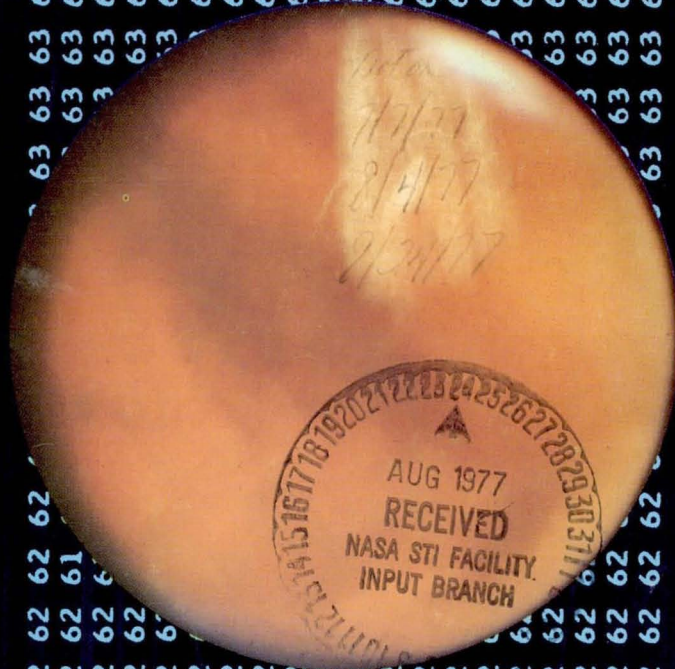


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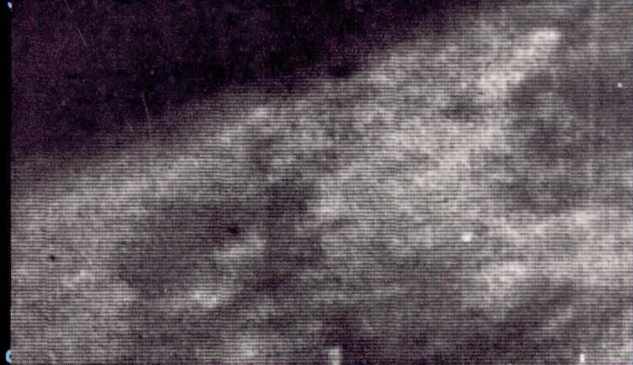
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Report from Mars

MARINER IV 1964-1965





REPORT FROM *MARS*: Mariner IV 1964-1965

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THE COVER: The first close-up picture of Mars (in black and white on the cover) was taken by Mariner IV at a range of 10,500 miles from the region in the center of the picture. The 410-mile-wide region shown is between Trivium Charontis and Propontus II. The light area called Phlegra is on the horizon. The picture was assembled from 240,000 digital bits transmitted by the spacecraft after the Mars encounter and processed by the IBM 7094 computer to remove bit errors and fiducial (identification) marks.

The color photograph of Mars was obtained by R. B. Leighton of the California Institute of Technology eighteen days before the opposition of September 1956, using the Mt. Wilson 60-inch reflector telescope. The photograph suggests that darker areas are not necessarily "green" as sometimes described, but may be a darker shade of the prevailing yellow-orange. The brilliant white south polar cap is probably a thin layer of frozen water, perhaps hoarfrost. (In accord with astronomical convention, south is at the top.) Craters photographed by Mariner near the evening terminator appear frosted. (Page 42.) The nature of the frost is unknown, but conditions would be consistent with its being water.

*The photographs of Mars on pages
4 and 6 are from the
Mt. Wilson and Palomar Observatories.*

Jet Propulsion Laboratory

California Institute of Technology

Prepared under Contract No. NAS 7-100

National Aeronautics and Space Administration

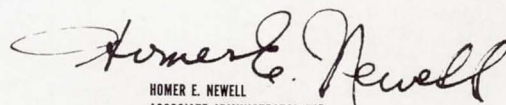
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PREFACE

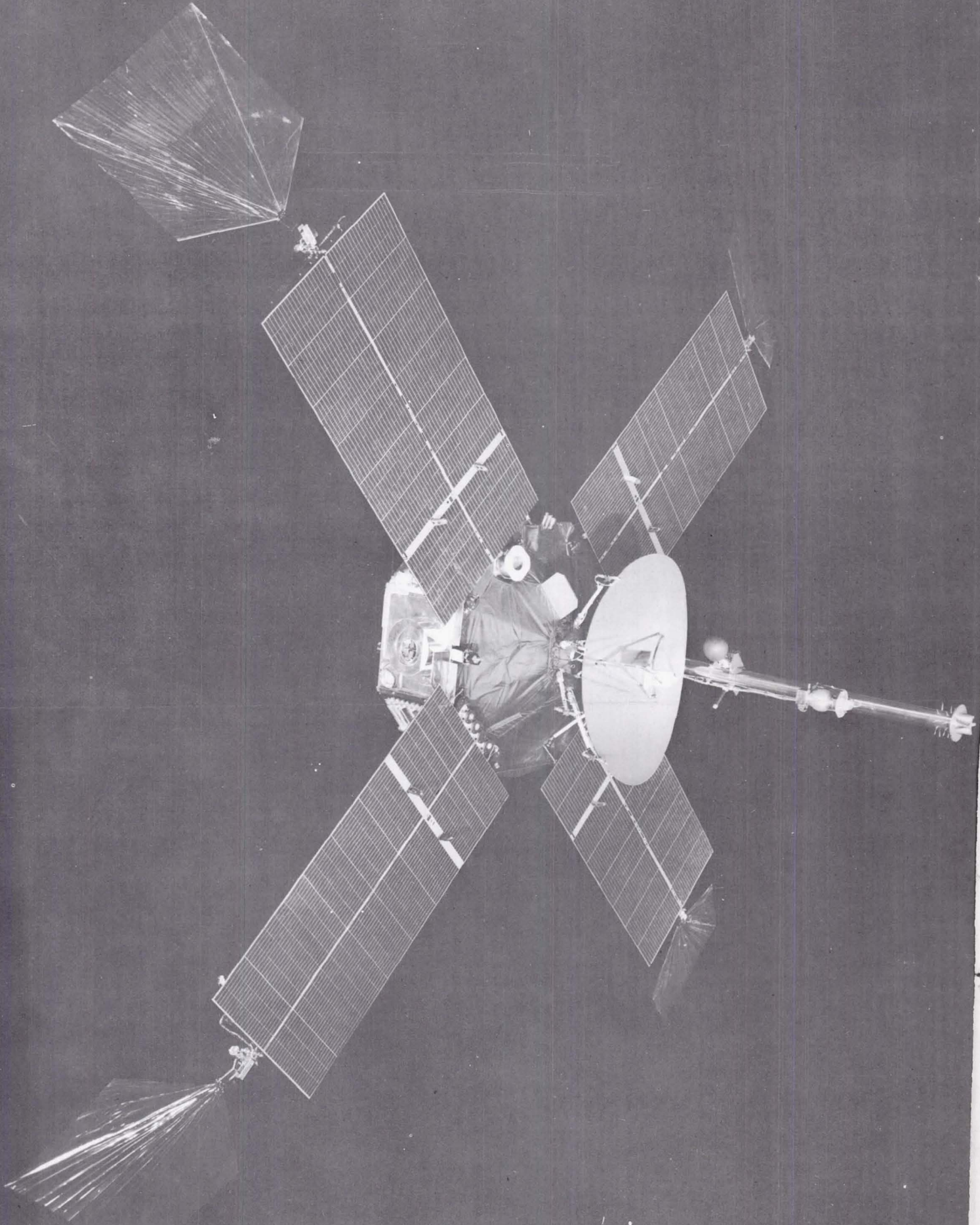
The successful mission of Mariner IV is a most gratifying conclusion to the first generation of lunar and planetary exploration, which has been based on lightweight automatic unmanned spacecraft in constant communication with Earth, designed for lunar impact or planetary encounter. The flight of this first Mars probe is noteworthy not only for the outstanding quantity and quality of scientific data but also as the verification of large and useful advances in a number of technological areas.

The Mariner Mars Project of 1964-1965 was conducted for the National Aeronautics and Space Administration by the Jet Propulsion Laboratory; it was made possible by the valued assistance and support of many government agencies, scientific institutions, and industrial concerns. Among these are NASA's Lewis Research Center (Launch Vehicle Systems Manager) and their prime contractors, Lockheed Missiles and Space Corporation and General Dynamics/Convair; Goddard Space Flight Center (Launch Operations) and other agencies at Cape Kennedy; the agencies of the Australian, South African, and Spanish governments which operate overseas tracking stations; many hundreds of American industrial contractors and vendors; and a number of scientists in various fields of endeavor.

The Project was established in late 1962 with the objective of conducting scientific observations near the planet Mars and returning the data to Earth for study and analysis; secondary objectives were to develop and study the equipment and techniques involved and to make certain scientific measurements of the interplanetary environment on the way to Mars. Successful accomplishment of these objectives under the severe constraints which were a part of the mission is a tribute to every single individual who shared in the preparation and execution of the Mariner Mars Project.



HOMER E. NEWELL
ASSOCIATE ADMINISTRATOR FOR
SPACE SCIENCE AND APPLICATIONS
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION



EXPEDITION FROM EARTH

Mariner has gone to Mars.

Though it sounds like a simple task, in retrospect the challenge was awesome. A journey of 8 months in space, 325 million miles long, had to be devised in less than two years and with less than 600 pounds of flight spacecraft weight.

Phase by phase the design, development, fabrication, assembly, and test were completed. Second by second the launch operations were carried out. Mile by mile the trip to Mars was accomplished. Bit by bit the engineering and scientific data were recorded, reduced, and studied.

A Giant Instrument

Mariner is far more than a spacecraft. It is a complex organism, a major new device of this age, called a system, which combines men and machines, techniques and plans, radar arrays, and computers. It is a huge, complex scientific instrument, engaged with remarkable versatility in a multiple scientific experiment to extend man's knowledge of Mars and the solar system by a quantum jump.

Only a tiny part of this instrument—the Mariner IV spacecraft—journeyed to Mars. Because of its monumental physical leap, and because the spacecraft is a fascinating object in its own right, there is a tendency to regard it as the whole instrument. Mariner consists of a large number of elements, all essential to its functioning: the spacecraft; the two-way communications stations of the Deep Space Network spread around the world; the Atlas/Agena launch vehicle, which placed the spacecraft on a true flight path; the Space Flight Operations Facility at JPL in Pasadena, where, from the November 28, 1964, launch to the commanded mission termination on October 1, 1965, the operations crews were on station every hour of every day; and an intangible something in the hearts and heads of Mariner's human element.

This instrument has scaled off the solar system and weighed Mars, observed almost a dozen solar flares in the season of the quiet Sun, photographed the craters of the Martian surface, measured the thin atmosphere of Mars, and sensed the radiation, magnetic, and cosmic-dust environment of interplanetary space from Earth's orbit out beyond Mars.

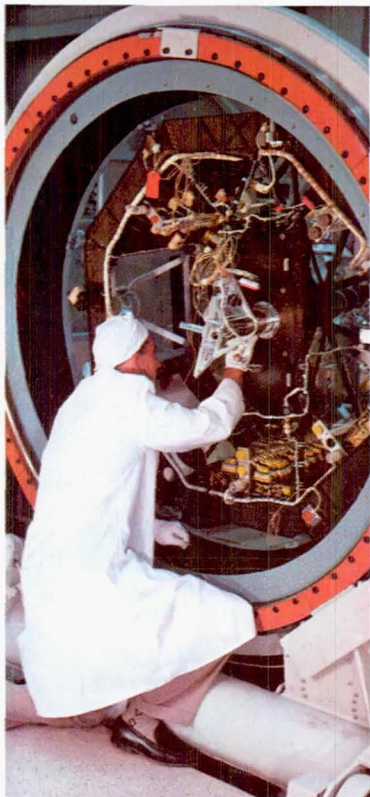
Trip Report

The Mariner IV mission commenced mid-morning on November 28, 1964, with a flawless launch from Cape Kennedy. Within 2 days, it was nearly half a million miles out, going more than 7,200 miles per hour; it was drawing power from the Sun, and had stabilized its attitude by locking on the star Canopus.

On December 5, Mariner was commanded to change its course slightly, using the 50-pound-thrust rocket motor built into the spacecraft. The maneuver shifted the rendezvous point at Mars from July 16, 1965, passing 150,000 miles ahead of the planet and north of the equator, to July 15, 6,100 miles behind the planet and above the south pole.

In mid-February and late March, Mariner shared the DSN tracking network and operational facilities with the Ranger VIII and IX lunar missions, giving up a 6½-hour communications period daily for 2 weeks each month. The Rangers were in flight for 2½ days in their historic missions to the Moon, attaining a maximum distance of less than a quarter of a million miles from Earth.

On March 27, Mariner IV equalled the deep-space endurance record set by Mariner II's 129-day mission past Venus; it bested the Mariner II long-distance communications record of just under 54 million miles on April 14.



Spacecraft assembly and testing



Launch operations mission control

It took a little less than 1 day from the time Mariner's planetary-encounter mode was turned on by ground command, early in the morning of July 14, 1965, until the first elements of the first close-up picture of Mars were received. During that day, the space environment near the planet was measured and examined, 21 pictures and a fragment of another picture were obtained and recorded on the spacecraft tape recorder, the spacecraft passed within 6,118 miles of Mars' surface, Mariner sent its radio signal—still transmitting information on magnetic field strength, radiation, and cosmic dust—through the Martian atmosphere in the occultation operation, and then, emerging, continued making space-environment measurements until it was time to play back the taped picture data.

After the 9-day picture-playback sequence, with periods of engineering-telemetry transmission sandwiched between the pictures, the tape was run through a second time to minimize errors in transmission. Finally, on August 2, Mariner was returned to the cruise mode in which it had sailed to Mars.

Two months later, as Earth left the beam of the high-gain antenna, transmission was returned by ground command to the low-gain omnidirectional antenna: the long stream of telemetry is no longer audible, though the primary carrier signal may be detected. A few minutes past 3 p.m., Pacific Time, October 1, Mariner's last message was received.

The Deep Space Network will track Mariner IV from time to time as a radio beacon, using the new extreme-range 210-foot antenna. If Mariner remains on the air long enough, Earth will again pick up its telemetry in Summer 1967.

Au revoir.



Encounter operations at Goldstone



Spacecraft performance analysis

MARS BEFORE MARINER

Though Mars has often been populated, irrigated, and civilized in speculation and in fiction, its characteristics are relatively unearthy. It appears to be a small orange-red desert world; ours is a robust green-and-blue world of jungle, grassland, and river, three-quarters ocean.

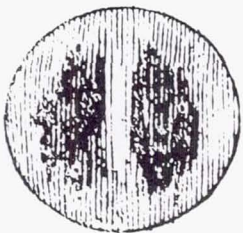
Mars has about half Earth's diameter, a ninth of Earth's mass, resulting in a surface gravity 38 per cent of Earth's, and an escape velocity of some 3.1 miles per second, as compared with 6.9 for Earth. Therefore, Mars is ill-equipped to retain much of an atmosphere; the Martian surface pressure is probably less than Earth's pressure at 5- to 15-mile altitudes. What air there is appears to lack oxygen and contains only enough water vapor to make its detection barely possible from Earth. The lack of oxygen and scarcity of water vapor, in turn, rule out liquid water (which must reach equilibrium with a vapor pressure above it) except very temporarily or underground. There are polar caps of ice or frost—possibly of frozen carbon dioxide rather than water—though probably extremely thin by Earth standards.

However, Mars' marked surface and thin atmosphere permitted astronomers to measure its 24½-hour day and the annual change of seasons as early as 1659. Mars' axis is tilted about the same as Earth's, so its seasons are comparable, though scaled to the 687-Earth-day Martian year. Earth vacationers might tend to regard the four Mars seasons as little more than variations in a bad winter: a hot midsummer afternoon on the equator might bring the ground temperature up to 85–100°F, but during the night it would drop to 100° below, and 6 feet off the ground the air wouldn't get above freezing all day.

A Dim View of Canals

Like the Moon, Mars abounds with so-called seas, bays, and the like. By this century, when the essentially waterless condition of the surface was recognized, the names had already been established, and the smaller bluish regions remained "mare," "sinus," and "lacus."

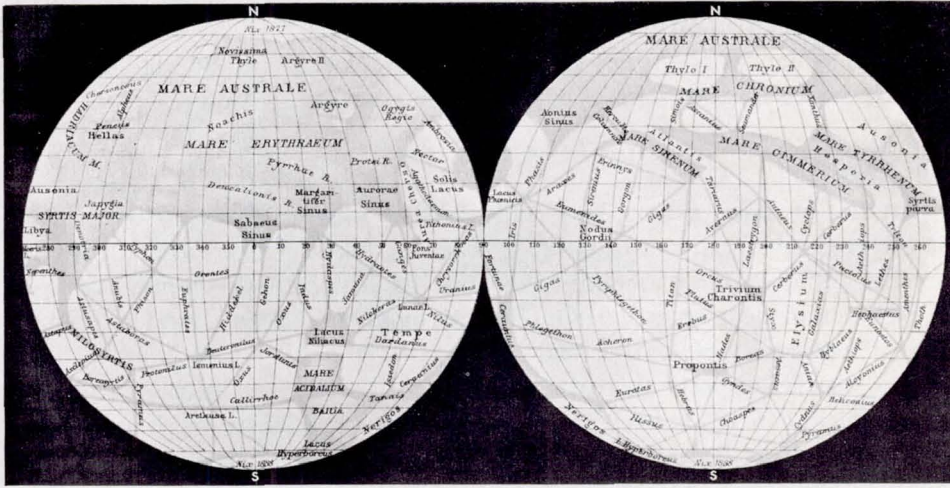
Even with the most powerful telescopes and under the most favorable atmospheric conditions, Earth's astronomers cannot get high-resolution pictures of Mars. To appreciate the difficulties under which the observers of Mars labor, imagine yourself watching moonrise at the end of a hot day. The Moon rises above an asphalt road still warm from the afternoon's baking. The faint, glowing disk wavers and dances in the warm rising air. Your impression of the Moon might be compared to the way astronomers see Mars. Mars is never closer to Earth than about 35 million miles, and that only about every 15 years. At opposition (the Sun and Mars are opposite, Earth and Mars adjacent), which occurs every 25 months, it may be as far as 62 million miles, as it was on March 5, 1965. And our atmosphere is always in the way.



Top: Sketch by Cassini (1666)

Center: Sketch by Herschel (1777)

Bottom: Mt. Wilson photograph (1956)

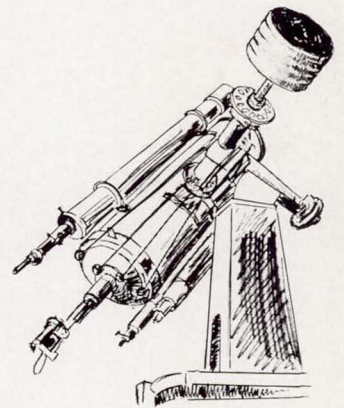


Canal map by Schiaparelli (1877-88)

Two and a half centuries after Galileo had been barely able to distinguish the disk of Mars in the first astronomical telescope, Guido Schiaparelli, working at Milan Observatory in 1877, noted surface features which have been argued about ever since. He called them *canali*—"canals" or "channels"—because they were dark and seemed to reach across the "lands" from "sea" to "sea." Thus began a great international dispute which was to make Mars famous to the public and somewhat infamous among astronomers.

