https://ntrs.nasa.gov/search.jsp?R=19650018349 2018-05-25T16:36:12+00:00Z

JPL TECHNICAL MEMORANDUM NO. 33-229

FACILITY FORM 602

N65-27950 (ACCESSION NUMBER)

(THRU)

38 (PAGES)

1 (CODE)

CR 63762 (NASA CR OR TMX OR AD NUMBER)

31 (CATEGORY)

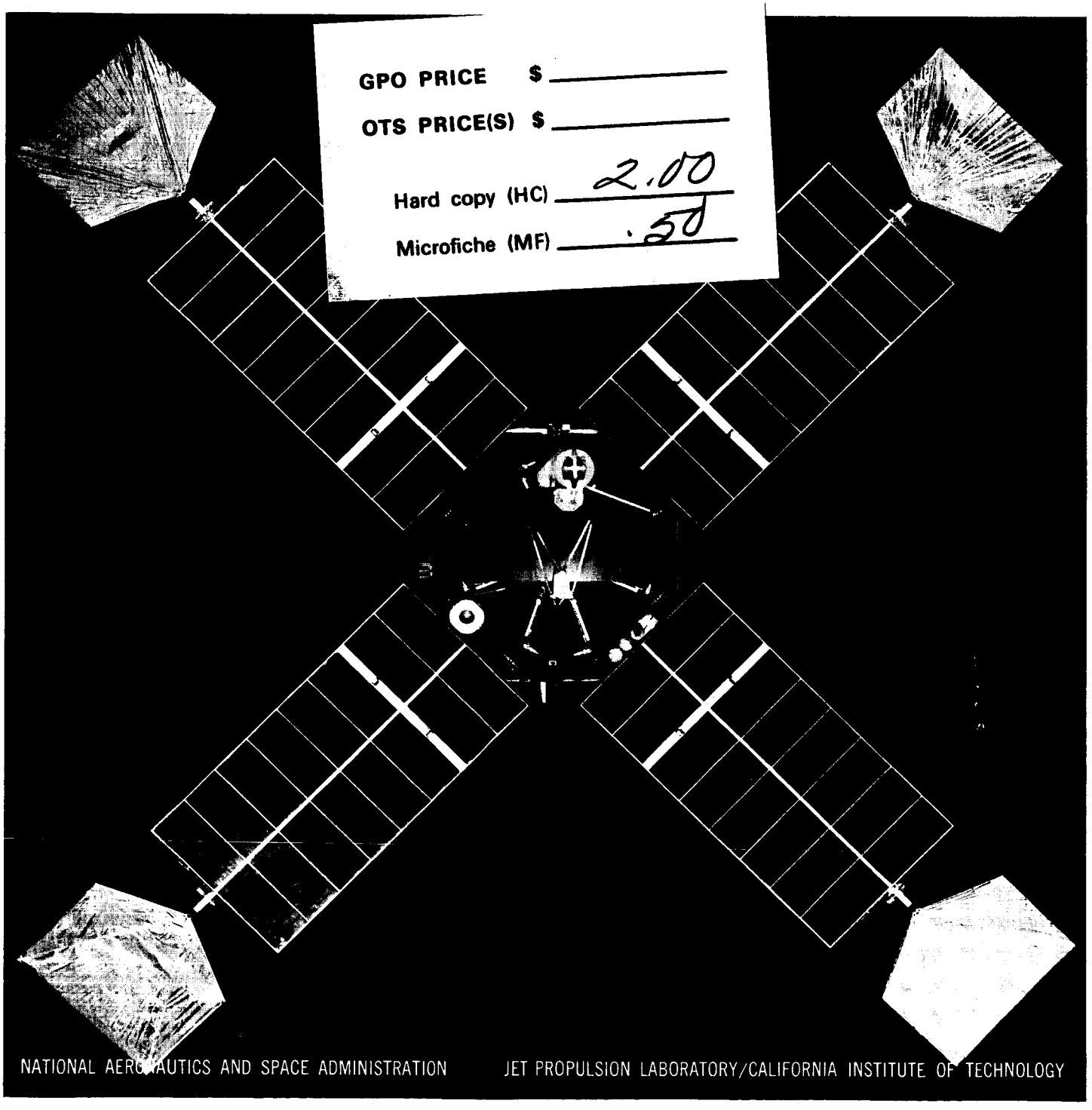
TO MARS: The Odyssey of Mariner IV

GPO PRICE $

OTS PRICE(S) $

Hard copy (HC) 2.00

Microfiche (MF) .50



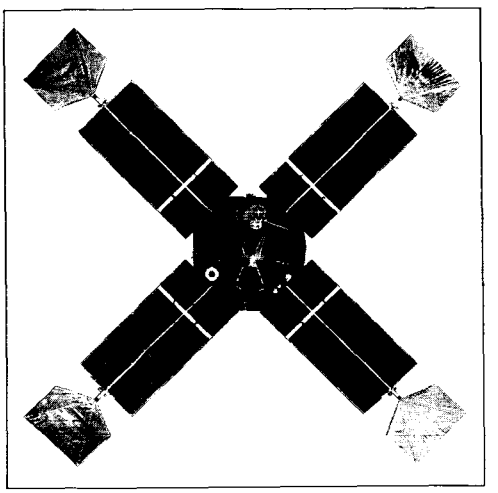
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY

Contents

Landfall at Mars	1
Another World	2
The Spacecraft	7
Mariner Leaves Port	15
In-Flight Events	20
Long-Distance Communication	24
The Scientific Experiments	28
Mars and After	30

The photographs of Mars on pages 2, 4, and 5 are reprinted through the courtesy of Mt. Wilson and Palomar Observatories.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



JPL TECHNICAL MEMORANDUM NO. 33-229

TO MARS:
The Odyssey of Mariner IV

JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY

Copyright © 1965
Jet Propulsion Laboratory
California Institute of Technology

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

