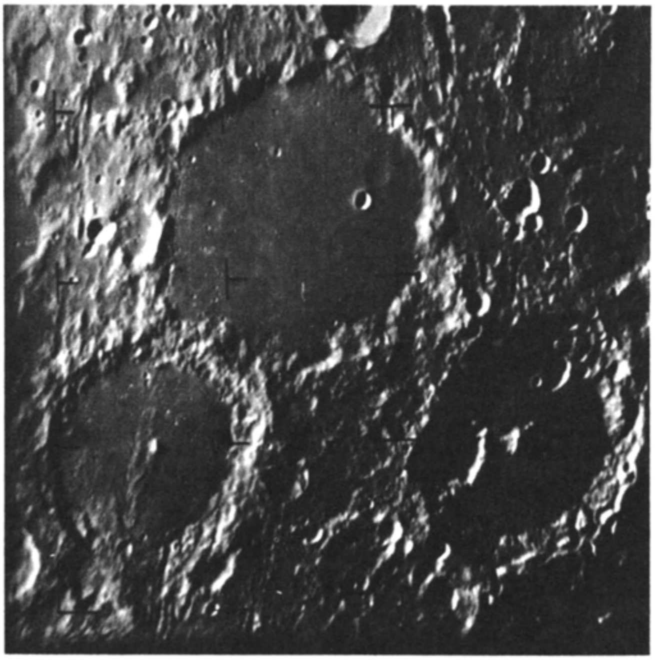
neering sensors were evaluated for anything which might be applied to the Ranger IX mission, just one month away. Ranger VIII's radio problem was intensively studied, and several identical radio modules were re-inspected for possible loose particles. Then Ranger VIII matters were put aside, and all efforts were concentrated on preparations for the final Ranger flight.

## INTO THE CRATER

On the night of November 3, 1958, before Ranger had been dreamed of, the Russian astronomer N. A. Kozyrev turned a 50-inch telescope on the crater Alphonsus. He detected — and photographed the spectrum of — a temporary reddish cloud, later attributed by many to a volcanic eruption. The incident stirred some controversy about, and lasting interest in, that particular crater. Alphonsus is 75 miles wide and has a central peak (where the red cloud was observed), a flat floor showing topography similar to that of the maria, and a number of diverse features, including rilles and dark-haloed craters suspected as possible volcanoes.

A band along the lunar equator constituted the lunar terrain of interest to the Apollo Project. Ranger had sampled West and East, reddish and bluish maria, crater rays, and a taste of the highlands. Alphonsus offered a sort of lunar-geologic garden — highland crater and terrain, mountain peak, walls, dark halos, and mystery — something for everyone, a target of major scientific interest.

The Ranger planners trimmed Ranger IX's launch window to a single day, for which by mission's end the Sun would be a revealing 10 degrees above the horizon at Alphonsus. Accordingly, on March 21, 1965, Ranger IX lifted off the pad, atop its Atlas/Agena vehicle, at 4:37 in the afternoon, Cape Kennedy time, and headed for its target.



Alphonsus (lower left), Ptolemaeus (top center), Albategnius (lower right) near center of lunar disk

Ranger IX's superb flight to its target was marked by two departures from previous practice, both intended to perfect the almost-perfect. Early tracking revealed a very good initial trajectory, with a projected impact only about 325 miles north of Alphonsus; a comparatively small midcourse correction was called for. If the maneuver was delayed a day, it could be "fine-tuned" — and the extra day of tracking would further refine the initial trajectory. The maneuver was commanded 39 hours after launch, and the result was an impact within 3 miles of the assigned target.

Ranger IX operations, spacecraft performance analysis area

Ranger IX's second maneuver was a terminal no-thrust maneuver performed to align the cameras to the 65-degree-elevation angle of the spacecraft's fall toward the Moon, placing the impact point on camera and minimizing image-motion smear. This resulted in a terminal photographic resolution of about 12 inches, as compared with Ranger VII's 16 inches.