Not everyone saw the "canals" to which Schiaparelli, and then an American, Percival Lowell, referred. Lowell was convinced of the implications of the word "canal"; he founded an observatory, whose contributions to science would include the discovery of Pluto, but whose early activity centered on Martian inland waterways. Lowell's maps showed what de Vaucouleurs describes as "a veritable cobweb" of canals (400 in 1900, almost 700 by 1909—including parallel "spare" channels). His books, *Mars and Its Canals* and *Mars as the Abode of Life* (published in 1906 and 1908, respectively), with speculations about irrigation from the polar caps, led to a considerable reaction. A popular idea was to attempt to communicate with the Martians by digging a canal in the shape of a huge right triangle in the Sahara, wireless communication being, of course, impossible over such a distance. Most astronomers saw the other side of the question. "Nobody has ever seen a true Martian canal," wrote one eminent observer after prolonged study through a powerful instrument. Others compared the drawings of different observers made on the same night, referred charitably to optical illusion, or suggested that the smaller the telescope, the more canals were claimed.

Photographic advances have resolved some differences by apparently resolving some canal-like features, but even photographs are subject to interpretation: there are still partisans, pro and con.



Interestingly, no Martian mountains of Rocky or Himalayan proportions have been identified: gradual slopes, modest east-west chains, or small prominences could not be spotted from Earth, and no shadows—the tell-tale index of the Moon's mountains—have been resolved.

The Thin Air

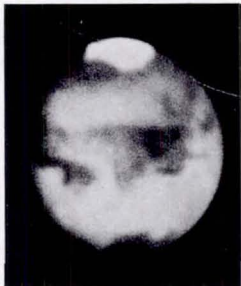
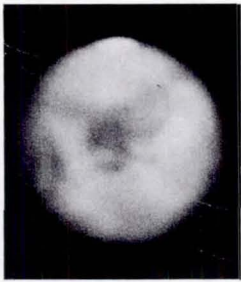
Studies of Mars' atmosphere indicate that it probably consists of nitrogen, argon, some carbon dioxide, a trace of water vapor, and a spectroscopically undetectable amount of oxygen (if any). This statement is based on well-founded speculation for the nitrogen and argon, and extremely skillful spectroscopy for the rest.

The spectroscope is an instrument used to analyze a beam of light for the chemical constituents of the luminous gas in which it originates (such as a flame or the Sun) or the partly opaque gas through which it shines (such as the atmosphere of Venus or Mars). Its output is a wide photograph of the color spectrum laced with a pattern of parallel bright (luminous) or dark (absorption) lines.

Carbon dioxide was detected first on the planet Venus. Nitrogen lacks a strong spectrographic signature of absorption lines in visible light and, in addition, Earth's nitrogen-rich air would mask the weaker indications from another planet. The same masking problem dogged the hunters for oxygen and water vapor on Mars after G. P. Kuiper's subsequent discovery of carbon dioxide on Mars. They calculated that if they shot the spectrogram when Mars and Earth were moving apart or together at the maximum speed, the doppler effect would shift the indications of Martian oxygen and water vapor out from under those of the terrestrial atmosphere. The latter refinement led at last to the conclusion that water vapor was barely in evidence and oxygen was too sparse to detect. Spectral evidence that the polar caps were water ice had been obtained in 1948.

The atmospheric pressure, which corresponds to the weight of the atmosphere per unit area at the surface, is a function (given Mars' gravitational field) of the total amount and kind of gases making it up. It can be measured only by very indirect means from Earth, related to the effects of the atmosphere on light. Some of the methods have involved studying the diffusion of various colors, the polarization, the variation of color across the disk, and the brightness of surface spots as they rotate from one limb of the disk to another and are seen through different slant thicknesses of the Martian air.

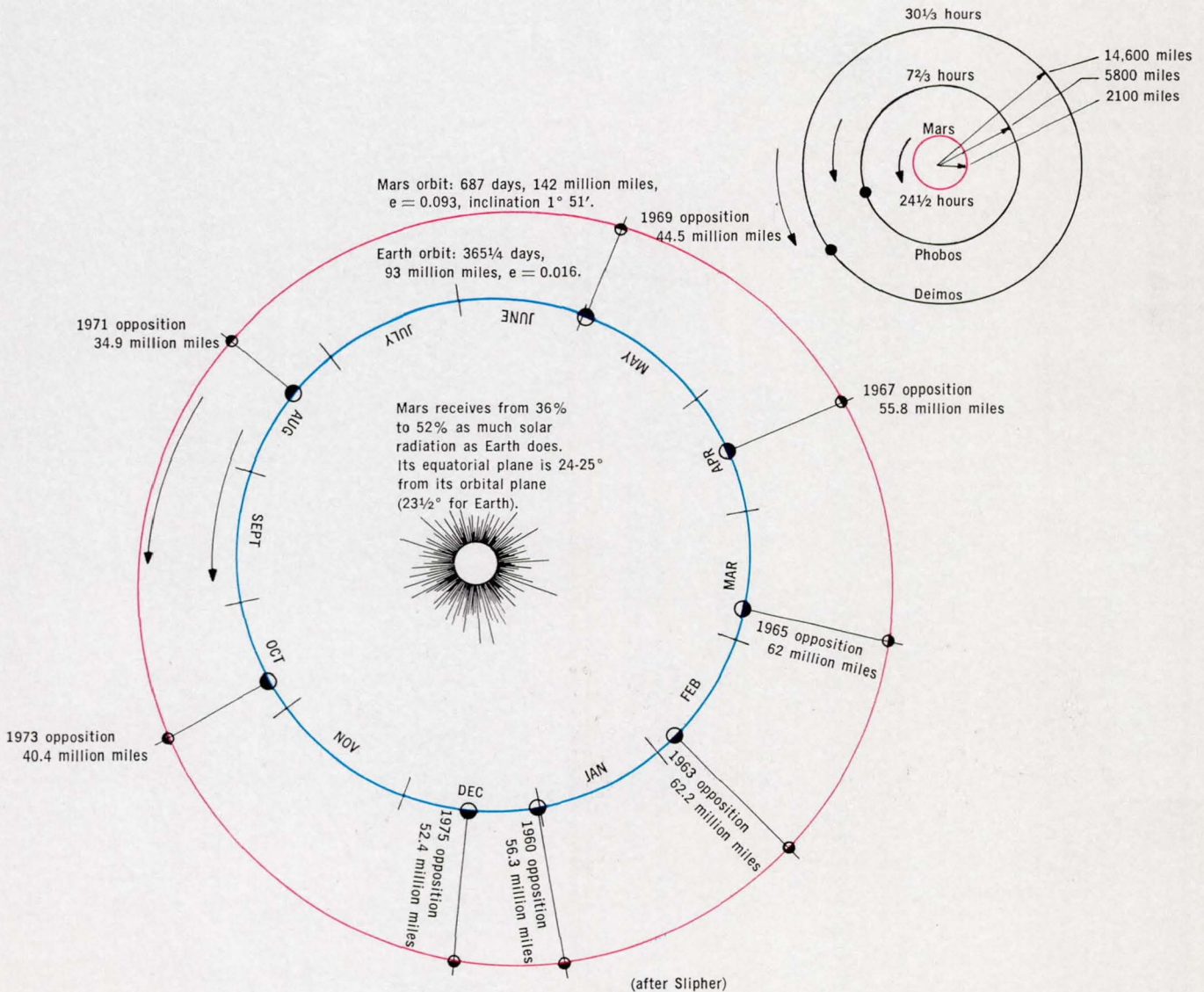
A very recent approach to the question of Martian atmospheric pressure, which may provide the most accurate Earth-based estimate, is based on the tool used to examine the composition of the atmosphere. The spectral absorption lines from the carbon dioxide on Mars are broadened or smeared, according to the theory, as a function of the gas pressure. Comparison with carbon dioxide spectra obtained at various pressures in the laboratory gives, after much analysis, the pressure value. Kaplan, Munch, and Spinrad, who applied this method to Mars, produced a value of 25 millibars, with an



Effect of atmospheric haze, 1956; Mt. Wilson photographs in orange light, July (top) and August

uncertainty of 15 millibars. Subsequent refinement raised this value slightly. Earth's standard sea-level pressure is just over 1013 millibars. Values estimated by other methods, with much greater uncertainties, yield a possible range from 200 millibars down to about 14 (corresponding to the pressure $4\frac{1}{4}$ to 18 miles above Earth's surface).

With Mars' smaller gravitational field, the atmosphere is not hugged close to the planet's surface as is Earth's. Yellow clouds, presumed to be fine dust swept up off the deserts, are frequently observed at altitudes from 3 to 6 miles, and occasionally much higher. The clouds have been observed to move as fast as 85 miles per hour, though more often in the 20- to 30-mile-per-hour range. Wind velocities necessary to pick up the dust may range as high as 125 miles per hour at 300 feet altitude.





TWO YEARS TO MAKE READY

When the Mariner Mars 1964 Project was authorized by the National Aeronautics and Space Administration in late 1962, it was recognized as an assignment somewhere between difficult and impossible. However, such tasks are characteristic of most aspects of space exploration in its present dawn age. The distances, forces, and hazards of interplanetary space are huge; though our knowledge and technical skill are growing rapidly, the unknown aspects remain extensive.

Mariner's Venus 1962 mission, then just successfully concluding, gave encouragement and contributed vital knowledge and experience to the Mars mission, but the scale of the problem was larger in all aspects. It was to the successful Mariner Venus team that the new problem was presented.

Mariner's Pedigree

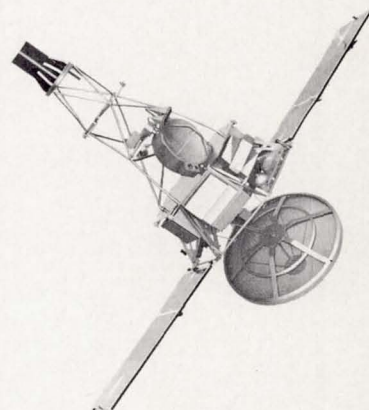
The Mariner Mars system would be the first of its kind, but not the first of its family. The dynasty was founded in late 1958 and 1959, when NASA and JPL worked out a linked series of unmanned lunar and planetary missions which would advance the technology of space exploration while accumulating basic and practical knowledge about the Moon, the planets, and the solar system.

A three-stage launch-vehicle system would have been needed, but the development of restartable second-stage rockets (which in effect made two stages out of one) made this unnecessary. Atlas/Agena was to be the launch vehicle for Ranger, the first lunar member of the series; early Mariner planetary and the Surveyor lunar spacecraft developments were first associated with Atlas/Centaur, a higher-performance system then being designed. Subsequent schedule changes, together with advancements in Agena and spacecraft technology, necessitated and made possible the quick development of an Atlas/Agena-boosted, lightweight planetary spacecraft and its successful use in the Mariner II mission to Venus.

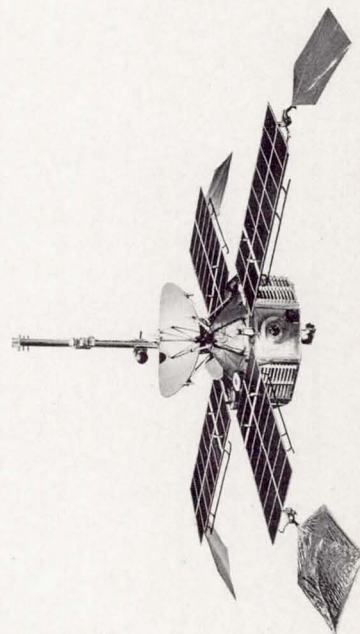
Now the same switch was suggested for the Mars mission: marry the best elements of the Ranger-Mariner II-Atlas/Agena system with the heavy Mars-spacecraft development and launch a Mars mission in 1964. There were less than 2 years to do the job, and a rigid deadline was imposed by the Mars launch opportunity. The Venus mission had been developed in less than a year. It could be done—just barely.

On a Larger Scale

The energy required to ship a pound of payload to Mars in 1964/65 is actually a little less than that which was needed to send it to Venus in 1962. The slightly lower energy requirement, however, turned out to be just about the only aspect of Mariner Mars that wasn't twice or three times as difficult as the earlier mission.



Mariner II



Mariner IV

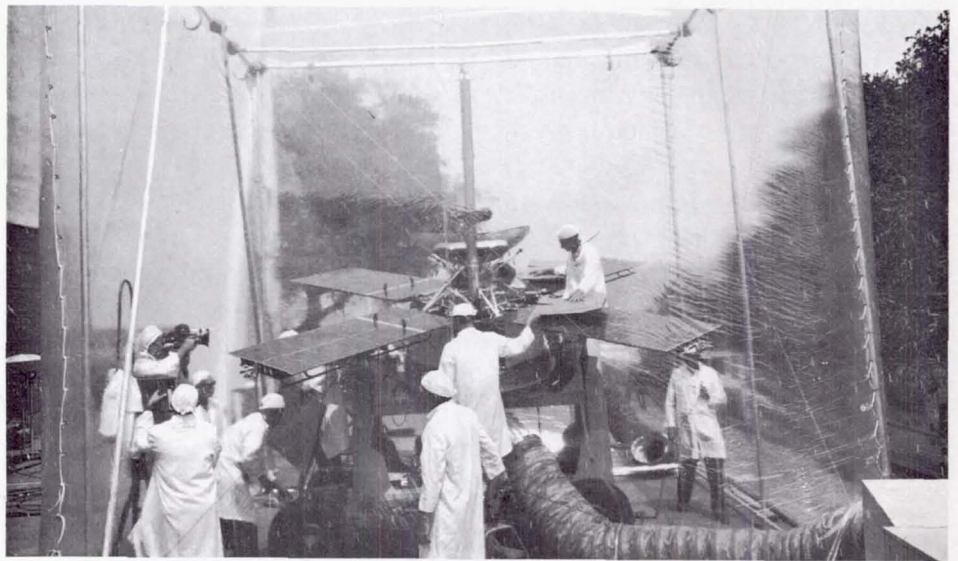
Consider service life, for example. New cars are guaranteed for years or tens of thousands of miles, if serviced regularly. TV sets are guaranteed for a year (except the tubes). A fine watch is guaranteed practically forever—just send it back to the factory. However, you cannot send a spacecraft back to the factory, or adjust the valves, or check the tubes, when it's 100 million miles out in space, and still going.

Mariner II had had to operate for about 2500 hours on its flight to Venus; Mariner IV had to be designed for 6000 to 7000 hours of flight life, on the way to Mars, at the planet, and beyond.

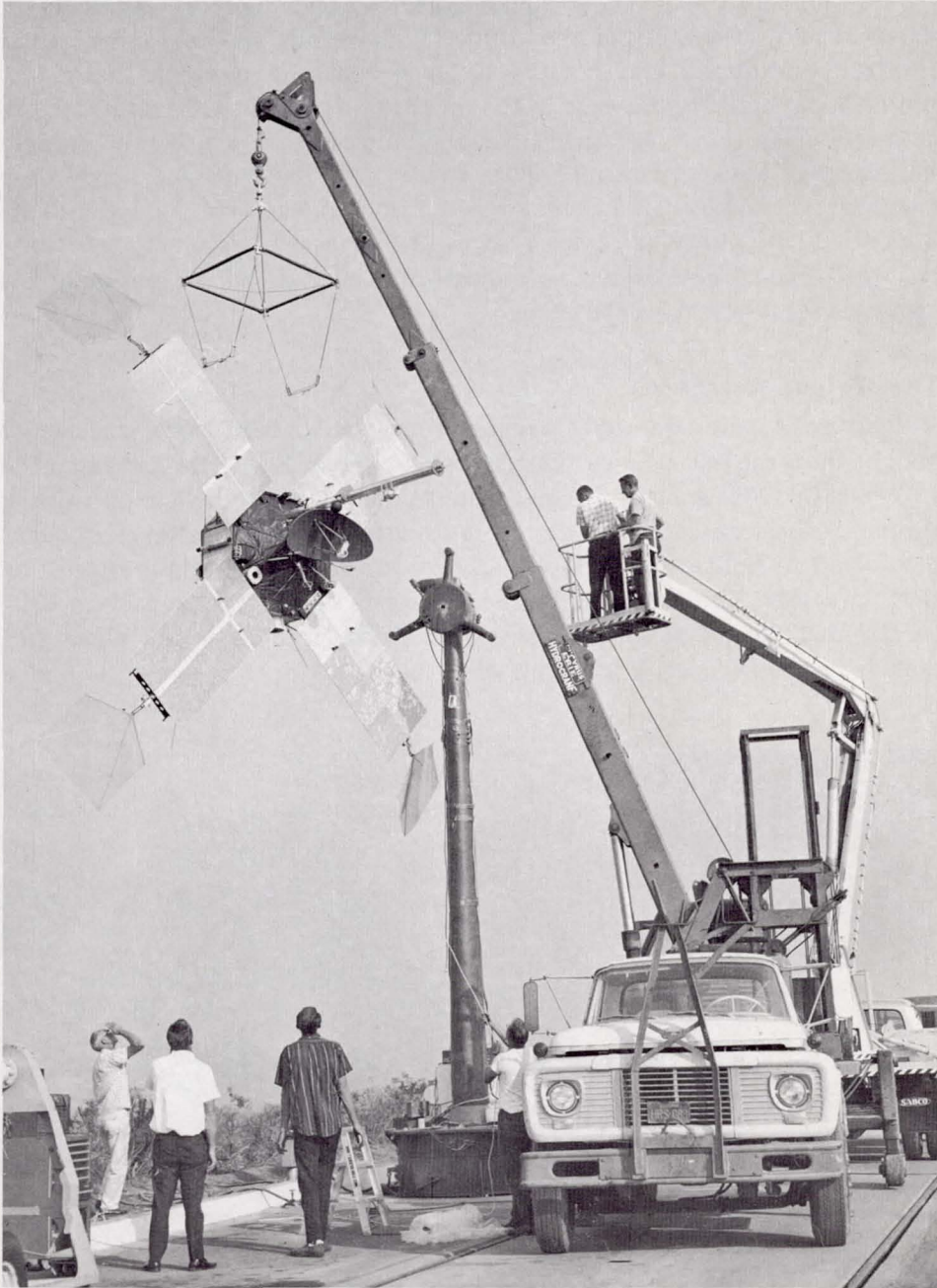
Then there was electrical power. Mariner Mars would need only a little—less than 200 watts—but it must come from sunlight, whose power decreases as you go away from the Sun. Mariner II had one solar panel partly disabled en route to Venus but drew nearly as much power from the undamaged one at Venus as it had received from both panels near Earth. Going out from Earth to Mars, the solar power decreases instead of increasing. Mariner Mars must have more than twice the solar-panel area of its predecessor—70 square feet as against 27.

Considering the environment through which the spacecraft must travel, we again see a sharp difference from any mission attempted before. Mariner II flew toward the Sun, braving increasing solar radiation, which helped with the power problem but aggravated the temperature-control problem. Mariner II had become hotter and hotter on the way to Venus; Mariner Mars would grow colder on its journey.