PREFACE

The Mariner Mars Project of 1964-65 is one of a family of flight projects conducted by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration's Office of Space Science and Applications. The Project has been made possible by the valued assistance and support of many government agencies and industrial concerns. Included are NASA's Lewis Research Center (Launch Vehicle System Manager) and their prime contractors: Lockheed Missiles and Space Company and General Dynamics/Astronautics; the Goddard Space Flight Center (Launch Operations) and other agencies at Cape Kennedy; the agencies of the Australian and South African governments which operate overseas tracking stations; and many hundreds of industrial contractors and vendors.

NASA authorized the Project in late 1962, with the objective of conducting scientific observations on 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 in carrying out the Mars mission, and to make certain scientific measurements of the interplanetary environment on the way to Mars.

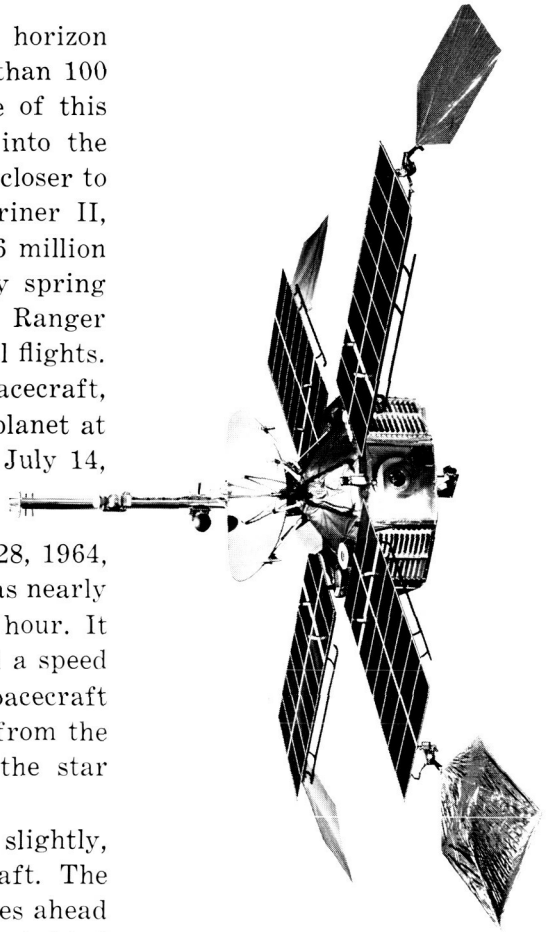
Mariner IV was launched on November 28, 1964.