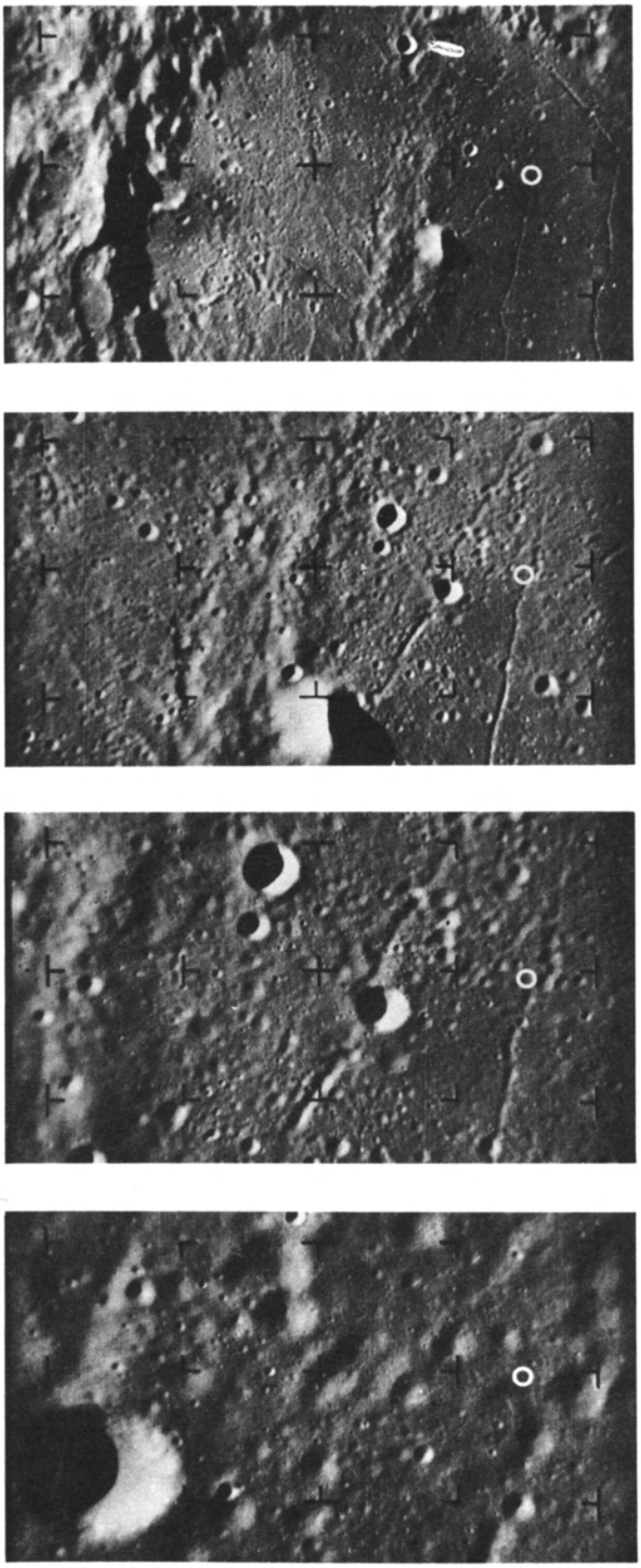
## LIVE FROM THE MOON

Ranger IX provided another novel departure from tradition. Shortly after the television cameras were switched to full power, their video output appeared before the photographic recorders at Goldstone, on monitors in the Space Flight Operations Facility and in the press room nearby, and on television screens across the nation and in a number of other countries.