In addition to the increased flight time and the change of direction, another inevitable dimension put a strain on the Mariner Mars mission: sheer distance. At Mariner II's maximum 54 million miles, radio waves



In outdoor test (within protective plastic tent), solar panels draw power from Sun to operate proof-test-model spacecraft



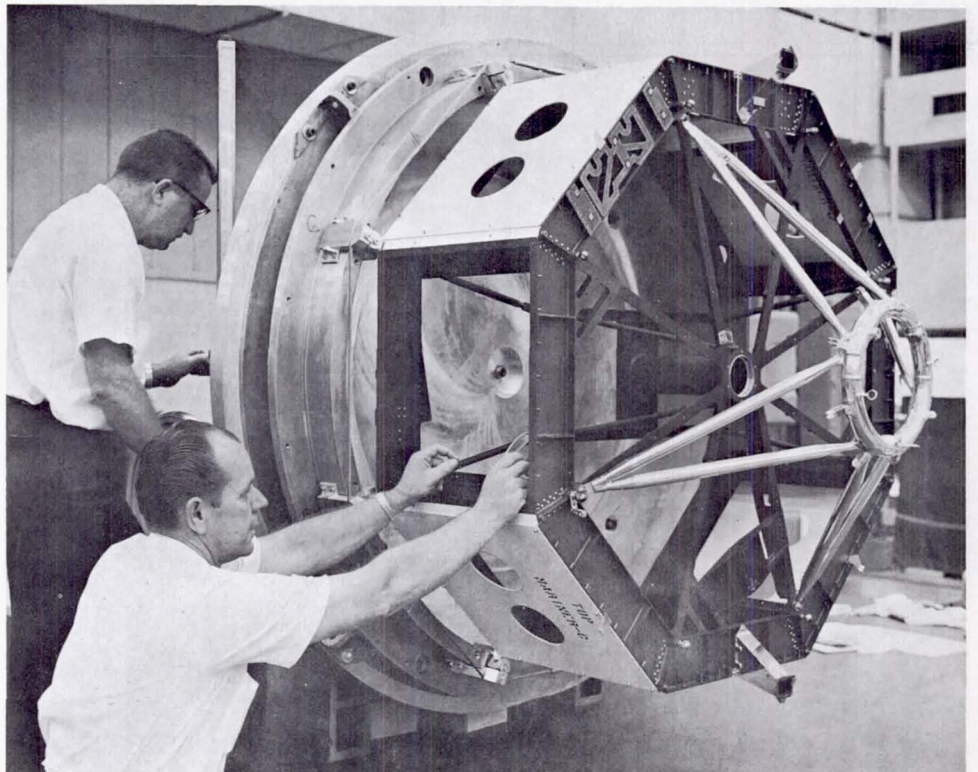
Preparations on antenna range for mapping actual characteristics of Mariner's two radio antennas

took nearly 5 minutes to come back to Earth; communication with the Mars spacecraft would be delayed about three times as long. More important, the communications system would have to be better . . . nine times better, since radio strength decreases as the square of increasing distance. Both the ground and flight units would have to be improved.

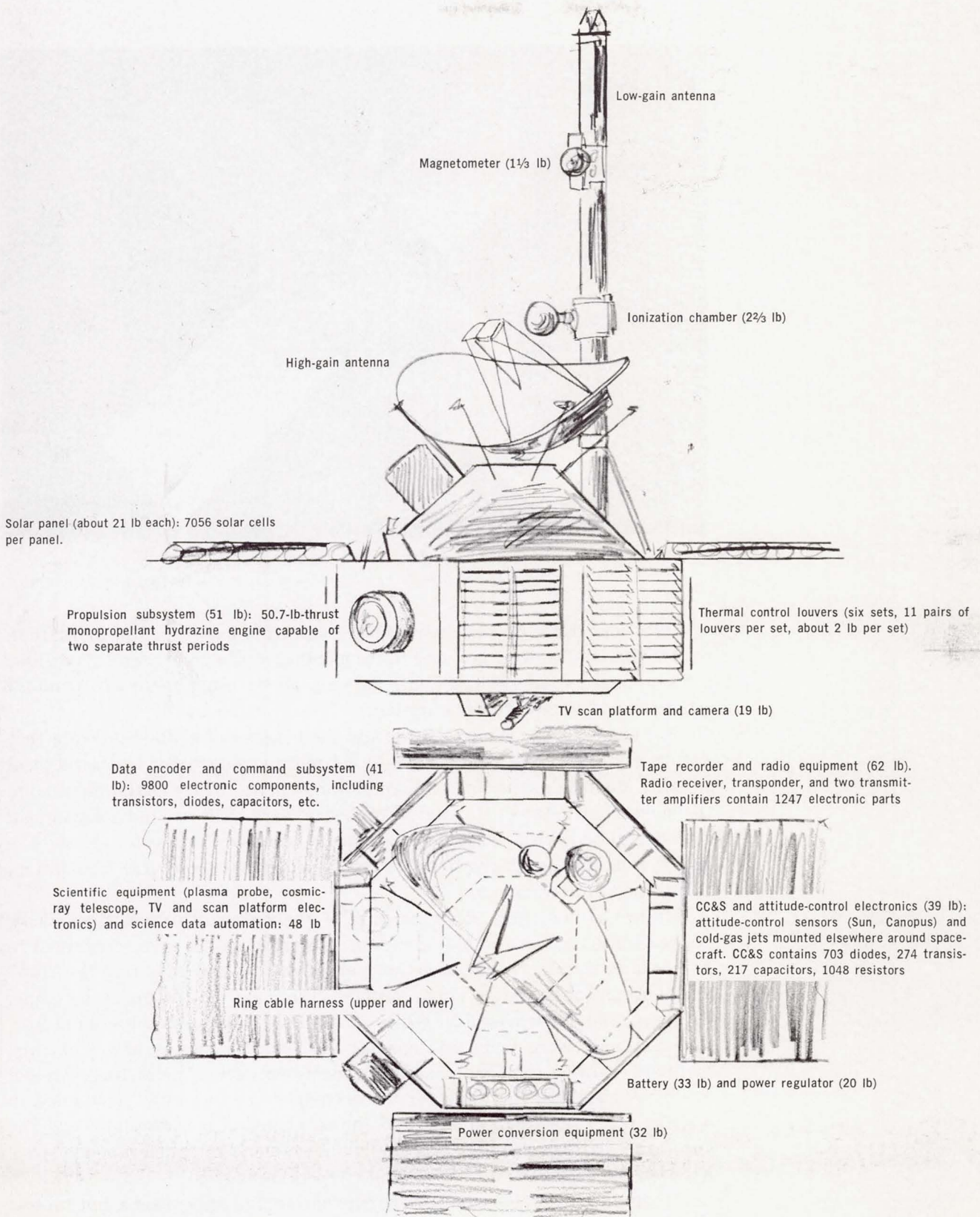
Beyond Mars, where one might expect to find another planet, is the asteroid belt, consisting of thousands of planetoids in independent solar orbits. Accordingly, astronomers believed that the meteoritic intensity might be expected to increase in the direction of this belt. In addition, the Mars path lay across several "cometary" meteor streams. Mariner might be expected, then, to run into more space dust than had previously been experienced. Mariner II's detector had recorded only two impacts in its 3-month flight. Since the total area of the spacecraft is about 200 times that of the small dust detectors, the detectors record only a fraction of the particles actually hitting the vehicle.

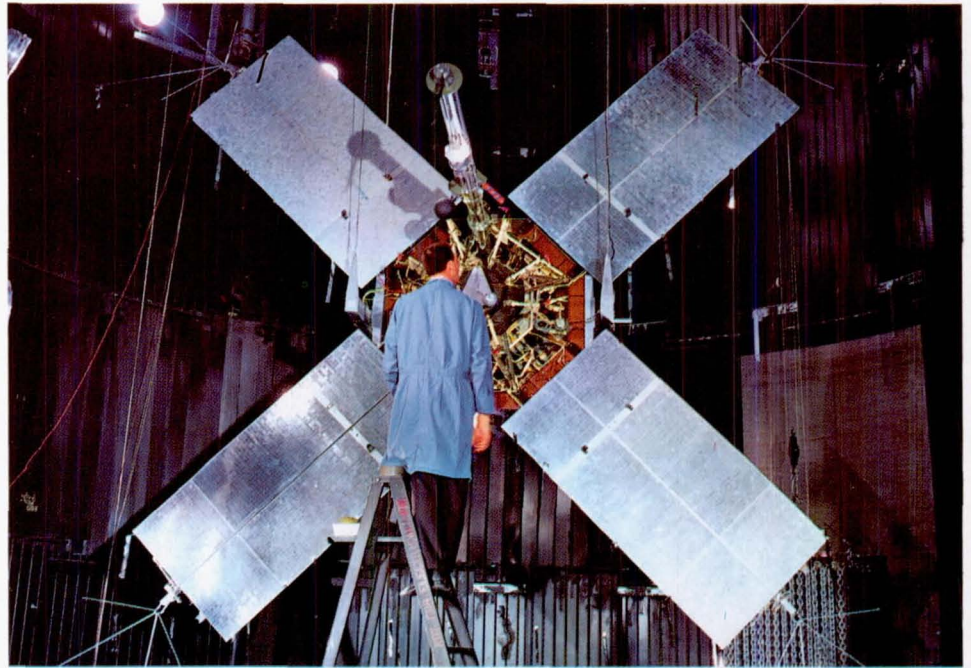
The Weight Watchers

Mariner's planners early decided they would need more spacecraft weight than the 450 pounds that the Atlas/Agena B vehicle had launched to Venus in 1962. A new version of the second stage of the launch vehicle, Agena D, basically a collection of improvements from better propellant utilization to lightweight materials, gave an 80-pound weight bonus for the spacecraft. The energy difference between Venus 1962 and Mars 1964 contributed 40-odd pounds. Thus, the spacecraft could weigh about 575 pounds; something could be done with that.



Initial checkout of octagonal structure





Preparation for test firing of midcourse motor in 25-foot space simulator

Question: How do you increase the scientific experiments, more than double the solar power, get nine times as much radio power, and guarantee a flight time two-and-a-half times as long, all within a mere 575 pounds? Answer: Get tough with the design.

For example, the bones of birds and the I-beams of girders indicate that nature and man have found ways to get more strength for less structural weight. Mariner's structural designers went further; they nearly eliminated the skeletal structure. Mariner's forebears were built around a hexagonal skeleton belted with electronic-equipment packages and crowned with a tower. For Mariner Mars the packages became the structural foundation, the tower a slim waveguide.

Eight shallow trays, deriving part of their strength from their close-packed contents, were joined in a ring; electrical cables were contained in two smaller concentric rings. A thermal shield was spread across the "top" and "bottom" of the larger ring. The fixed elliptical-dish antenna, solar-panel dampers, and the waveguide, which ended in a small omnidirectional low-gain antenna, were mounted topside; the Canopus sensor and planetary scanners were on the shady-side deck. Between decks, the attitude-control gas bottles and the fuel tank for the deep-space rocket motor (mounted in a shear plate replacing one unit of the octagonal ring) were stowed. The spacecraft battery, too big for a shallow tray, also protruded into the space between the decks.

Mariner's four solar panels were conventional in appearance, but radical in construction. Corrugation-stiffened sheet-metal floor structures were

supported by stamped-aluminum-sheet-metal spars about the gauge of kitchen aluminum foil. The panel structures weighed less than $\frac{1}{2}$ pound per square foot.

Keeping Cool and Keeping Warm

An object in space will be warmed by the rays of the Sun, and cooled by its own radiation to the black sky around it, at a rate dependent on its temperature. It will thus eventually stabilize at a temperature primarily dependent on its distance from the Sun: near Earth it would be about 125°F warmer than at Mars' distance. Its sunlit side, if it is not rotating, might be several hundred degrees hotter than the shady side.

Mariner couldn't tolerate such conditions. Its electronic components have certain temperature limits within which they will operate properly, even as we humans do. Their temperatures must be controlled.

The isolation and vacuum of outer space rule out contact conduction and convection; the only controllable heat-transfer factor affecting the spacecraft is surface radiation. The surfaces, then, must be controlled. If painted black, they will radiate or absorb; if polished like mirrors, they will reflect and neither absorb nor radiate.

Explorer, the very first United States spacecraft, had been painted with black and white stripes, the area of white stripes (reflecting surface) calculated to maintain the necessary temperature in Earth orbit. A more advanced development, a heat blanket of layers of very thin aluminized-Mylar plastic, gave Mariner Mars good, yet lightweight, insulation coverage.

A sophisticated thermal-control device, a set of polished aluminum shutters which could open to expose a radiating surface beneath, was tested on one compartment of Mariner II in its flight to Venus. The shutters are activated by bimetallic strips, like inexpensive dial thermometers or the thermostat in an electric blanket. As the temperature rises, the strip uncoils, the shutters open, and heat radiates away to space. Then, as the compartment cools, the strip coils up again, closing the shutters to conserve heat.

Thermal-control louvers of this type were designed for six of Mariner's electronics trays; they would keep the temperature inside between 55 and

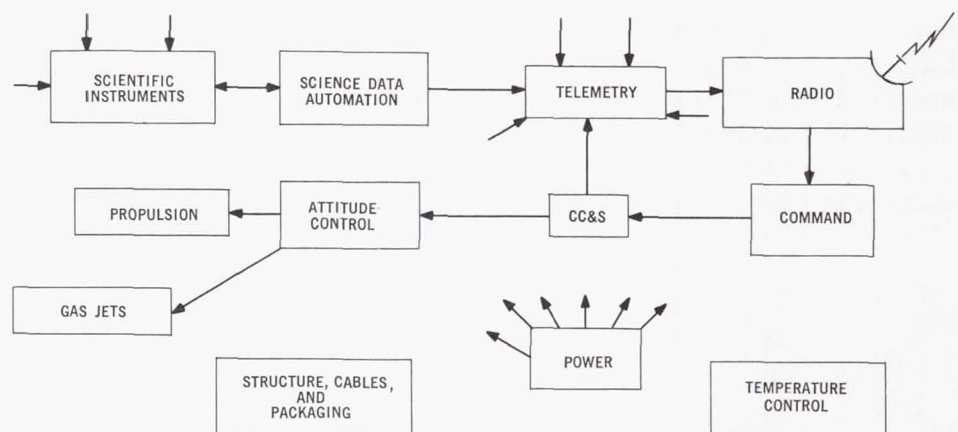


85°F. An aluminized-Mylar shield would protect the sunny upper deck and the shady lower deck; the upper blanket was surfaced with black Dacron. The backs of the solar panels, which absorb a great deal of solar heat in the process of tapping the Sun for photoelectric power, were blackened to re-radiate heat and keep the solar cells within their operating range of 10 to 130°F. Most other exposed metallic surfaces were polished; exposed cables were wrapped with fiberglass or aluminized-Mylar tape. The fixed high-gain antenna dish was painted green: it would cool from its upper operating limit near Earth to about room temperature at Mars.

Put Them All Together

Some philosopher has remarked that you can't get from "1 + 1" to "2" just by understanding the "1." Systems engineering might be likened to the "+" sign. It started with a job to be done. Each of the Systems of the Mariner Mars 1964 Project (Launch Vehicle, Spacecraft, Deep Space Net, and Space Flight Operations) was divided into subsystems or units.

In the case of the Mariner Mars spacecraft, the functional units are: structure, radio, command, telemetry, central computer and sequencer, power, attitude control, pyrotechnic-actuator control, thermal control, cabling, and postinjection propulsion; these make up what is often called the spacecraft "bus." The scientific-experiment "passenger" units are science data automation, planetary scan system, television and its recorder, and six interplanetary-environment instruments: magnetometer, plasma probe, ionization chamber, trapped-radiation and cosmic-dust detectors, and cosmic-ray telescope.



All in all, nearly 140,000 parts were carefully screened and put together, inspected, subsystem-tested and system-tested, and re-tested. All members of the Mariner team labored long and hard in the development and fabrication of the components and the assemblies they constitute; Mariner IV is the sum of these parts.



System test

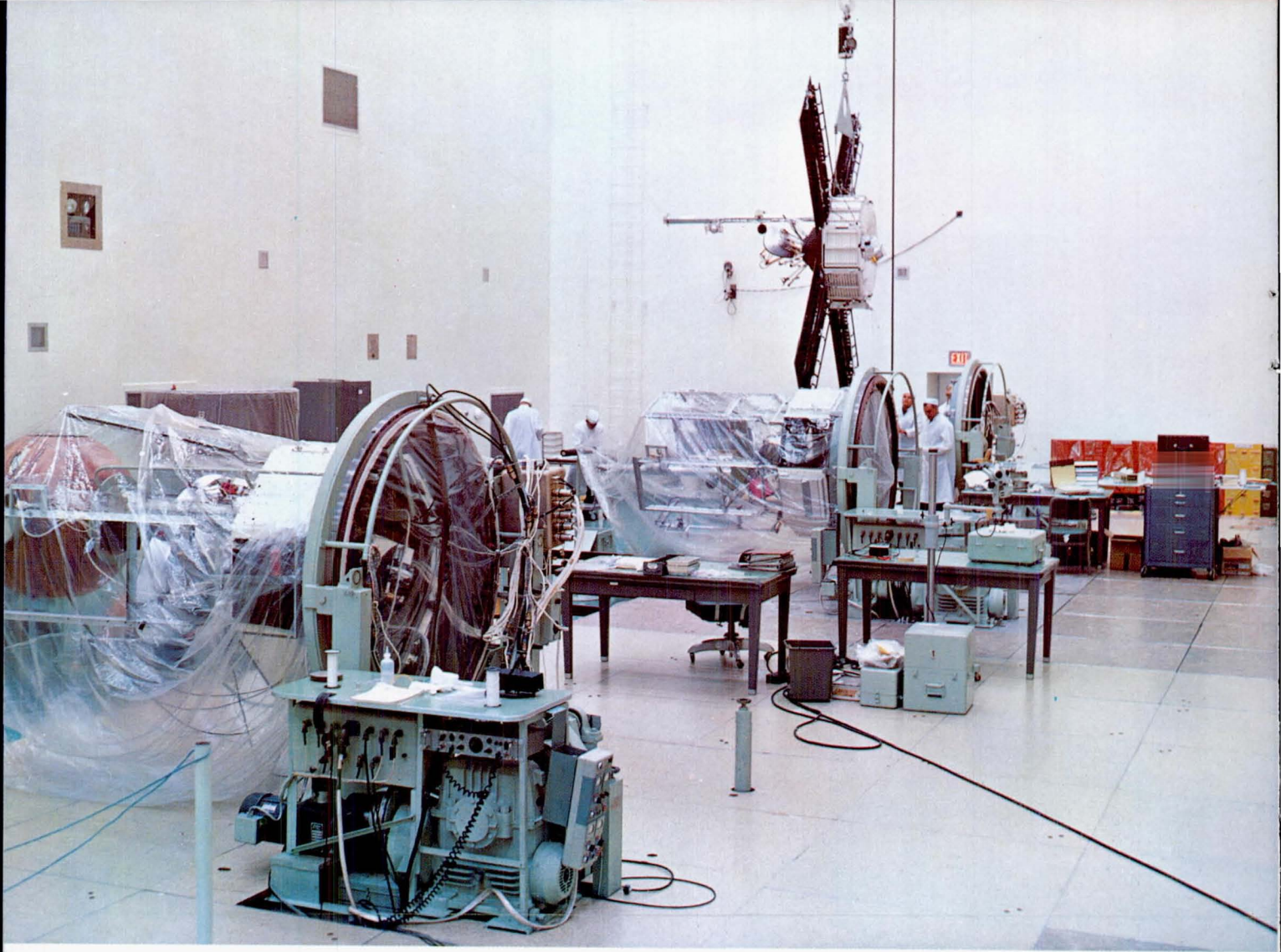
Outer Space on Earth

Though space exploration serves experimental science, it is not itself purely experimental; this is evidenced by the distaste with which spacecraft developers brush off such labels as “cut and try,” “file to fit,” “shoot and hope.” With the exception of extremely long missions such as Mariner IV, most space projects live nine lives on the test bench before they are allowed one life in flight: the emphasis is on performance as predicted from test experience.