LANDFALL AT MARS

This summer, mankind's horizon recedes about 150 million miles, to a spacecraft coasting past the planet Mars.

In 1957-58, during the International Geophysical Year, our horizon stretched around the Earth and into space above for little more than 100 miles; each year thereafter, science has extended our knowledge of this near region of space, while at the same time probing further into the unknown. Starting in 1958 with the Pioneer spacecraft we pushed closer to the Moon, a quarter of a million miles away. Late in 1962, Mariner II, man's first emissary to other worlds, scouted the planet Venus, 36 million miles distant from the Earth. By the summer of 1964 and early spring 1965, the Moon's surface was being examined at close range by Ranger spacecraft, and, nearer home, manned vehicles were making orbital flights.

Meanwhile, far beyond the Moon, past the Earth-orbiting spacecraft, Mariner IV was headed for Mars. It was to rendezvous with the planet at 0105 Greenwich Mean Time, July 15, 1965, or about dinner time, July 14, in California.



Mariner IV was launched from Cape Kennedy on November 28, 1964, by an Atlas/Agena D rocket without incident. Two days later, it was nearly half a million miles out, moving at more than 7,000 miles per hour. It appeared to be following Mars at a range of 127 million miles and a speed of over 60,000 miles per hour relative to the planet's motion. The spacecraft was oriented facing the Sun, and was drawing electrical power from the solar panels; it had just 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 changed the rendezvous point at Mars from 150,000 miles ahead of the planet and north of the equator on July 16, 1965, to 5600 miles behind the planet and above the south pole on July 15.

As the range lengthened, Mariner's radio output was stepped up on schedule to maintain contact with Earth. On December 13, a longer-life and slightly more powerful transmitting amplifier was turned on. Then,

early in March, as the range became excessive for the omnidirectional broadcast antenna and Earth entered the beam of the fixed parabolic-reflector antenna, antennas were switched by on-board command.

On the hundredth day, March 8, 1965, Mariner IV was nearly 30 million miles from Earth, and less than 45 million from Mars. A few weeks later, by April 14, it had bested the U.S. long-distance communication record, just under 54 million miles, set by Mariner II's Venus flight.

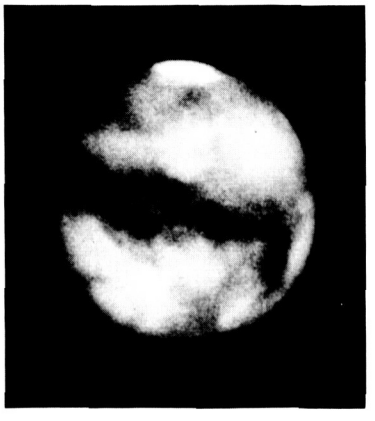
So far in its journey, Mariner has measured the fields and particles around Earth far above the night side and in interplanetary space; it has observed the Class II solar flares of February 5 and April 11 and 17; and it has sampled the sparse but increasing cosmic dust between Earth and Mars.

Now it approaches Mars.

ANOTHER WORLD

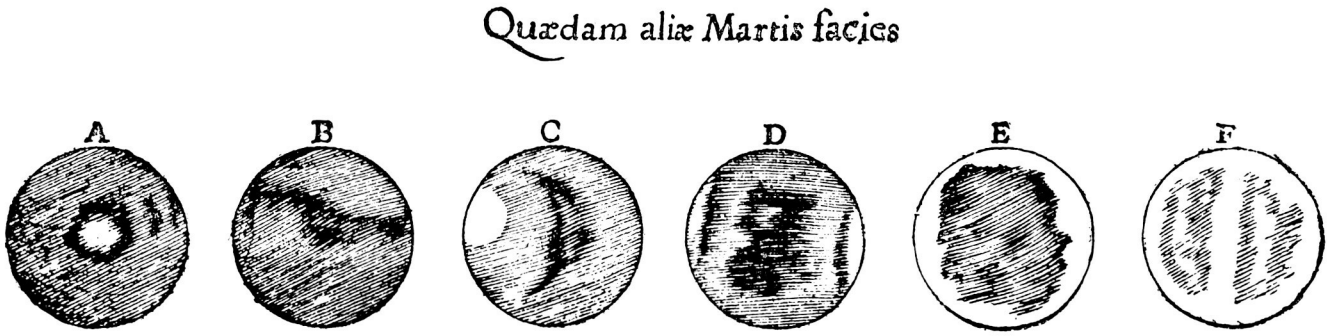
Though Mars has often been populated, irrigated, and civilized in speculation and in fiction, its characteristics are relatively unearthly. It appears to be a small orange-red desert world; ours is a robust green-and-blue world of jungle, grassland, and river, three-quarters ocean.