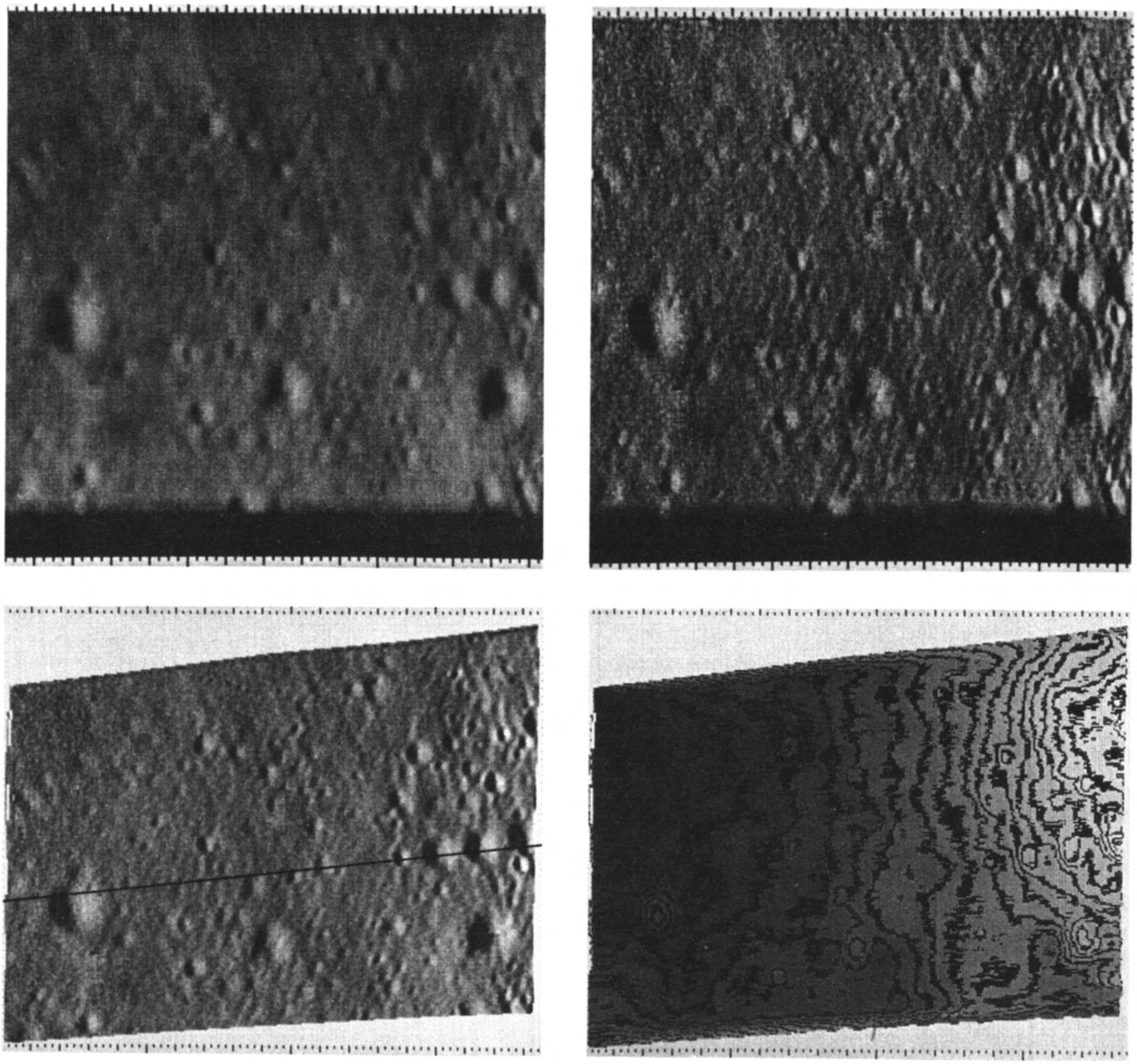
A microwave link from Goldstone to JPL, together with a conversion apparatus (designed for the Surveyor project) which stored the Ranger video momentarily and converted it to the TV picture format of commercial television, providing engineers, experimenters, and public with a real-time view of Ranger IX's camera B series of pictures, at a rate of about 5 seconds per picture. "Live from the Moon" was the matter-of-fact identification applied to the screen by the television networks.

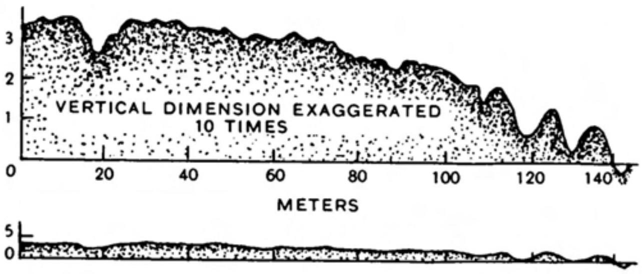
More than 5800 photographs were obtained and recorded, soon to be processed for the experimenters. Even as the grandeur of Alphonsus unfolded before them on the monitor screens, the experimenters had been forming ideas, changing ideas, exchanging ideas. Now they set to work, continuing the study of Ranger VII and VIII data, adding the new group. The photographs were pored over, compared, and measured. Different forms of computer processing were tried. As Urey had noted earlier, new questions were raised faster than old ones were answered. Though it was recognized that Ranger had no capability to measure the physical properties of the lunar surface, questions of structure and strength kept coming in.