Mariner Mars’ development schedule allowed less than 1000 hours for testing each flight article for a 6000-hour mission—a tight schedule for a large and exacting job.

A Mariner Mars temperature-control model—a full-scale spacecraft duplicating the heat-generating and heat-transferring properties designed into the flight articles—was built and tested as long as possible in JPL’s 25-foot space simulator, which was equipped to approximate the black, cold vacuum of space and the blazing radiance of the Sun. Correction factors learned from the flight of Mariner Venus had been engineered into this test device to achieve the best possible Earth-surface reproduction of space conditions.

Before the flight spacecraft were built, a prototype or proof-test model was put together. Serving as a final test bed in subsystem development, as well as the initial system-test vehicle, this spacecraft was at one end of the development loop: modifications found necessary in proof testing were themselves retested on the same craft. At the end of the design evolution and after 1100 hours of system test, the proof-test model had evolved into a functional duplicate of the flight spacecraft; they, in turn, were spared the rigors of prolonged design evaluation by the existence of the test spacecraft which could never fly a mission. The proof-test spacecraft was also used for inter-system testing, verifying compatibility of the spacecraft with ground equipment. It then supported both flight missions by simulating observed flight situations so that they could be studied at close range.

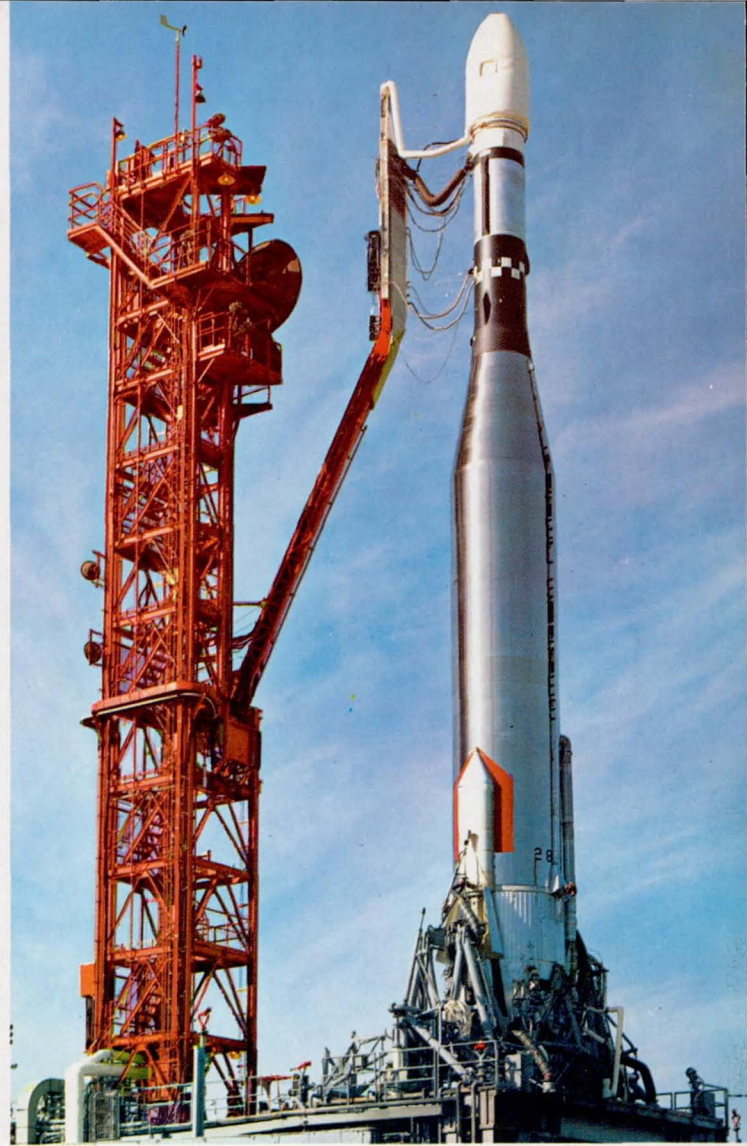
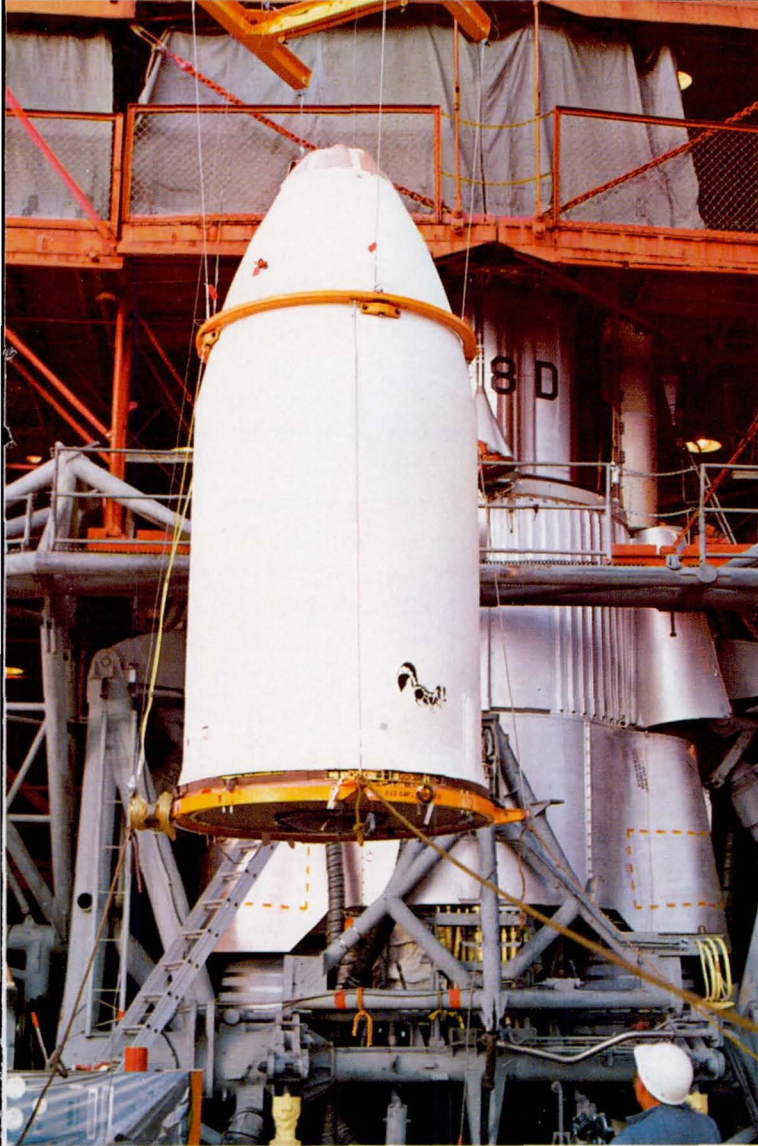


MARINER LEAVES PORT

Three Mariner Mars spacecraft began the journey to the planet Mars from a canyon north of Pasadena, California, at the Jet Propulsion Laboratory, where they had been designed, assembled, and tested for months. Two of the three would fly; the third was a spare. They were partly disassembled, carefully packed, and loaded on moving vans. On September 11, 1964, after a four-day journey, the last van reached the Air Force Eastern Test Range, Cape Kennedy, Florida.

Here each spacecraft was carefully inspected and retested. There were spare parts for the individual plug-in units of the Mariner spacecraft. The calendar and the high quality standards would allow no tinkering or repair in the conventional sense: replacement of modules, if necessary, should solve faulty-parts problems.

At the Cape, two 100-foot-high Atlas/Agenda D rockets were waiting, each standing in its own launch complex. The engineers could select either one for the first launch, and could launch the two missions as close as 2 days apart if desired.



Spacecraft and launch vehicles were given separate system tests, assuring that each would function in every phase of its role in the mission. The mechanical, electrical, and radio compatibility of spacecraft, vehicle, ground equipment, and tracking system were tested. Finally, at the beginning of November, the Mariner III spacecraft and launch vehicle stood on the pad, going through a dress rehearsal. The actual Mars launch period opened on November 4 and lasted for only about a month.

Interplanetary Navigation

Unlike a conventional aircraft, a spacecraft spends most of its time falling. The first few minutes of the flight, and then, a day or a week later, a few more seconds, are all the powered flight it ever has. Accordingly, its captain must plot his course before the ship leaves port; this process is more gunnery than navigation.

Every planet of the Sun travels an ellipse, a closed curve which resembles a circle stretched out in one dimension. The Sun is at one focus of the ellipse, not at the geometric center. As the planet comes closer to the Sun, it speeds up; as it goes outward, it slows.

An interplanetary spacecraft is as subject to these laws as are the planets. It must be given the correct velocity—speed and direction—so that it will arrive at the intersection of its orbit with that of the planet just as the planet gets there. Most of the necessary velocity can be picked up from Earth—which orbits the Sun at an average of 66,600 miles per hour—but the rest must be provided by the booster vehicles.

The velocity required to reach Mars is lowest, and within reach of present-day rocket power, when the Earth launch and the Mars arrival occur almost on opposite sides of the Sun. Such conditions prevail only for a few weeks every 25 months, limiting the practicable launch periods to those times. The absolute minimum velocity would be needed when the injection point, the Sun, and the arrival point form a straight line but, because of the tilt of Mars' orbit plane relative to Earth's, this coincidence hardly ever happens.

Near Earth, the entry point of the Earth-to-Mars ellipse is relatively fixed in space. Since the Earth turns under this point, it is within the safe firing angle from Cape Kennedy (24 degrees south from due East) for only a few hours per day; as the injection point sweeps from East to West, the rocket must be guided to meet it. Using the Atlas/Agena D, the technique is to launch into Earth orbit, coast until the injection zone is almost reached, and then restart the Agena to transfer from Earth orbit to solar orbit.

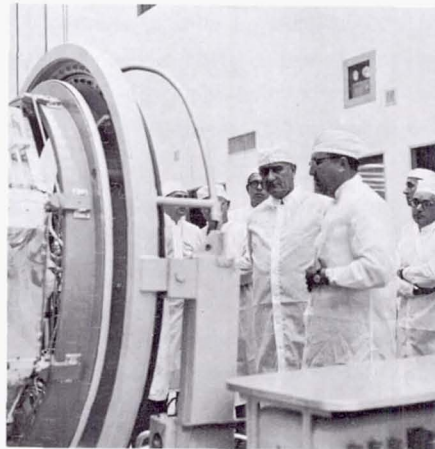
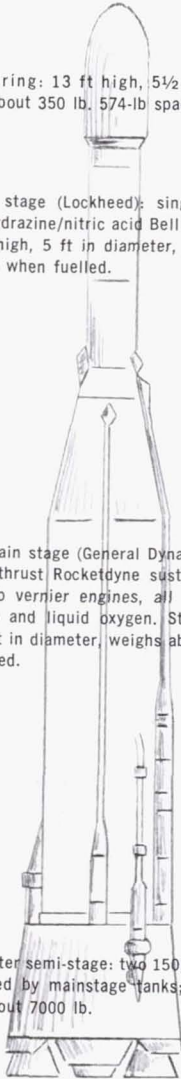
Several thousand Mariner Mars trajectories were calculated, accommodating the changing relationship of the planets day by day, and the changing angles near Earth from minute to minute. They took into account not only Earth, Sun, and Mars, but the perturbing effects of the Moon and the planet Jupiter, and the pressure of light from the Sun. The latter would, over the course of the flight to Mars, push Mariner about 10,000 miles away from the Sun.

Nose fairing: 13 ft high, 5½ ft diameter. Weight about 350 lb. 574-lb spacecraft inside.

Agena D stage (Lockheed): single 16,000-lb-thrust, hydrazine/nitric acid Bell engine. Stage is 23 ft high, 5 ft in diameter, weighs about 15,300 lb when fuelled.

Atlas D main stage (General Dynamics): single 57,000-lb-thrust Rocketdyne sustainer engine, two 500-lb vernier engines, all burning RP-1 (kerosene) and liquid oxygen. Stage is 67 ft high, 10 ft in diameter, weighs about 130 tons fully fuelled.

Atlas booster semi-stage: two 150,000-lb-thrust engines fed by mainstage tanks; 16 ft wide, weighs about 7000 lb.



Left: President Johnson inspects Mariner prelaunch operations. Right: Inside the blockhouse at launch

Nine Hours

Mariner III was launched toward Mars about midday on November 5. Minor launch vehicle difficulties encountered on the first day's countdown had been solved to the engineers' satisfaction; the prelaunch countdown was normal; the weather was good. The tall, snub-nosed space vehicle rose from Launch Complex 13 with an air of confidence.

Nevertheless, within minutes the mission was doomed, though it took nearly 9 hours for it to die. The cylindrical fiberglass-honeycomb nose fairing, or shield, designed to protect the spacecraft during the smashing thrust up through the atmosphere and then to be jettisoned, failed during the climb through the air. When the time came, it could not be ejected.

Early indications of trouble came at the end of powered flight. Because of the dead weight of the nose fairing, the velocity was too low. The spacecraft would not reach its target.

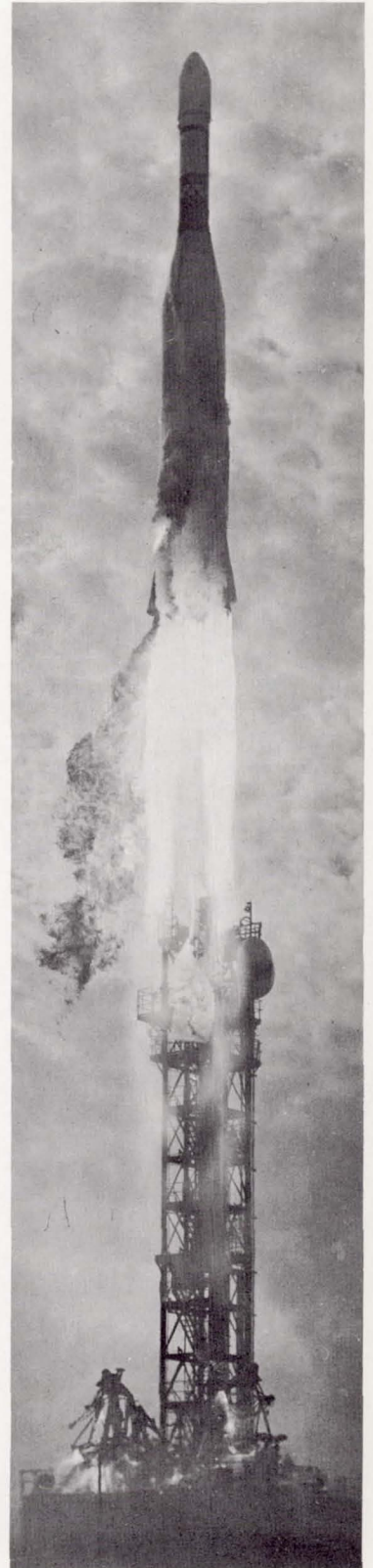
About 5½ minutes later, after spacecraft and Agena had separated, the spacecraft unsuccessfully attempted to deploy its solar panels. Without solar panels, there was no solar power. Studying the telemetry from Mariner, building up piece by piece a picture of the trouble, and conducting failure-mode tests on the proof-test spacecraft, the operations teams commanded Mariner III to conserve power by switching off the scientific equipment, repeatedly commanded panel deployment, and were in the process of igniting the spacecraft rocket motor in an attempt to remove the nose shield by force when, 8 hours 43 minutes after launch, the spacecraft battery ran out of power.

Mariner's team wasted no time. The problem was identified, studied, and solved. A quick, thorough test program detailed and verified the conditions which had caused the failure. Experiments were conducted with fiberglass nose shields, and a new all-metal shield was designed, developed, and built in record time by the Launch Vehicle team. A little over 3 weeks after the launch of Mariner III, another Mariner/Atlas/Agena stood ready on the pad, with the new metal nose shield installed.

Mariner IV: A Good Sendoff

On November 27, the first countdown of the new Mariner was interrupted by radio difficulties. On Saturday, November 28, at 1:37 in the morning, EST, the launch countdown began for the Atlas and Agena; the spacecraft was activated at 4:32 a.m. Launch operations crews went through the long list, establishing and checking communications, forecasting the flight weather, monitoring spacecraft and launch vehicle condition, filling the Agena oxidizer tank, and switching equipment into a state of readiness. At 9:22 a.m. EST, the clock had counted to zero without a hitch; the report was "clear to launch." Liftoff occurred 1.309 seconds later.

As it rose, the space vehicle rolled to an azimuth of 91.4 degrees, just South of due East, and began to pitch over from its vertical ascent. Shedding its two massive booster engines, Atlas carried on with the single sustainer. A ground computer fed guidance commands to the vehicle until



the sustainer engine was shut down and the velocity properly adjusted with two small rocket engines. Then the huge, empty Atlas was detached and Agena took over. Before the Agena engine was started, the aerodynamic nose cover had to be jettisoned. This time, it came off easily.

Agena's 16,000-pound-thrust engine couldn't lift the weight of the Agena vehicle and the encapsulated Mariner spacecraft if they were on the ground. But starting at an altitude of 100 nautical miles and a velocity of 13,000 miles per hour, it could and did thrust Mariner to orbital velocity, about 17,500 miles per hour. The Agena engine then shut off, and the vehicle coasted for almost 41 minutes. Swinging around Earth to bear on its target, Agena flamed into action again. When the big engine shut down for good, the spacecraft was traveling at 25,598 miles per hour along a path that led within 150,000 miles of Mars. The application of one-fifth of the spacecraft on-board propulsion power would bring that path within the desired target zone, between 4000 and 8000 miles above the planet's surface.

Launch operations were described as nominal: it was a good shot.

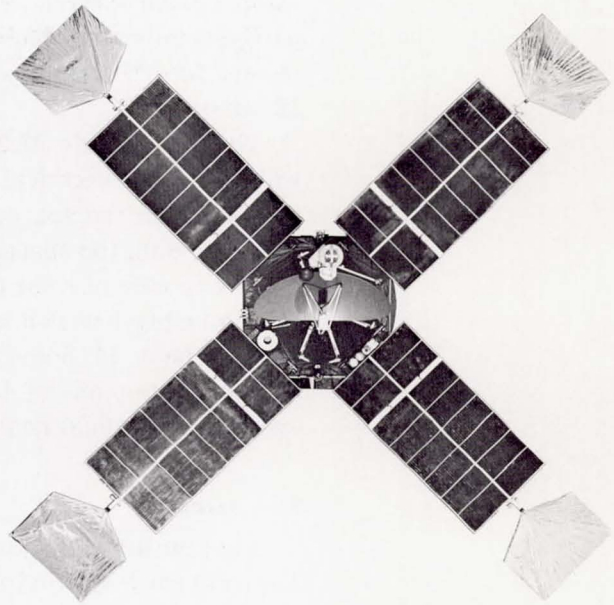
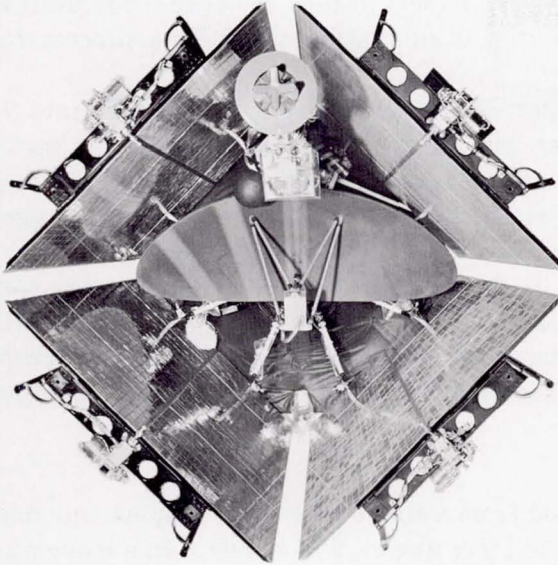
TO MARS

A minute and a half after entering the path to Mars, Mariner and Agena passed into Earth's shadow for a period of almost 12 minutes. There, in the dark, spacecraft and Agena separated. A 3-minute timer was started, and, simultaneously, the spacecraft radio power was switched up and the interplanetary scientific instruments were turned on. When the 3-minute timer ran out, electric current was applied across the solar-panel pin-puller squibs.