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 five- to fifteen-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 carbon dioxide rather than water—though probably extremely thin by Earth standards.



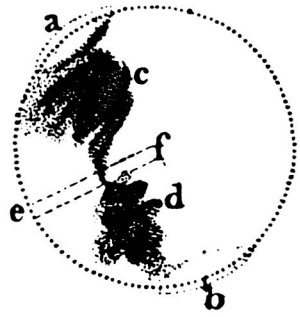
Mars in red light, 1956

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



Mars 1666 (Cassini)

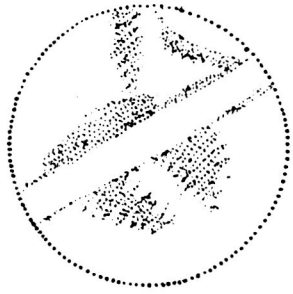
vacationers might tend to regard the four Mars seasons as little more than variations in a bad winter: a hot midsummer afternoon might bring the ground temperature up to 85–100°F, but during the night it would drop to a hundred below, and six feet off the ground the air wouldn't get above freezing all day.



A Dim View of Canals

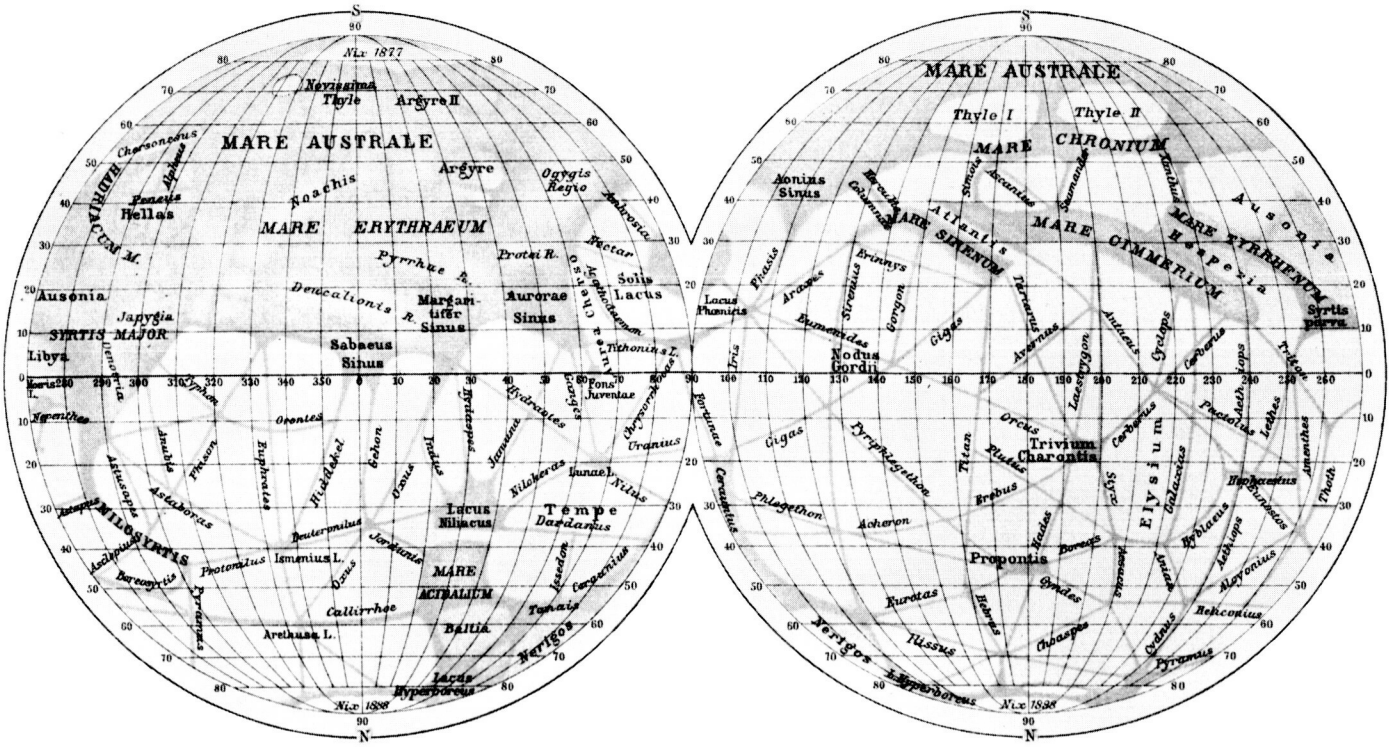
Like the Moon, Mars abounds with what we now know to be waterless seas, bays, and the like. However, by this century, when it was realized that they weren't water, the names had already been established, and the smaller bluish regions remained "mare," "sinus," and "lacus."