Some welcome conclusions emerged. The general fine-scale similarity of Cognitum, Tranquillitatis, and the Alphonsus floor, the dominance of the topography by the results of primary and secondary small-particle bombardment, and the apparent acceptability of such terrain for potential landing sites were acknowledged. The degradation of the surface caused by these bombardments was found to be general, to have greatly softened and smoothed the terrain — note that the Ranger IX pictures were taken with illumination only 10 degrees from the horizontal



Ranger IX views of Alphonsus, from 140 miles, 65.4 miles, 35 miles, and 12.2 miles; sunlight from left, North at top, impact area marked by white circle



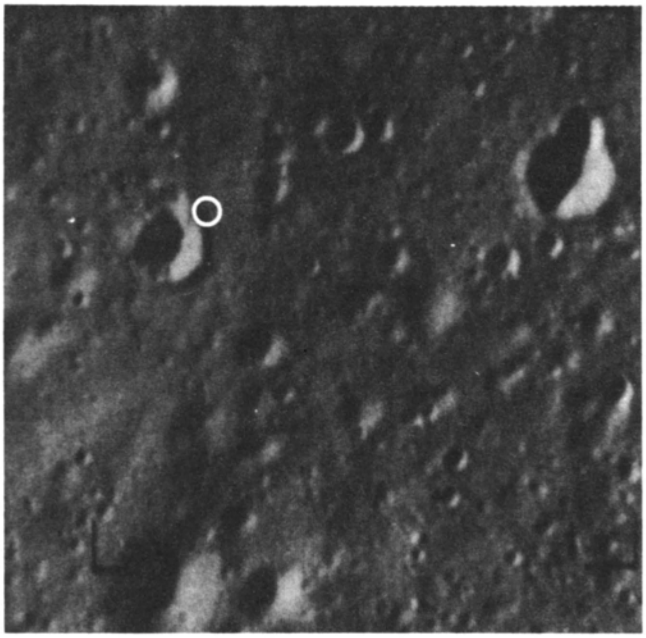



Many kinds of information may be extracted from Ranger pictures by computer processing. Ranger VIII's last $P_3$-camera photo is shown digitized for IBM 7094 handling at top left. Filtering to enhance detail is shown at top right. At lower left, picture has been rectified to a vertical view of the terrain; a contour map of the same area, and cross-section elevation profiles, are shown at right

— and, judging from the scarcity of hills and ridges, the interaction of the bombardment process and surface properties appears to have precluded or destroyed most such positive relief.

New signs of variety on the Moon were noted with interest. More "dimple" craters and a few more "rock" features were added to those exhibited by Ranger VII; rilles of apparent parallel-fault-subsidence origin and others which seemed to resolve partly into strings of craters were noted, and close examination of Alphonsus' dark-haloed craters gave renewed evidence of volcanic activity. Highland terrain near Alphonsus was concluded to be much battered and partly covered by debris.

Many striking ideas about the Moon's nature and evolution have resulted from the Ranger flights. Several continue to be debated, even as the data are being published; but one idea seems to be generally accepted: Ranger was a good thing.



The final Ranger IX partial-scan photo; impact occurred on crater rim

Mr. Oran Nicks, who as Director of Lunar and Planetary Programs for NASA's Office of Space Sciences and Applications in Washington had seen the Project grow, learn, and do its job, put it this way: "I'd like to read from the letter sent to Dr. Pickering on December 21, 1959, to initiate the Ranger Project. '. . . The lunar reconnaissance mission has been selected with the major objective being the collection of data for use in an integrated lunar-exploration program. The transmission of high-resolution pictures of surface detail appears most desirable. The system should detect lunar detail whose characteristic dimension is as little as 10 feet . . .' I think you could see this morning that those objectives were fulfilled.

"What you couldn't see, and what we couldn't see in the beginning of this Project, were some of the other things Ranger would do . . . provide the capability for doing Mariner II-to-Venus . . . that Mariner IV, now on its way to Mars, would be a direct descendant of Ranger and use much of its technology . . . the tracking capability and the TV advancements . . . I think the exploration of the Moon and the planets is in good hands and off to a very good start."

So, onward from Ranger.


Ranger IX post-impact press conference: a summing up

# RELATED BOOKS

The following short list of books, which extends subjects only lightly touched upon in the account of the Ranger VII mission, is not intended as a proper bibliography. It is a handful of books, some inexpensive, others available in libraries, all fairly up-to-date, all interesting. There are plenty of others.


## GENERAL AND HISTORICAL

*Missiles, Moonprobes, and Megaparsecs,* by Willy Ley. Signet Science Library, New York, 1964 (paperback).

*The History of Rocket Technology,* edited by E. M. Emme. Wayne State University Press, Detroit, 1964 (13 independent essays and a bibliography).

*Exploration of the Moon,* by Franklyn M. Branley. Natural History Press (American Museum of Natural History), Garden City, N.Y., 1963 (paperback).

## RELATED SPACE FLIGHT MISSIONS

*Mariner: Mission to Venus* by the staff of the Jet Propulsion Laboratory. McGraw-Hill, New York, 1963 (paperback).

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