A squib is a small, electrically fired explosive charge attached to a cylinder-piston arrangement, enabling a one-stroke internal-combustion engine to open or close a bolt or valve. These mechanisms would be used later to turn the propulsion system on and off and to release the scanning platform carrying the TV camera. Eight pairs of squibs (they are usually mounted in pairs for increased reliability) were mounted on the spider-like legs which held up and steadied the four solar panels during launch. Now they fired, pulling the pins and releasing the panels.

Opening for Business

Under spring tension, the panels hinged away to the deployed position. At the end of each opening panel, a silver fan unfolded and spread. These fans are solar pressure vanes, a new attitude-control trim device in a first

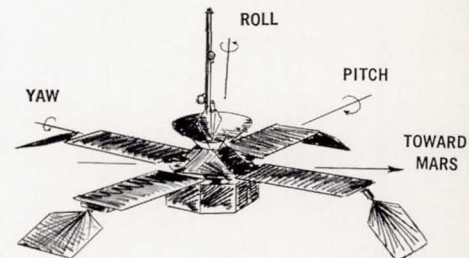


flight test; they were designed to balance the spacecraft against the endless pressure of sunlight, saving attitude-control-jet gas and permitting a longer stable flight.

Now the spacecraft came back into the sunlight, and, the attitude-control system having already been switched into a Sun-seeking operation by the central computer and sequencer, Mariner turned toward the Sun.

Usually called CC&S, a central computer and sequencer serves as combination brain and alarm clock for the Ranger-Mariner family. It provides the master synchronization for spacecraft operations, the rhythm for telemetry transmission and command interpretation, and a number of set commands (such as Sun search, star search, and midcourse maneuver), and conducts complex maneuvers in accordance with instructions sent from Earth.

Searching for the Sun consists of placing the pitch and yaw control systems under the command of the Sun sensors. The spacecraft is treated as though it were a ship or aircraft traveling in the direction in which the solar panels face: yawing moves the prow or nose to the left or right, pitching moves it up or down, and rolling spins the ship around. Mariner left this mode of travel behind with the launch vehicle, and normally moves almost at right angles to the "nose" direction, but the names stuck. In Mariner's cruise mode, pitching or yawing means rotating around one or the other pair of solar panels, and rolling means turning like a propeller.



There are Sun sensors on Mariner's upper and lower decks; their output signals drive control-amplifier chains, which use puffs of nitrogen gas from paired jets on the tips of the solar panels to turn the spacecraft until the panels face the Sun, and to stop it in that position. This process took 12 minutes.

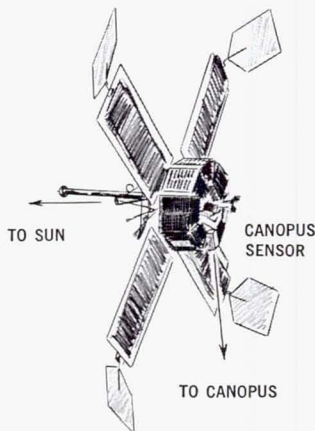
Now Mariner's 28,224 solar cells were converting sunlight into 700 watts of raw electrical power, which, in turn, was converted to various forms to run the spacecraft and recharge the battery. At Mars' distance from the Sun, the spacecraft would still generate 300 watts, leaving a good margin in case of solar cell damage in the space environment.

Like a big jewelled windmill, the spacecraft rolled slowly through space for the next 15 hours; the known roll rate was used to calibrate the magnetometer, one of the interplanetary sensors, so that the spacecraft's own magnetic field could be subtracted from the magnetometer readings.

Star Lock

Imagine a weight suspended from a single long cord: it spins and spins. A second cord, approximately at right angles, will steady it in a moment. A line of sight on the star Canopus, second brightest in the sky, and located near the ecliptic south pole, was to be Mariner's second stabilizing cord.

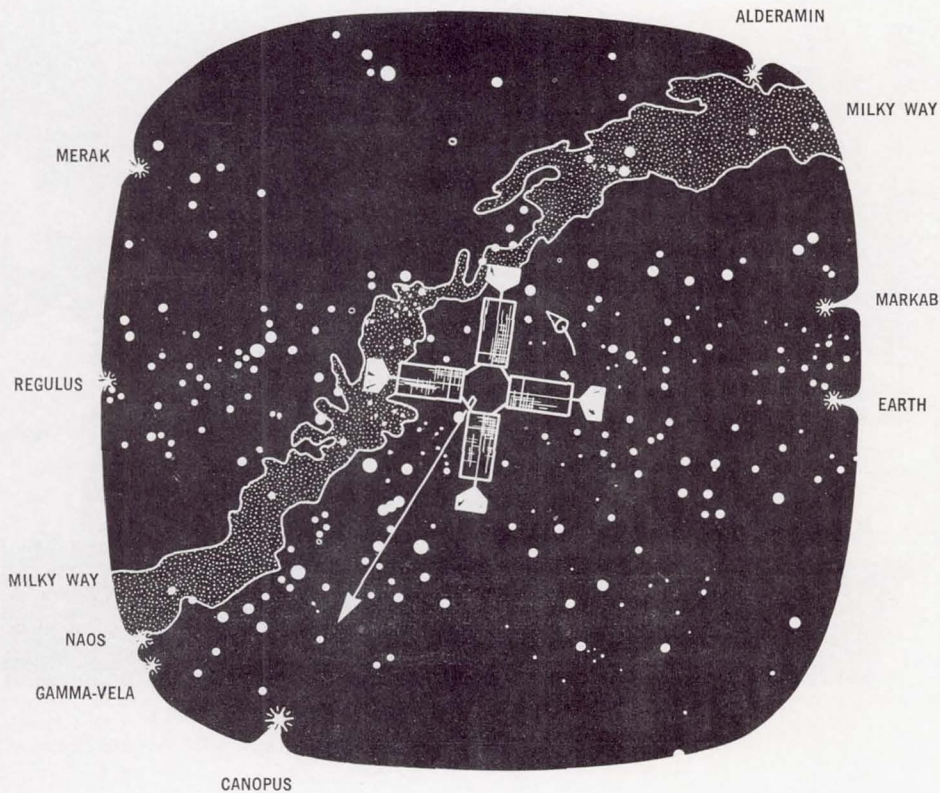
Mariner Mars was the first space mission using or needing a star as a reference object; earlier missions, remaining near Earth or traveling to Venus, had sighted on the home planet. But during this flight, Earth would transit across the face of the Sun, and through much of the flight it would appear as a relatively dim crescent. A bright reference source, at a wide angle away from the Sun, was necessary. Canopus filled the requirements for such a reference source. Mariner's Canopus sensor is mounted on the shady side of the spacecraft ring, pointing outward at an angle, so that its field of view covers an area in the shape of a shallow cone.



An electronic "logic" in the attitude-control system was set to respond to any object more than one-eighth as bright as Canopus. Including Canopus, there were eight such objects visible to the sensor as Mariner swung around in the search mode; it was no surprise when the system acquired one of the other seven. The engineers had prepared brightness charts, corresponding to star maps of the ribbon of sky the star tracker would inspect, and the stars were recognized as they came around. It took more than a day of star-hopping to find Canopus.

Change of Course

A lunar or planetary mission has too great a range and too small a target to be accurately guided from the brief initial powered flight. Thrust must be applied later, in what has come to be called the "midcourse correction" maneuver—a double misnomer, in that it occurs earlier than the midpoint of the flight, and, rather than correcting a mistake, increases the

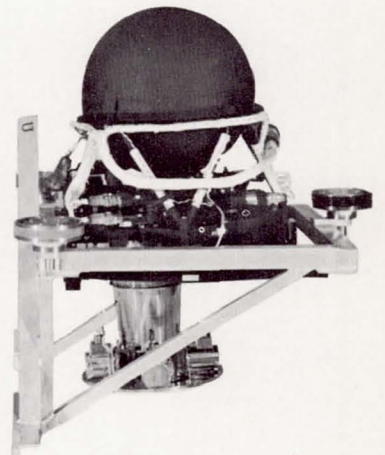


Star brightness graph in circular form, with spacecraft locked on Canopus; predicted brightness indicated by distance in from circumference

possible accuracy. All members of the Ranger-Mariner family used essentially the same type of small rocket engine to apply this thrust. Mariner IV's propulsion system was modified so that it could be used twice if necessary, and its thrust was calibrated so accurately that the resulting change of velocity could be metered by the burning time alone.

After about a week of tracking to determine the flight path and Mars arrival time, the thrust maneuver was scheduled for December 4. All the necessary ground commands had been received by the spacecraft, when it suddenly "lost lock" with Canopus. Though Sun lock was not disturbed, the spacecraft had no roll reference from which to orient its rocket motor, and the maneuver had to be postponed by ground command until Canopus lock could be regained.

Next day, the thrust maneuver was successfully carried out. Three quantitative commands from Earth had the CC&S store in its electronic memory the dimensions of the required maneuver, which were a negative pitch turn of 39.16 degrees, a positive roll turn of 156.08 degrees, and a thrusting time of 20.07 seconds. Then three direct commands told the

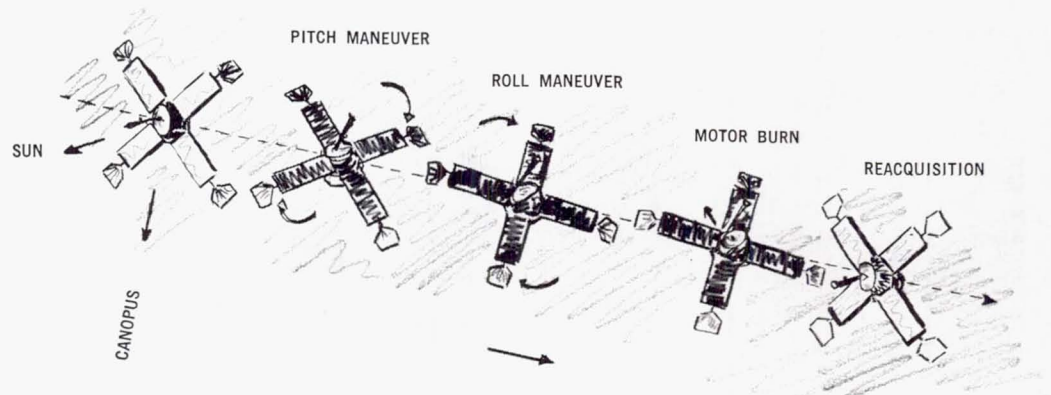


Midcourse motor



Flight-path analysts calculate trajectory and midcourse maneuver.

spacecraft to cock the system, take off the electrical safety catch, and ignite the engine. Since the motor was initially pointed almost along the direction of flight, the turns aimed it back in the general direction of Earth but high above the plane of the orbit. The pitch and roll were performed with better than 1 per cent accuracy, the velocity change with about 2½ per cent accuracy. As planned, the angle of flight was changed less than ¼ degree, and the velocity was increased a little more than 37 miles per hour. Mariner was headed straight for its target, which was 7 months and 300,000,000 miles ahead.

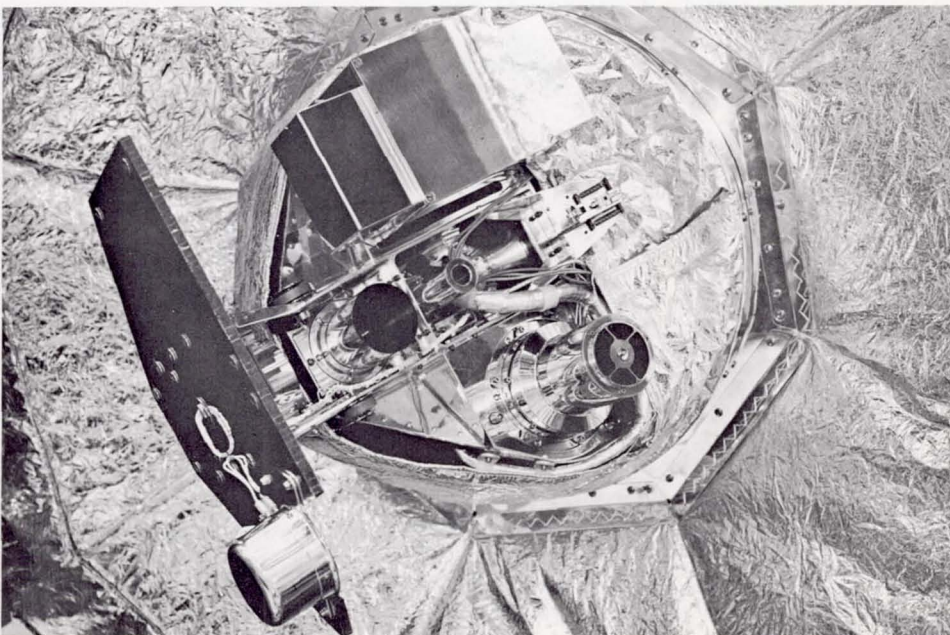


The Routine of Space

During the long cruise to Mars, it was housework and homework for Mariner. The housework consisted of many routine tasks, programmed in the CC&S and supplemented with a few ground-commanded operations, designed to maintain the spacecraft in condition to carry out its mission at the planet. The homework consisted of a constant examination of spacecraft condition and performance and the space environment through which it was passing, and the reporting of these measurements to Earth, where they were correlated and studied.

The CC&S, which was counting the time until a number of Mars-encounter operations should be ordered, sent counting pulses back to Earth about every $2\frac{3}{4}$ days, permitting the operators to check the clock operation. As the spacecraft moved around the Sun, Canopus tended to drift sideways out of the field of the star tracker, and on four occasions the CC&S adjusted the angle of the tracker.

The attitude-control system kept Mariner's roll axis pointed within $\frac{1}{4}$ degree of the Sun, using puffs of nitrogen gas from jets on the solar-panel tips each time the attitude reached the prescribed limit. The fan-shaped solar vanes on the ends of the panels were automatically adjusted to help maintain Mariner's balance against solar pressure. Similarly, the spacecraft was stabilized in the roll direction on the star Canopus, after some initial light-sensing difficulties. The disturbance of December 4 was repeated, probably because tiny dust particles, brightly lit by the Sun, moving with the spacecraft drifted in front of the tracker the total image appeared too bright to be Canopus, and the control system turned on the gyros to roll Mariner in search of the correct brightness. After several

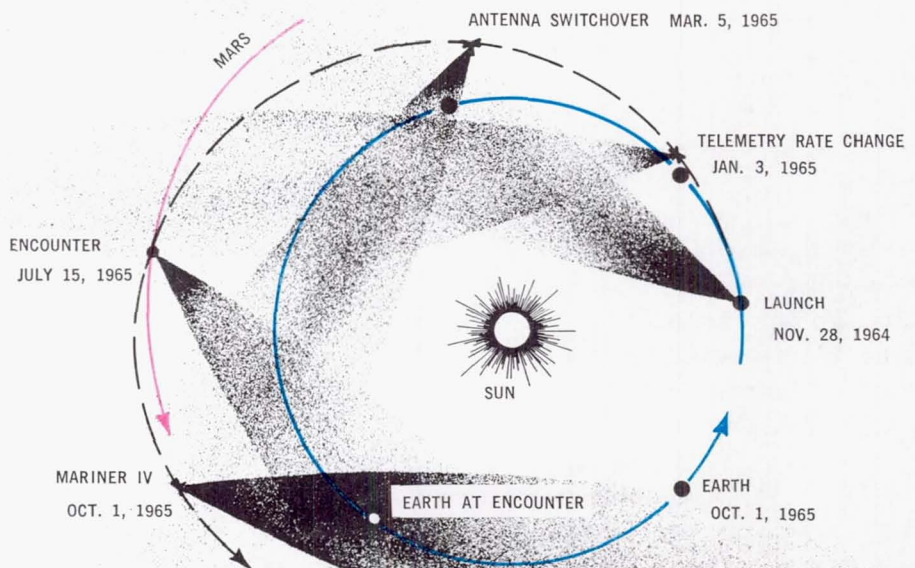


For the first 2½ months of flight, TV optics (lower center, pointing right) and planet sensors were protected by a metal cover (shown hinged to left and down); on February 11, the cover was unlocked and pivoted open by command from Earth.

days, the spacecraft was commanded to ignore excessive brightness, and the trouble ceased.

The radio subsystem provides Mariner's tenuous link with Earth. Broadcasting continuously at 2300 megacycles with about 10 watts of power, the radio carries scientific measurements, data on the condition of the instruments, and some 90 meter readings on the spacecraft performance and status. The measurements are coded digitally, after the manner of teletype or Morse, rather than in analog form as used by commercial radio and TV and the Ranger spacecraft, and are imposed on the radio signal by a technique called phase-shift-keyed modulation.

On December 13, the radio was switched from a cavity power amplifier to the longer-life, slightly more powerful traveling-wave tube. The rate at which telemetry was transmitted was slowed from $33\frac{1}{3}$ bits per second, or one readout every $12\frac{1}{2}$ seconds for the most frequently sampled measurements, to $8\frac{1}{3}$ bits, or one readout every 50 seconds, on January 3. Most of the measurements were sampled much less often: every 500, every 5,000, or even every 10,000 seconds. Scientific measurements occupy two thirds of the transmission time, except during certain maneuvers, when they are turned off, or on special occasions, like Mars encounter, when they take over the whole transmission. On March 5, the radio was transferred by on-board command from the omnidirectional broadcast antenna to the fixed narrow-beam parabolic dish. The range had lengthened to 6 million miles, and Earth had entered the beam of the antenna, where it would remain until well after the spacecraft had passed Mars.