Even with the most powerful telescopes and under the most favorable atmospheric conditions, 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.



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.

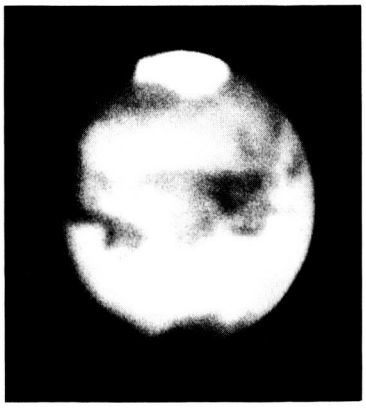
Mars 1777 (Herschel)



Schiaparelli's map (1877-88)

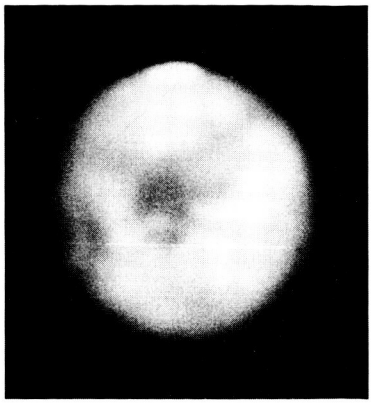
Not everyone saw the "canals" to which Schiaparelli, and then an American, Percival Lowell, referred. Lowell was convinced of the implications of the word "canal"; he founded an observatory, whose contributions to science would include the discovery of Pluto, but whose early activity centered on Martian 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.



Mars, August 1956 (Mt. Wilson, orange light)

Interestingly, there do not seem to be any mountains of Rocky or Himalayan proportions on Mars: gradual slopes, modest east-west chains, or small prominences could not be spotted from Earth, and no shadows—the tell-tale index of the lunar mountains—have been resolved.



Martian atmospheric haze, September 1956 (Mt. Wilson, orange light)

The Thin Air

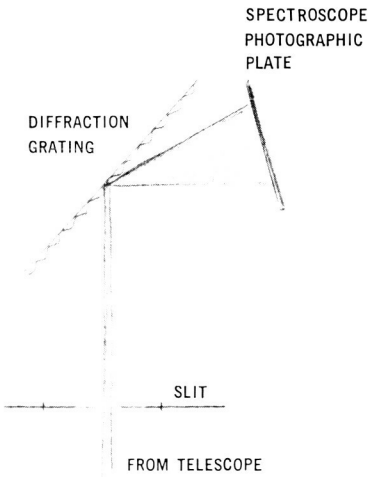
Studies of Mars' atmosphere indicate that it probably consists of nitrogen, argon, some carbon dioxide, a trace of water vapor, and a spectroscopically undetectable amount of oxygen (if any). This statement is based on well-founded speculation for the nitrogen and argon, and extremely skillful spectroscopy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