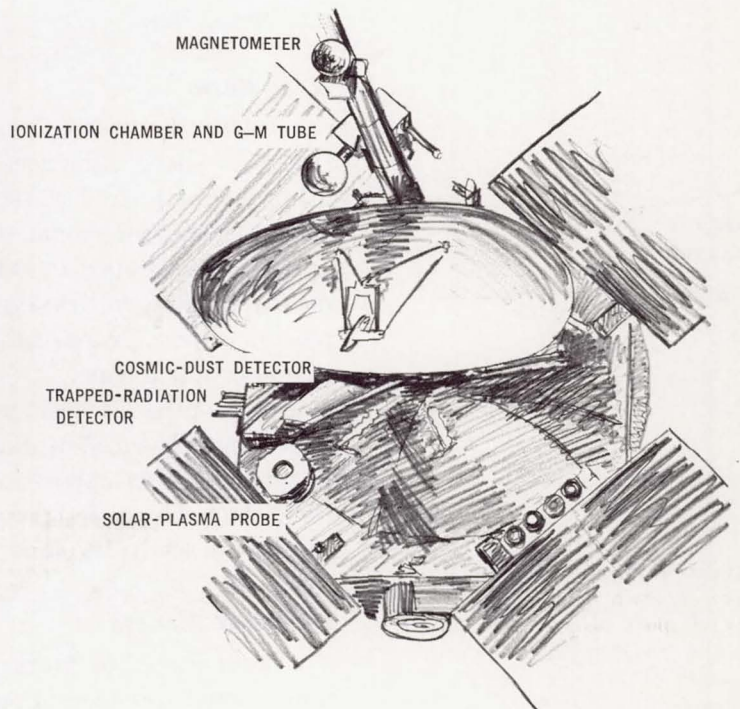
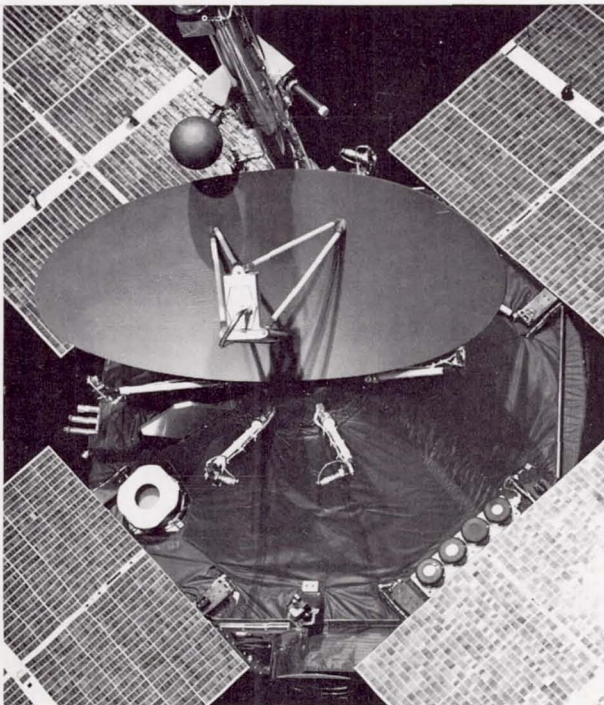
Mariner's fixed high-gain antenna covers a long, narrow region of space, pointed about 38 degrees forward from the Sun direction; Earth was within this region for the last 7 months of the mission.

THE INTERPLANETARY PULSE

Mariner's voyage to Mars involved an extended presence in the environment—meaning the magnetic fields, solar and cosmic radiation, and whatever matter or particles were there—of the solar system. Study of this environment during the earlier mission of Mariner II to Venus had provided understandings to the benefit of the Mariner Mars project, as well as adding to scientific knowledge of the Sun and its surroundings. Six instruments to observe and measure these fields and particles were accordingly flown on Mariner IV.

Six Sensors

The solar-plasma probe was designed to measure the charged particles making up the solar wind, a hot ionized gas streaming out at hypersonic velocity from the corona of the Sun. Electrons, protons, and alpha particles (helium nuclei) are detected in 32 energy bands ranging from 30 to 10,000 electron volts. The energy of the stream varies continuously, solar surface disturbances giving rise to plasma storms. Unfortunately the failure of a resistor in the instrument's circuitry 8 days after launch rendered its data exceedingly difficult to interpret. Reduction of the data transmission rate returned a number of readings to intelligibility, but a progressive decline was observed. Partial calibrations during the flight gave hope that much more information might be salvaged from the data.



Next in energy range among the charged-particle or radiation detectors is the trapped-radiation detector, designed to measure the Van Allen belts of Earth, similar formations around Mars, and related phenomena in space. Four detectors with acceptance angles of 60 degrees, three pointed 70 degrees and one 135 degrees away from the Sun, detect electrons above 40,000 and 150,000 electron volts and protons above $\frac{1}{2}$ million, above 3.1 million, from $\frac{1}{2}$ to 11 million, and from 0.8 to 4.0 million electron volts.

The ionization chamber and Geiger-Mueller tube measured the ionization caused by charged particles, and the number of particles, in the range above $\frac{1}{2}$ million electron volts for electrons and 10 million electron volts for protons. The Geiger tube was saturated, possibly by the solar flare of February 5, and failed on March 3; the companion ionization chamber failed, probably as a consequence, shortly afterwards.

The cosmic-ray telescope is mounted on the shadowed side of the spacecraft and has a 40-degree field of view. It detects protons in three ranges from 0.8 to 190 million electron volts, and alpha particles in three ranges from 2 to far more than 320 million electron volts.

Mariner's helium magnetometer has a sensitivity of 0.5 gammas and a dynamic range of ± 360 gammas along each of three axes. (At Earth's surface, the magnetic field is about 50,000 gammas.) It is mounted high on the spacecraft's low-gain antenna boom to minimize the effect of spacecraft fields, which were calibrated early in the mission.

The cosmic-dust detector consists of an aluminum plate perpendicular to the spacecraft velocity vector. Two surface penetration detectors (on either face) and a microphone attached to the plate indicate the momentum of each hit (greater than 0.00006 dyne-sec), the direction, and the number of hits.

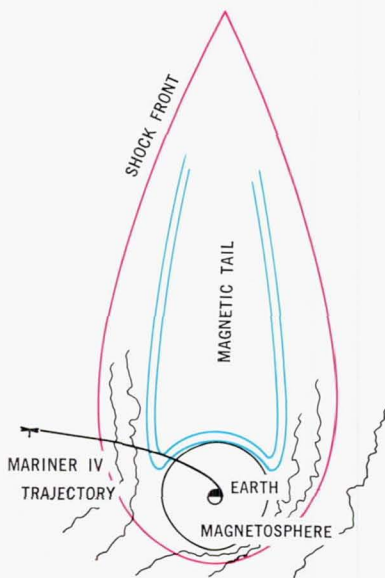
Near Earth

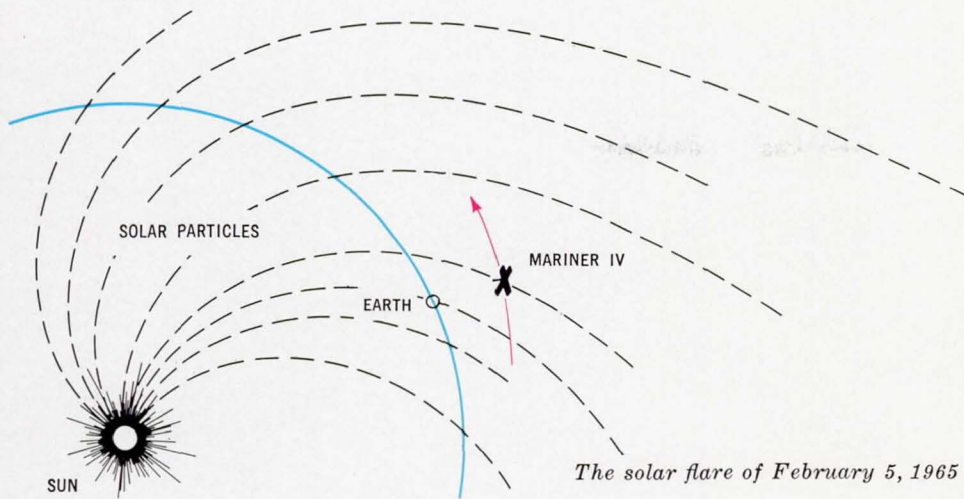
During the first 2 days of the mission, Mariner IV passed through the region of space influenced by the Earth: the Van Allen belts, the attenuating magnetic field which holds them together, and the interface between solar plasma and geomagnetic field which is their source. The layers of the candle-flame-shaped interaction between Earth and Sun were pierced and measured in turn, leaving their traces in the data of the magnetometer, plasma probe, trapped-radiation detector, and ionization chamber, and cosmic-ray telescope.

Two months later Mariner again passed through what was expected to be a zone influenced by Earth, when at a range of about $12\frac{1}{2}$ million miles it came close to opposition—directly behind the Earth as seen from the Sun. Any magnetic-plasma disturbance here, corresponding to Earth's "wake" in the interplanetary sea, was too faint to detect.

Between Planets

From Earth to Mars, Mariner IV indicated the impact of about 200 micrometeorites, compared with two impacts noted between Earth and





Venus in 1962. The pattern was generally one of irregular increase going toward Mars, with a falling off as the orbit of Mars was approached, suggesting that each planet sweeps a relatively dust-free path for itself as it travels around the Sun, and that—over the region from Venus to Mars at least—the particles become fewer as one nears the Sun. No well-defined dust streams were identified, though encounter with a few cometary-orbit streams associated with shooting-star events had been predicted.

Mariner made its journey during the period of the “quiet sun”: the minimum-activity portion of the 11-year solar cycle. Nevertheless, en route to Mars, it detected the effects of solar flares in February, April, May, and June. These were evidenced as magnetic disturbances (caused by the passage of charged particles), as increases in the flow of the particles themselves at various energy ranges, and even as indications from the cosmic-ray telescope, which points away from the Sun but apparently detected solar particles scattered or reflected by disturbances in the interplanetary magnetic field. A number of these flares were observed optically in the Sun’s atmosphere from Earth.

Experiment Data

Description	Experimenters
TV subsystem: up to 21 pictures of Martian surface	R. B. Leighton*, B. C. Murray, and R. P. Sharp, all of CIT, and R. K. Sloan and R. D. Allen of JPL
Helium magnetometer: planetary and interplanetary magnetic fields	E. J. Smith* of JPL, P. J. Coleman Jr. of UCLA, L. Davis Jr. of CIT, and D. E. Jones of Brigham Young University and JPL
Solar-plasma probe: quantity rate and energy of positive ion “wind”	H. L. Bridge* and A. Lazarus of MIT, and C. W. Snyder of JPL
Ionization-chamber/particle-flux detector: corpuscular-radiation “dose rate”	H. V. Neher* of CIT, and H. R. Anderson of JPL
Trapped-radiation detector: low-energy solar charged particles and planetary “radiation belts”	J. A. Van Allen*, L. A. Frank, and S. M. Krimijis, all of State University of Iowa
Cosmic-ray telescope: high-energy charged particles	J. A. Simpson* and J. O’Gallagher of University of Chicago
Cosmic-dust detector: micrometeorite count and momentum	W. M. Alexander*, O. E. Berg, C. W. McCracken, and L. Secretan, all of NASA/GSFC, and J. L. Bohn and O. P. Fuchs of Temple University
Occultation (no instrument): Martian atmosphere as deduced from its effect on spacecraft’s signal during occultation by the planet	A. J. Kliore*, D. L. Cain, and G. S. Levy, all of JPL, V. R. Eshelman and G. Fjeldbo of Stanford University, and F. Drake of Cornell University

*principal investigator



Project scientists and experimenters



ONE DAY WITH ANOTHER PLANET

Mariner IV approached its rendezvous with Mars in good condition to carry out its mission. All critical elements were working well; most spacecraft measurements were close to ideal. The plasma probe was still functioning, though in a limited sense, and the ionization chamber was out of service. Chances for recovery seemed remote. But the spacecraft attitude was stable, the temperatures were within expected margins, and the radio signal was coming in steadily to the Earth at about 0.000000000000000001 watt: a bit faint for conventional receivers*, but well above the threshold for the fantastically sensitive Deep Space Instrumentation Facility stations at Johannesburg, Madrid, Canberra, Woomera, and Goldstone. Periodically during the flight, the ground transmitters were turned on for command transmission or two-way tracking; now, as encounter approached, they were in two-way operation.

The spacecraft's planetary science platform, containing the TV camera and planet sensors and capable of scanning through a wide angle to point the camera at Mars, had been partly exercised by ground command earlier in the flight, and the lens cover had been removed. But the tape recorder and other elements had not been operated since before launch.

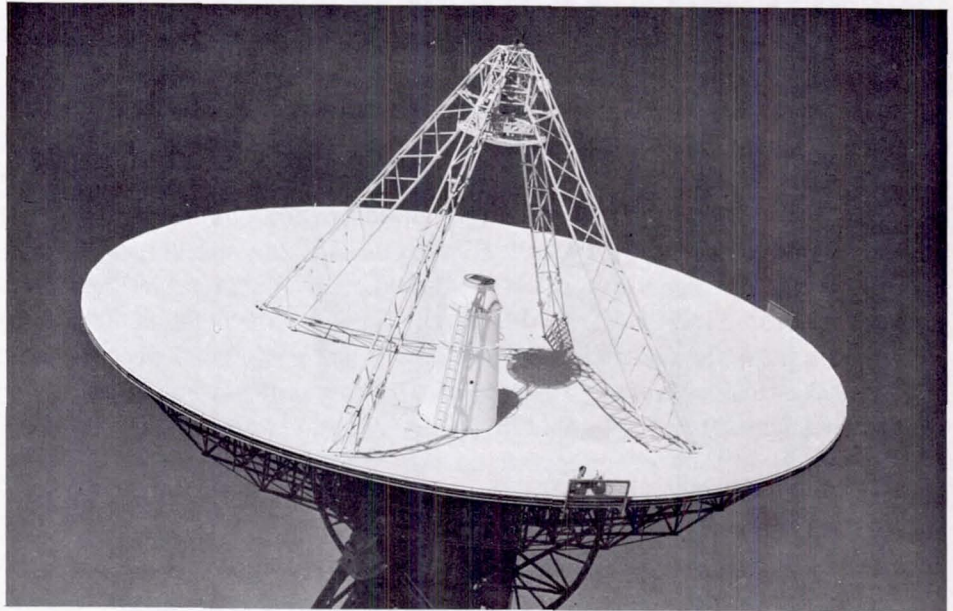
Landfall

Mariner-Mars encounter began properly with an event on Earth, not one in space. The Johannesburg DSIF station transmitted a command to turn on the TV scan platform, anticipating by about an hour a similar on-board command from the CC&S. This was the first of eleven ground commands transmitted to the spacecraft during encounter operations.

Unlike the Ranger Project, which kept constant two-way contact with the spacecraft, Mariner communications were mostly spacecraft-to-Earth, with the ground transmitters brought into use only periodically: for testing, for precise doppler tracking—when a stable oscillator's frequency is sent to the spacecraft, multiplied by a known factor (240/221), and sent back for comparison with the original signal so accurately that a change in velocity of 1 millimeter per second can be observed—and for command transmission. The commands are coded digitally, like the telemetry: each command is a string of 26 1-second-long bits, each bit recognizable as either a one or a zero, and each command corresponding to a particular switch closure leading to an action on board. At Mars' distance, it took 12 minutes for the command to travel to the spacecraft, and 12 minutes more for the resulting action or acknowledgement to be observed back on Earth.

Acting on the first encounter command, the camera platform began cycling back and forth through a 180-degree arc, making a complete

*An average home TV set signal is about 0.0000001 watt.

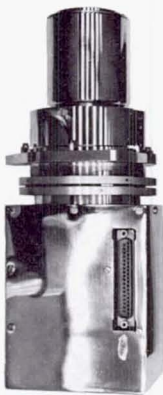


New S-band tracking station near Madrid, Spain, monitored the encounter with Mars.

circuit every 12 minutes. The TV camera began exposing pictures every 48 seconds, alternating between red and green filters, but no picture information was recorded at this stage: Mars was not yet in view.

Two hours and 42 minutes after turning on the platform, the operators commanded it to stop, positioning it only $\frac{3}{4}$ degree from the optimum angle for photographing Mars. Backing up this command, a wide-angle sensor would have stopped the cycling on sighting the planet. Now a narrow-angle sensor would activate the tape recorder and begin recording pictures of Mars as soon as it was actually in front of the lens.

A third command was sent 5 hours after the platform had been positioned, switching off spacecraft-bus telemetry so that the entire transmission was given over to the scientific experiments, their status, and their findings. Of particular interest at this critical time was the condition and behavior of the TV subsystem.



Shutterbug

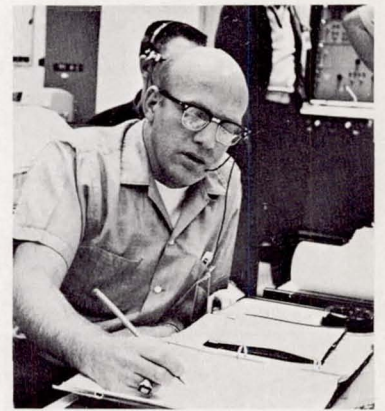
Mariner's searching eye is built around the vidicon, a TV image tube whose compact dimensions and modest power requirements recommend it for spacecraft use. (The Ranger spacecraft also employed vidicons.) The science control subsystem shutters the camera optics every 48 seconds, placing red and green filters alternately before the lens. A telescope of 12-inch focal length and 1-degree field of view brings the image to the TV tube, on whose faceplate it is about 0.22 inch square. Scanning the image in 200 lines (of 200 dots or picture elements each), the TV camera produces a digital signal of 240,000 bits per picture, which is recorded on a two-track

1/4-inch magnetic tape loop 300 feet long, capable of recording a little more than 21 pictures. The tape runs over the recording head at about 13 inches per second and stops between pictures to save tape. Only two out of every three pictures taken are recorded on the tape, resulting in a chain of pairs of overlapping alternate-color pictures extending all the way across the disk of Mars.

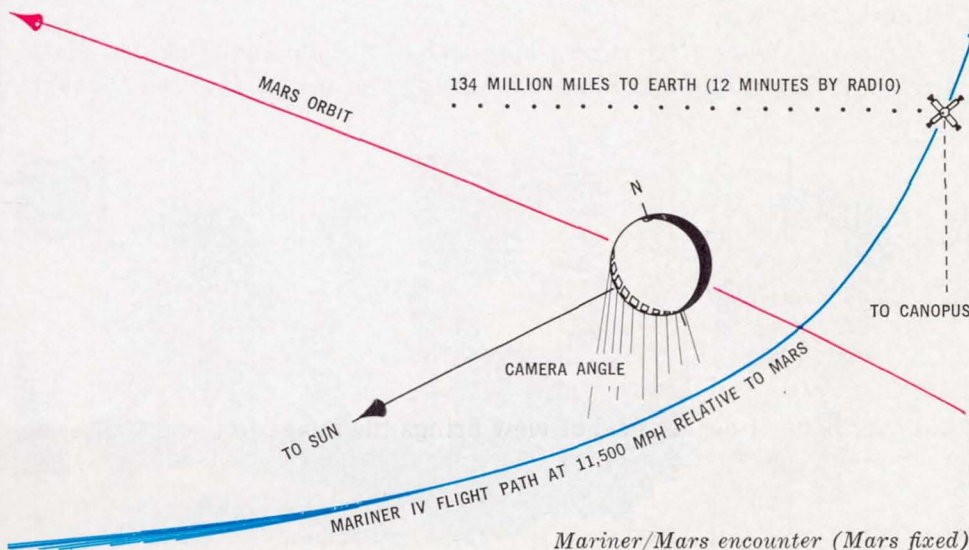
The picture recording sequence was started automatically at 0018 15 July Greenwich Mean Time (the standard 24-hour system used in space operations); 12 minutes later, at 5:30 p.m., July 14, California time, the Goldstone DSIF station received notice of this event from the spacecraft. While the 26-minute sequence was still underway, two signals were received indicating that the end of the recording tape had been reached, prematurely and perhaps disastrously. Other telemetry received argued the contrary. Mariner's captain and crew, back on Earth, could only wait it out.

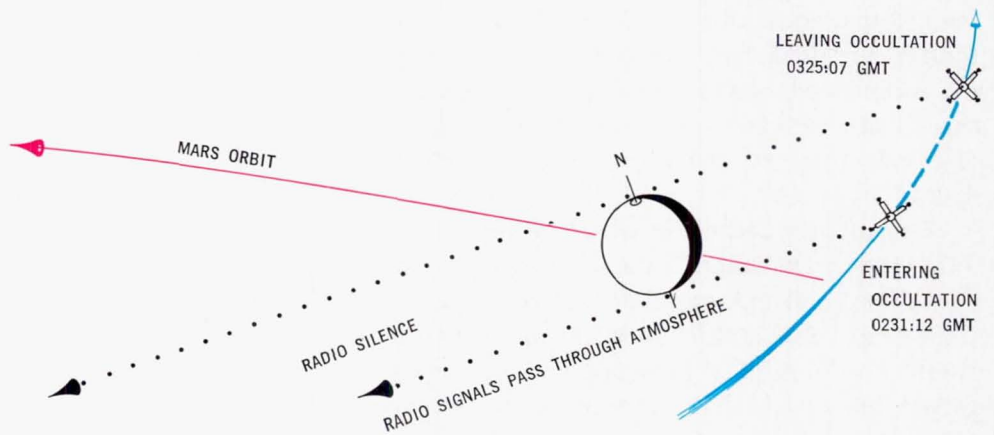
Two backup commands had been sent to shut off the picture-recording operations and return the spacecraft to the cruise mode of mixed engineering and science data; the second command was repeated six times, to ensure the turn-on of the cruise science, which was dependent upon ground command. The television subsystem, having recorded part of picture No. 22 and filled its magnetic tape, shut itself off and ordered the telemetry system into cruise mode, and the cruise science came on as soon as commanded.

The spacecraft had been approaching the Martian surface throughout the picture-taking sequence: the range had been 10,500 miles (along the camera axis) for the first picture, and had shrunk to 7,400 miles when picture No. 17 was exposed. A quarter of an hour later, Mariner IV came within 6,118 miles of Mars, which was going around the Sun more than 11,000 miles per hour faster than Mariner.



Space Flight Operations Director





Occultation geometry (Mars fixed)

Behind Mars

The mission had been designed to occult the spacecraft behind the planet, so that the Martian atmosphere could be observed from its effect on Mariner's radio signal. The occultation of stars behind planets had previously played a part in various planetary investigations, and observations of the occultation of the satellites of Jupiter by the planet from opposite sides of Earth's orbit led to the first accurate estimate of the speed of light (the apparent delay across 186 million miles being about 1,000 seconds, a value of 186,000 miles per second was calculated).

Going one stage further, Mariner provided a "coherent source" of precisely calibrated frequency, backed up by detailed predictions and extremely accurate equipment. The position and motion of the tracking stations, the actual spacecraft flight path, the transmission of the signal across 150 million miles, and the effects of Earth's atmosphere all had to be and were precisely known. It would be the apparent changes in spacecraft motion, caused by the refraction of the signal, which would reveal the properties of Mars' atmosphere.

About $1\frac{1}{4}$ hours after closest approach, the radio signal grazed Mars' ionosphere. Then, like a fishing line cutting the water, it sliced through.



For 2 minutes, the 2300-megacycle signal was bent and slowed by the atmosphere, and then it vanished. For the first time in 7½ months no Mariner signal was beaming to Earth. Almost an hour later Mariner's signal reappeared on the other side of Mars, and tracking began again.

Mariner's flight path was bent slightly by Mars' gravity during the spacecraft's close brush with the planet. The tilt of its orbit relative to the Earth's was changed from 8 minutes to 2½ degrees, the period of the orbit was extended from 529 to 587 days, and the orbit was widened considerably.

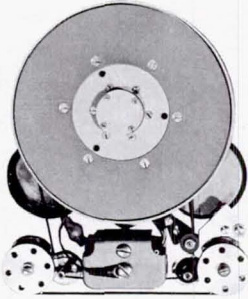
Home Run

Mariner continued sampling the space environment just outside the orbit of Mars for 8½ hours; then the spacecraft's CC&S turned off the cruise science and began the playback mode, in which engineering telemetry would alternate with playback of the TV picture data at 1/100 inch per second by the tape recorder—if picture data had been recorded. Doubt still clouded the air in the control rooms on Earth as the first segment of engineering telemetry began to appear: had the end-of-tape signal received during the picture-taking phase been an erroneous signal or a true indication of erroneous spacecraft behavior?

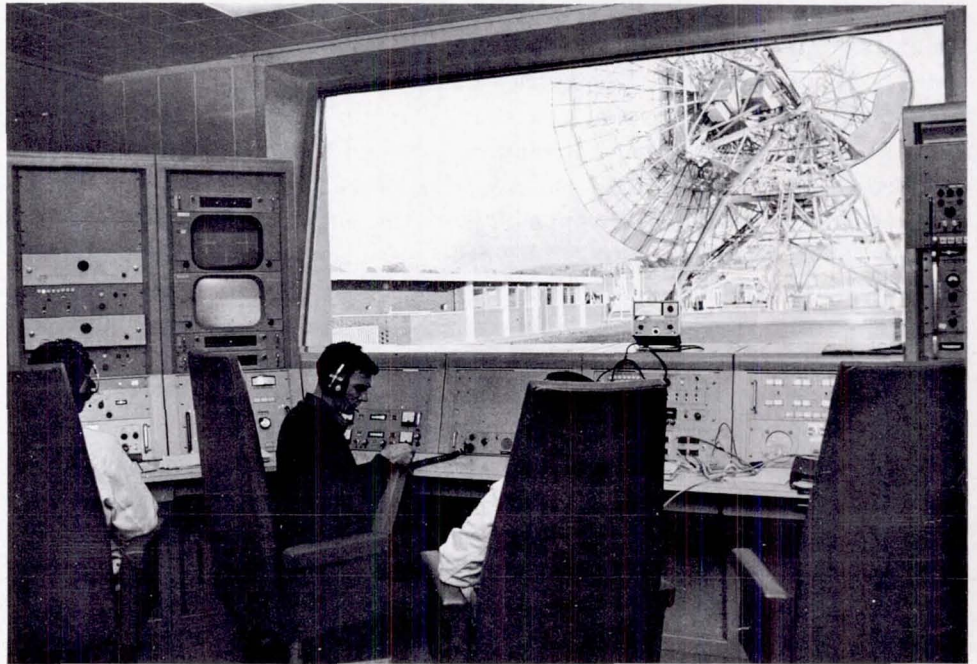
A long hour and 8 minutes later what should have been the first elements of picture No. 1 began to appear in the telemetry. At 2½ minutes per line of the picture, it was several minutes before enough lines had been received so that the edge of the Martian disk could be recognized.

The Mariner crew of technicians, engineers, scientists, and managers had waited and worked more than 2½ years since the start of the project, 7½ months since the start of the mission and, on this sleepless day of encounter, 23 hours for this picture of Mars. But they were not too tired to cheer.



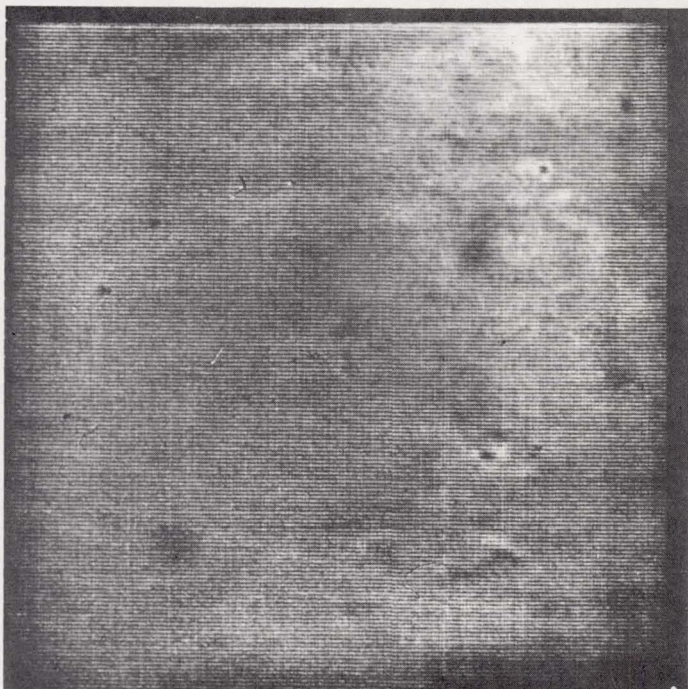
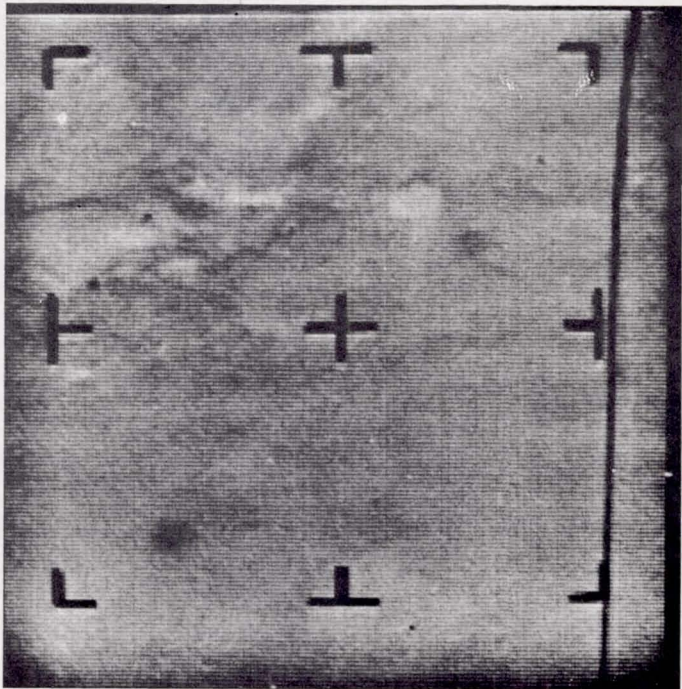
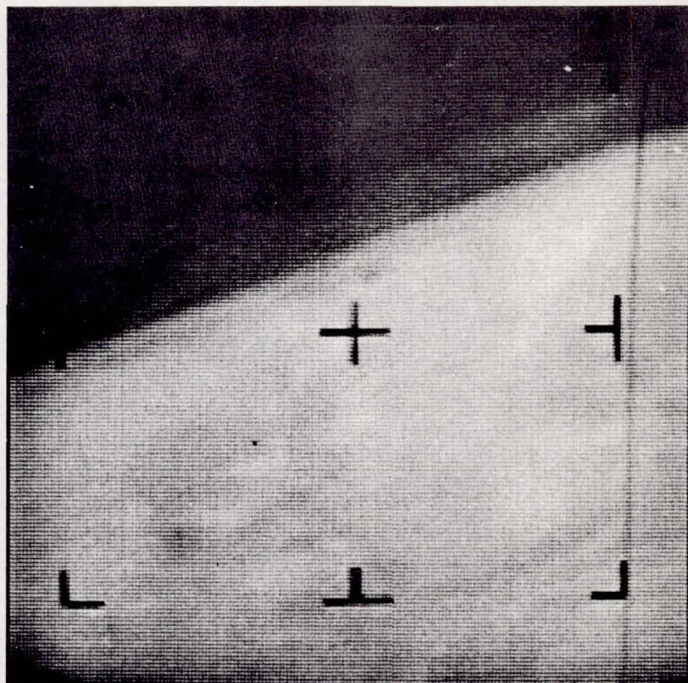
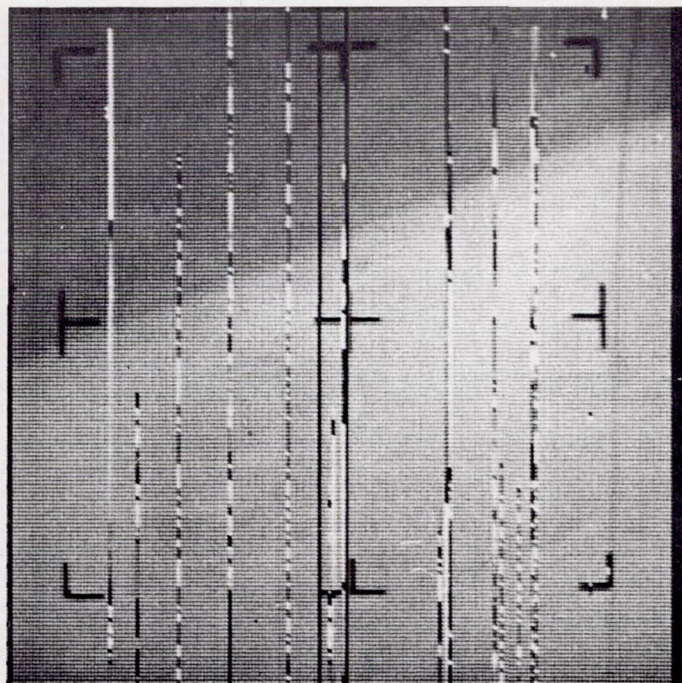


The tape recorder continued to read out the brightness of each element of the first picture until it was complete. In the interval between pictures, corresponding to stopping the tape and starting it again, almost 2 hours of engineering measurements were transmitted. This process, the slow and painstaking buildup of each picture followed by 2 hours of spacecraft diagnostic telemetry, continued through the fragmentary twenty-second picture and through a second run of the whole tape, while the spacecraft drew on past Mars and away from Earth, and beneath it the Earth turned, bringing one after another each of the great receiving antennas to bear on the spacecraft, until all of the data had come home to Earth.

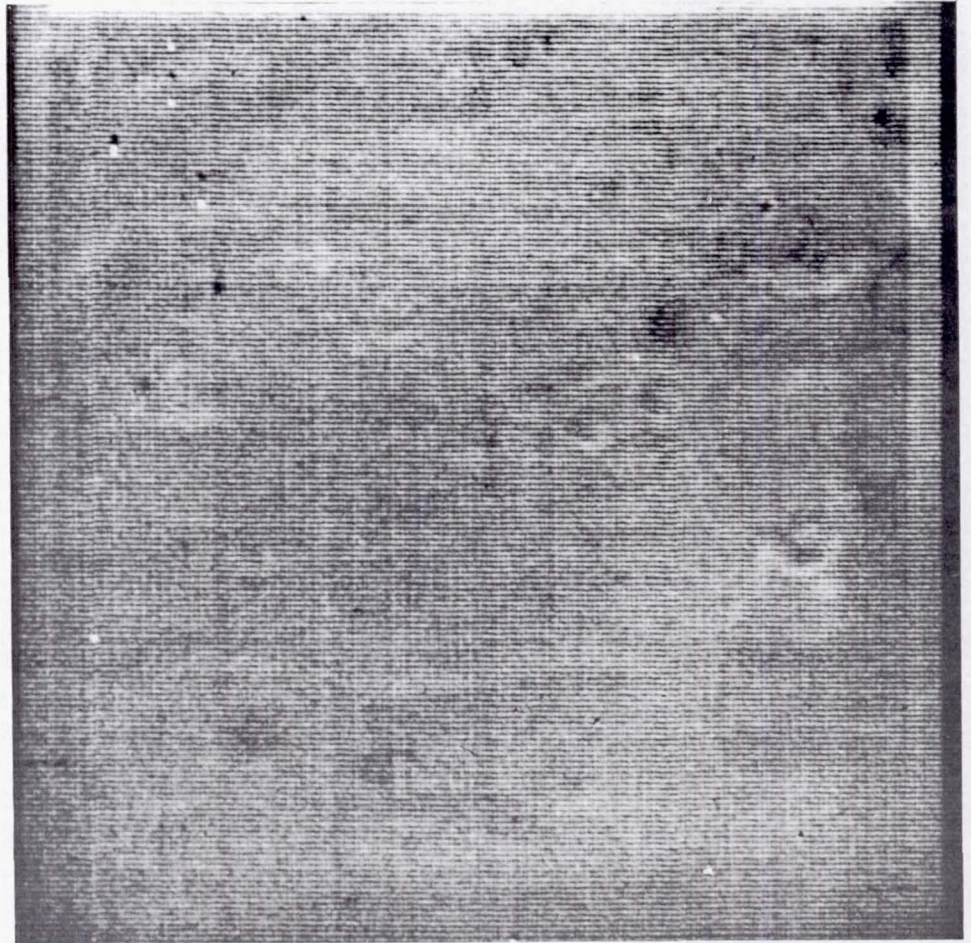


NEW VIEW OF AN OLD WORLD

Twenty-one pictures don't go very far in covering a whole planet; nor do two passes through the atmosphere with a single radio beam, or a few hours of magnetic and charged-particle data. But by comparison with the tenuous and indirect sources of information previously available for the study of Mars, in the context of the various theoretical models of Martian conditions, and given the elegant modern techniques of data-handling, correlation, and calculation, Mariner's view of Mars is a broad and profound one indeed.



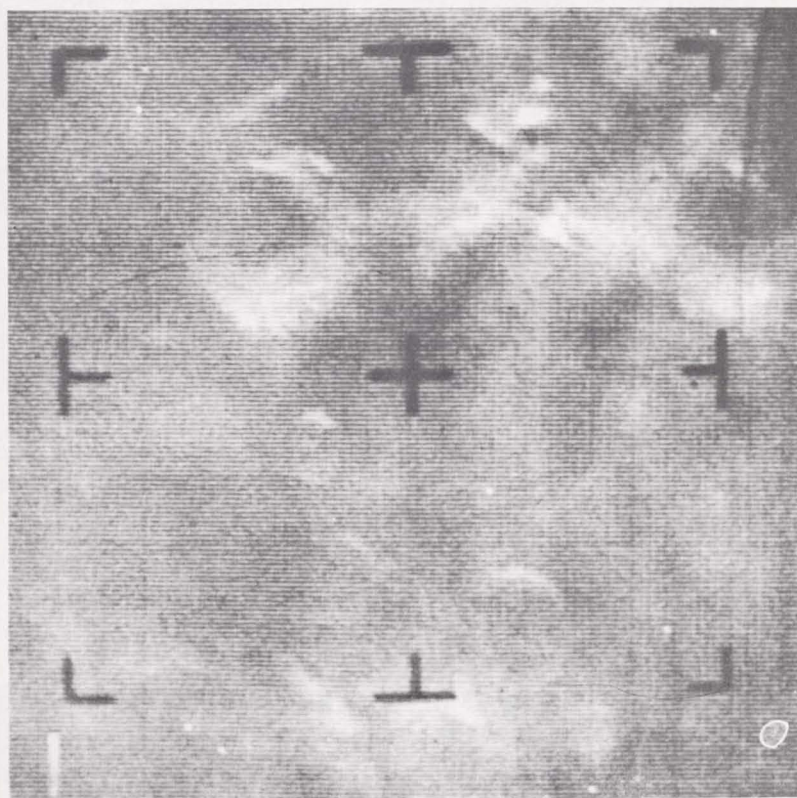
Three early pictures of the Martian surface. Picture No. 1 (top) shows the light region Phlegra on the limb of the planet. The spacecraft was approximately 10,500 miles from the area in the center; a red filter was used. "Raw" picture is at left, computer-processed version at right. Below, pictures 3 (left) and 4 (right) show the light region southeast of Phlegra and Trivium Charontis. The Sun is 14 deg from the zenith; slant range is 9500-9300 miles. Green filter was used on No. 3, whose contrast enhancement factor is 5; No. 4 is through a red filter, and its contrast is tripled. No. 3's lower right corner overlaps No. 4's upper left; north is approximately at top.