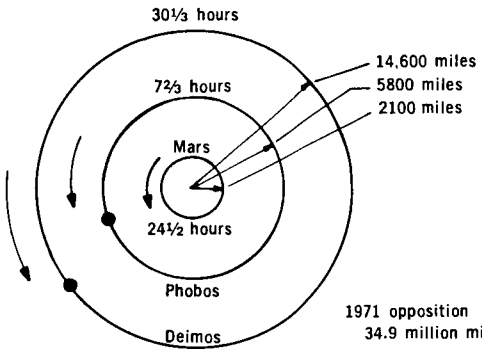
The atmospheric pressure, which corresponds to the weight of the atmosphere per unit area at the surface, is a function (given Mars' gravitational field) of the total amount and kind of gases making it up. It can be measured only by very indirect means from Earth, related to the effects of the atmosphere 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 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,

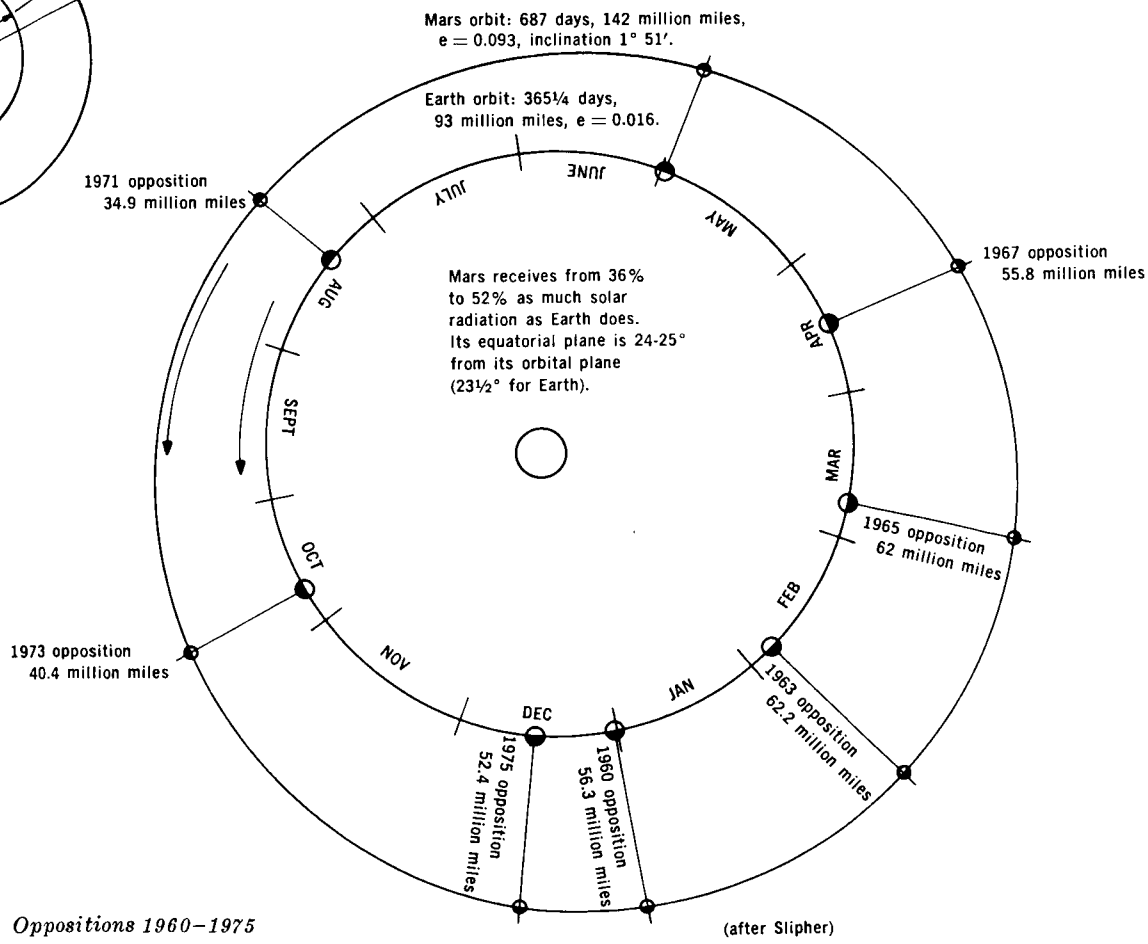


who applied this method to Mars, produced a value of 25 millibars, with an uncertainty of 15 millibars. Subsequent refinement raised this value slightly. Earth's standard sea-level pressure is just over 1013 millibars. Values estimated by other methods, with much greater uncertainties, yield a possible range from 200 millibars down to about 14 (corresponding to the pressure 4¼ 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.