Craters

The most arresting single phenomenon of the entire mission is the discovery of dense-packed lunar-style impact craters on the Martian surface. Though the television experiment's principal investigator had casually mentioned the possibility of Mars craters in a press briefing before the encounter, and the scientific literature reveals at least one prediction of a Moon-like surface on Mars, the actual presence of craters as they appeared in the developing pictures amazed the watching group of scientists.

More than 70 craters appear in the Mariner IV pictures, which cover less than 1 per cent of the surface: if these areas are representative of Mars, there might be 10,000 craters within the 75- to 3-mile size range shown in the photographs. Slopes measured so far range only up to 10 degrees; no features sharp enough to cast shadows were observed. Crater rims rise perhaps hundreds of feet above the surrounding terrain, and their interiors are depressed in the thousands of feet. One large elevation change, possibly that of a giant crater only partially seen, was estimated at 13,000 feet.

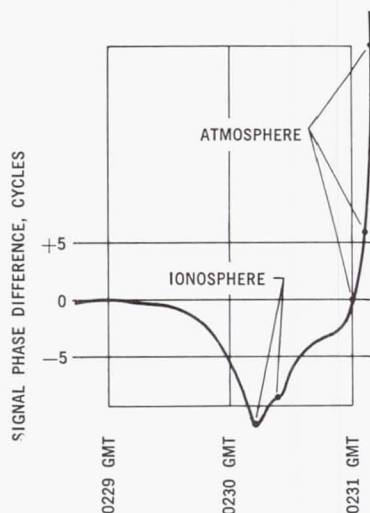


Three photographs of Martian craters. Picture No. 5 (top, p. 40), taken through a red filter at a range of 8400 miles, definitely put Martian craters on the map. Ghostly craters along the northern border of Phaethontis, pictured on this page, may have been rimmed with frost. Picture 13 (top) was taken through a red filter, No. 14 through green; slant range is 7600 miles, area of each picture about 175 by 140 miles (west by north). Lower right corner of 13 overlaps upper left corner of 14; Sun was 30-35 degrees above northern horizon. North is at top in all three pictures, and contrast is approximately doubled.

A number of craters near the evening terminator—and hence in the cool of the afternoon—appear frosted. The nature of this frost is unknown, but the conditions would be consistent with its being water.

No clear evidence of the famous Martian canals was apparent in the Mariner pictures. We must remember that the glistening lunar crater rays were resolved on magnification by Ranger cameras into chains and clusters of small secondary-debris craters. Possibly some equally unsuspected explanation may link the Earth-based and spacecraft views of the Martian surface.

The unearthly appearance of Mars as seen from the spacecraft had a major impact on our idea of Mars. This Martian topography is very old and, apparently, very little changed. Impact craters of Martian and lunar proportions very likely existed on Earth at one time, but the processes of growth and weathering, of mountain-building and canyon-carving, have long since ground all but a very few away to nothing. Mars is more like the Moon in its apparent lack of such smoothing.

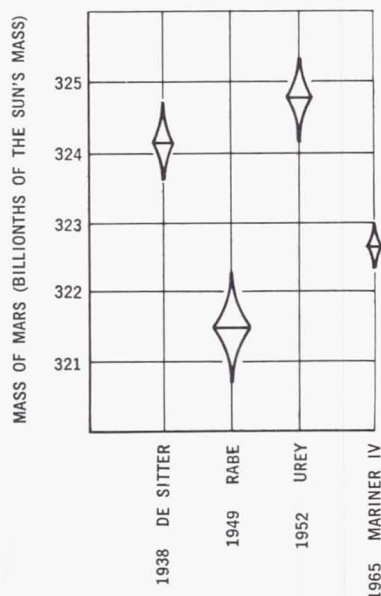


The Thinnest Air

Mars' ionosphere and atmosphere, as measured by the impinging radio beam from the departing Mariner spacecraft, are somewhat less dense than had been expected. The maximum electron density encountered by the beam was 90,000 electrons per cubic centimeter, at an altitude of about 80 miles. From this the density at the subsolar point was calculated to be 150,000. Indications of a second ionized layer below the denser one were observed. The atmospheric pressure at the surface was estimated at 4 to 7 millibars (0.4 to 0.7% of Earth's surface pressure), depending on the argon/nitrogen/carbon dioxide proportions assumed for the composition.

According to the principal investigator for this experiment, comparison of various atmospheric properties suggests that carbon dioxide is the majority constituent, and that the proportion of nitrogen is very small. This would provide the best agreement with the telescopic Mars atmosphere studies which were based on carbon dioxide spectral lines. Moreover, a thin blanket of air correlates very well with the cratered appearance of the surface, for a dense atmosphere might have shielded the planet from most of the meteoritic impacts, believed to be responsible for the craters.

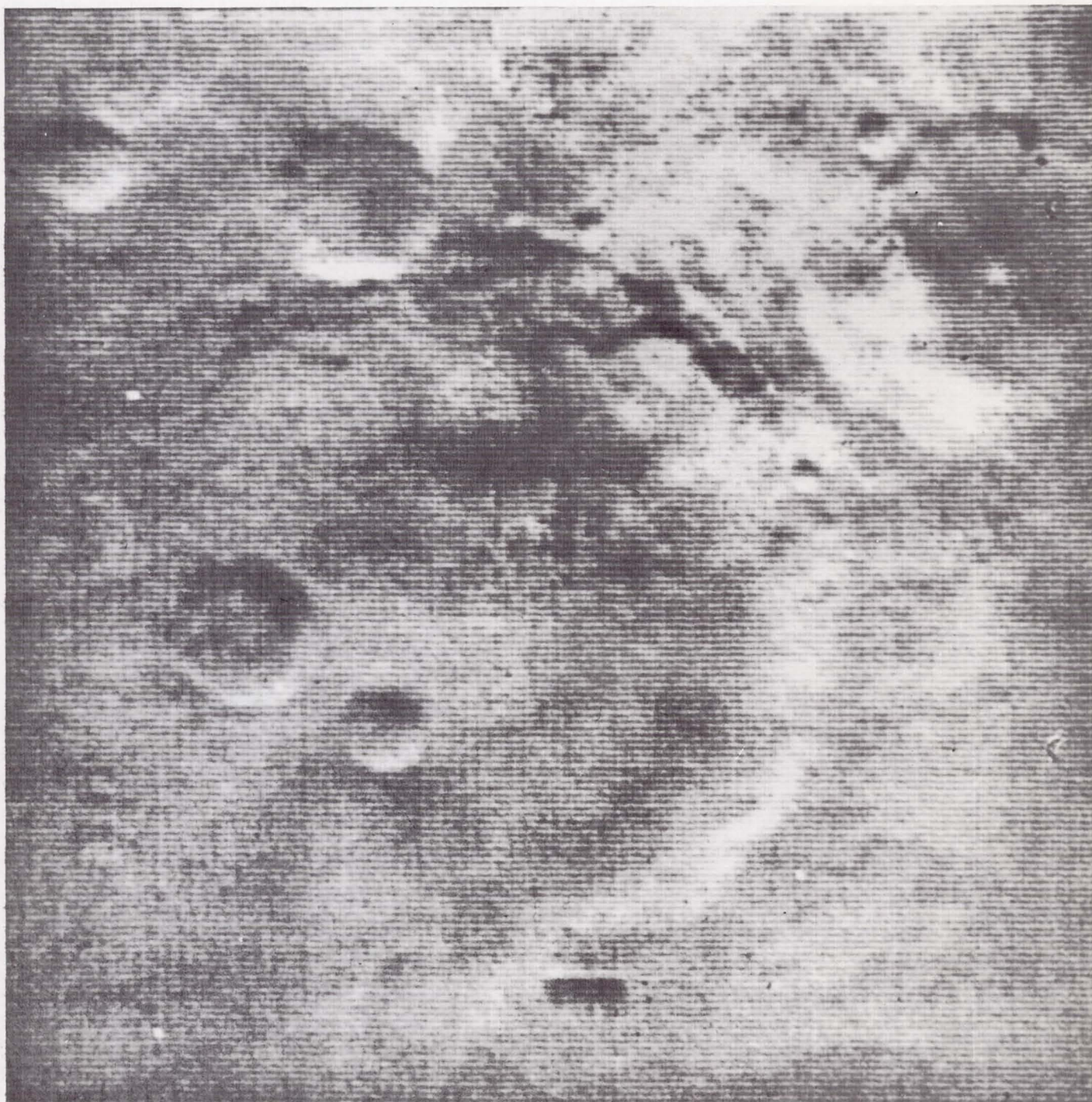
Mars occulted the spacecraft with its sunlit side, between Electris and Mare Chronium. The signal emerged above Mare Acidalum, on the night side; the ionosphere was so tenuous as to be undetectable.



Martian Fields

Mariner's interplanetary instruments searched in vain for evidence of Earth-like radiation belts or magnetic fields. The radiation levels to which the scientists had become accustomed in the interplanetary phase of the mission continued virtually unchanged through the encounter with Mars.

From the perturbation of Mariner's orbit at encounter, the trajectory analysts derived the mass of the planet Mars as being 0.03227% of the



Mariner's eleventh picture of Mars, "one of the most remarkable scientific photographs of this age" in the words of the experimenters, shows a 75-mile-diameter crater, with a 3-mile crater in its eastern rim. Contrast is quadrupled; filter used was green. Sun was 47 degrees from zenith, range was 7800 miles, area 170 by 150 miles (west by north) in Atlantis, light region between dark areas, Mare Cimmerium to west and Mare Sirenum to east.

Sun's mass (that is, Mars contains about 1,428,000,000,000,000,000,000 pounds of mass).

The magnetometer experimenters estimated that Mars' magnetic moment is no greater than 0.03% of Earth's. This would account for the absence of radiation belts and magnetic shock layers around Mars, though they have been observed above Earth. The more interesting problem lies in accounting for the absence of Mars' magnetic field or conversely, the presence and strength of Earth's.

The initial exploration of space in the past several years, of the Moon in 1959-65, of Venus in 1962, and now of Mars, has increasingly turned our attention inwards toward our own planet. Reporting the results of the Mariner Mars Project to President Johnson, the experimenters spoke of "the uniqueness of Earth" in our solar system. Yet the buried secrets of Earth's origin and early evolution may lie exposed upon these distant worlds, waiting to be picked up.

Mariner IV has opened Mars as we might open a book at random, to glance at one page. We have the whole book—and the rest of the library—yet to read.



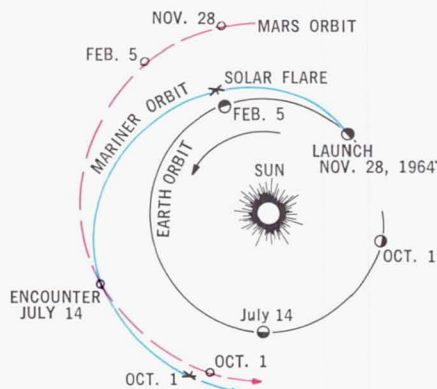
Presenting Mariner IV results to President Lyndon B. Johnson

The Log of Mariner IV

November 28, 1964		March 10-25	Johannesburg station assigned to Ranger IX test and operations; 6½-hour daily telemetry blackout
1422:01.39 GMT	Liftoff		
1507:10	Spacecraft/Agena separation	March 17	Ionization-chamber instrument failure (Geiger-Mueller tube failed March 3)
1515:00	Solar panels deployed	April 16	Solar-flare indications
1530:57	Sun lock completed	May 26	Solar-flare indications
November 29		June 5 and 15	Solar-flare indications
0659:03	Canopus search started	July 14	
November 30		1427:55	Mars encounter science command transmitted from Earth
1102:47	Canopus lock completed	1440:32	Command received: encounter science on
December 4		1710:18	Camera-pointing command transmitted from Earth
1305:00	Midcourse maneuver attempted by ground command;	1722:55	Command received: camera pointed
to 2402:44	Canopus lock lost. Maneuver cancelled from Earth, Canopus reacquired after seven commanded "star-hops"		
December 5		July 15	
1305:00	Successful midcourse maneuver (6 ground commands)	0017:21	TV picture recording sequence started at spacecraft
to 1658:19		0043:45	TV picture recording sequence complete
December 6	Component failure in plasma probe: scientific data partly unintelligible	0100:57	Closest approach to Mars (6118 miles above surface)
December 7-9	Canopus lock lost, Gamma-Vela acquired repeatedly	0219:11	Spacecraft passes behind Mars at 55°S, 177°E, 15,850 miles
December 13	Transmitting amplifiers switched (to Traveling Wave Tube)	0231:12	Spacecraft signal loss on Earth
December 17	Star lock lost, reacquired; star-hop commanded from Earth, Canopus reacquired. Star sensor desensitized to excess brightness by ground command	0313:04	Spacecraft emerges from occultation at 60°N, 34°W, 24,260 miles
January 3, 1965	Telemetry rate switched by on-board command from 33⅓ to 8⅓ bits per second; plasma-probe data improved at new rate	0325:06	Spacecraft signal reacquired at Earth
January 10-13	Johannesburg station assigned to Ranger VIII test: 6½-hour daily telemetry blackout	1141:50	Picture playback mode initiated
February 5	Solar flare detected by science instruments	1301:58	First data from Picture 1 observed on Earth
February 7-22	Johannesburg station assigned to Ranger VIII test and operations; 6½-hour daily telemetry blackout	2138:07	Picture 1 data complete on Earth
February 11	TV lens cover removed, planetary equipment checked and prepared (12 ground commands)	2332:27	Start of Picture 2 reception on Earth
March 3	Plasma-probe failure mechanism analyzed, permitting 70% data recovery	July 24	Picture playback complete; second run started
March 5	Spacecraft transmission switched from omni to high-gain antenna by on-board command	August 2	Second picture playback complete; spacecraft returned to cruise mode by ground command
		August 26	Conditioning commands transmitted to spacecraft (to prevent accidental midcourse sequence) for post-encounter cruise
		August 30-September 2	TV test: five pictures of black sky obtained and transmitted to Earth
		October 1	Spacecraft transmission switched from high-gain to omni antenna by ground command; telemetry no longer detectable on Earth

Mariner's Course

Mariner position and velocity log

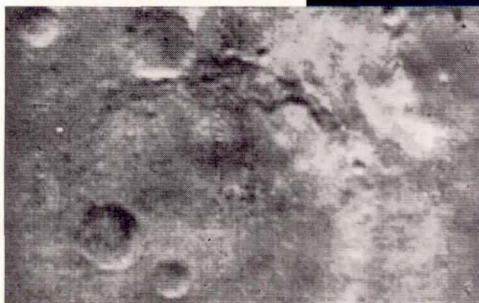


Date	Distance traveled along trajectory, mi	Straight line distance, mi			Velocity, mi/hr	
		From Earth	From Mars	From Sun	Relative to Earth	Relative to Mars
Dec. 1, 1964	525,782	517,870	126,953,200	91,824,713	7,288	61,438
Dec. 11	22,649,177	2,203,995	116,862,720	92,624,158	6,973	57,050
Dec. 21	40,241,575	3,873,488	106,848,830	94,011,320	6,977	52,869
Dec. 31	57,574,471	5,575,079	97,078,054	95,924,270	7,406	48,672
Jan. 10, 1965	74,583,451	7,450,269	87,675,436	98,281,742	8,586	44,548
Jan. 20	91,219,961	9,670,634	78,740,116	100,994,350	10,362	40,573
Jan. 30	107,451,878	12,394,127	70,342,943	103,972,235	12,748	36,801
Feb. 9	123,261,850	15,769,341	62,528,068	107,131,110	15,561	33,269
Feb. 19	138,644,479	19,858,102	55,316,411	110,394,380	18,561	29,996
March 1	153,605,290	24,680,278	48,709,726	113,695,700	21,815	26,987
March 11	168,155,150	30,232,660	42,694,447	116,978,530	25,167	24,243
March 21	182,311,410	36,456,459	37,244,945	120,195,680	28,501	21,759
March 31	196,094,740	43,301,215	32,326,122	123,308,240	31,929	19,528
April 10	209,528,220	50,705,889	27,895,443	126,284,444	35,320	17,544
April 20	222,636,480	58,579,830	23,904,586	129,098,570	38,621	15,804
April 30	235,445,090	66,823,342	20,315,235	131,719,930	41,944	14,308
May 10	247,980,100	75,427,220	17,042,164	134,151,990	45,190	13,043
May 20	260,267,760	84,264,046	14,044,672	136,371,970	48,342	12,010
May 30	272,334,370	93,270,057	11,266,975	138,368,640	51,521	11,202
June 9	284,206,150	102,362,020	8,655,916	140,133,630	54,598	10,608
June 19	295,909,190	111,453,380	6,162,774	141,660,360	57,610	10,206
June 29	307,469,390	120,485,400	3,744,829	142,943,780	60,667	9,971
July 9	319,123,300	129,375,820	1,366,265	143,980,310	63,632	9,872
Encounter						
July 14	325,982,177	134,400,890	6,118	144,469,060	66,732	11,379
July 29	344,383,125	146,806,930	3,551,506	145,483,970	70,822	9,934
Aug. 8	356,021,476	154,772,430	5,948,908	145,921,360	73,921	10,053
Aug. 18	367,628,758	162,416,900	8,377,324	146,167,370	77,018	10,200
Aug. 28	379,223,366	169,701,290	10,839,023	146,221,220	80,161	10,355
Sept. 7	390,823,717	176,561,700	13,330,474	146,082,750	83,197	10,503
Sept. 17	402,448,243	182,962,130	15,842,742	145,752,490	86,243	10,629
Sept. 27	414,115,356	188,870,060	18,361,883	145,231,690	89,318	10,722
Oct. 1	418,798,296	191,082,640	19,367,460	144,970,440	90,511	10,748
Farthest from Earth						
Dec. 30, 1965	527,941,670	215,830,190	37,508,045	131,984,010	114,868	8,866
Closest to Sun						
June 7, 1966	768,384,900	196,945,440	40,167,187	103,080,860	133,815	20,177
Closest to Earth						
Sept. 8, 1967	1,374,126,700	29,167,205	122,889,320	120,339,200	7,476	61,294

Orbital characteristics for planets and Mariner spacecraft

	Earth	Mars	Mariner III	Mariner IV after launch	Mariner IV after maneuver	Mariner IV after encounter
Length of ellipse, miles	195,794,000	283,090,000	214,000,000	231,100,000	239,640,000	248,560,000
Perihelion distance, miles	91,342,000	128,330,000	92,000,000	92,180,000	92,230,000	102,531,000
Aphelion distance, miles	94,452,000	154,760,000	122,000,000	146,920,000	147,410,000	146,029,000
Tilt of ecliptic	0°	1° 51'		0° 8'	0° 7¾'	2° 32½'
Period ("year"), days	365	687	449	528	529	587
Inclination of roll plane (equator) to orbit plane	23½°	24-25°	?	90°	90°	90°
Period of rotation ("day")	23 hr 56 min	24 hr 37 min	?	528 days	529 days	587 days





**NATIONAL
AERONAUTICS
AND
SPACE ADMINISTRATION**