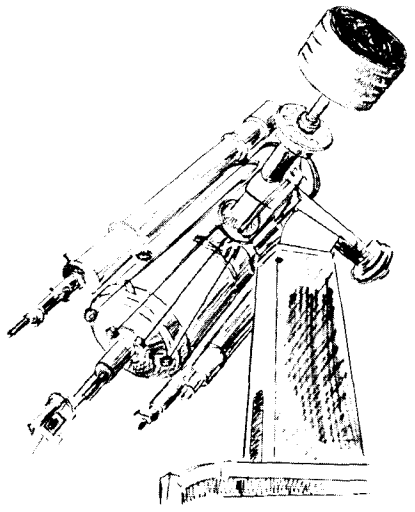
Mars and its moons



Oppositions 1960–1975

(after Slipher)

The Mars Patrol



Mars, as we have seen, is a tough nut to crack. The speculations associated with the question of canals doubtless helped to turn astronomers away from Mars, and planetary investigation in general remained a backyard branch of astronomy for some years. The age of space exploration helped in the growth of the new science of planetology, which lures geologists, biologists, meteorologists, chemists, and engineers into the field of astronomy, and, during the last five years has wrought a great renaissance in planetary studies, particularly of the Moon, Venus, and Mars.

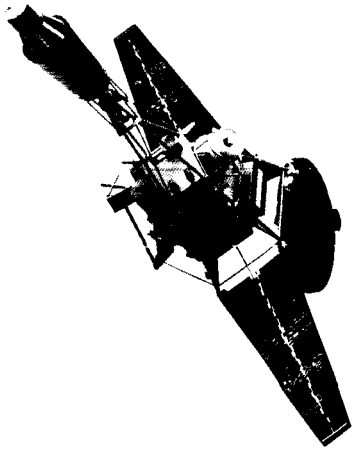
In 1963 the International Astronomical Union's planetary commission established planetary data centers at Meudon in France and at Flagstaff, Arizona. Observatories in the U.S.A., Japan, USSR, South Africa, France, and many other nations contribute to this program of collecting direct photographs of Mars and other planets. The 1965 Mars opposition will add considerably to the collection. JPL's Table Mountain Observatory and other nearby facilities are being used in a special effort in conjunction with Mariner. In addition, here and abroad, spectrographic searches for new and supplementary information about the surface and atmospheric composition and properties are being carried out. Thus, Mariner is not alone in investigating Mars.

THE SPACECRAFT

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

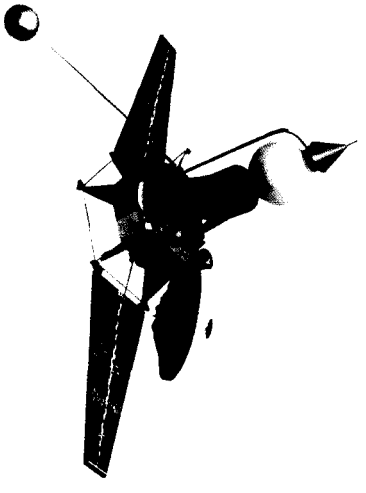


Ranger I (1961)

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 two 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.



Ranger III (1962)

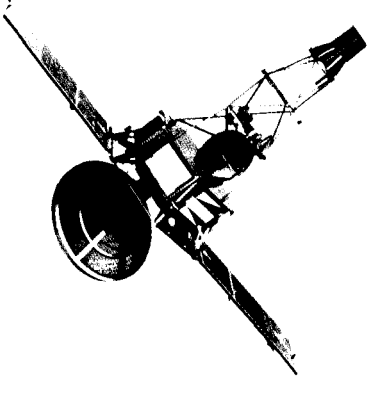
On a Larger Scale

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.

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 a hundred 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 enroute to Venus but drew nearly as much power from the



Mariner II (1962)

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 become colder on its journey.

Mariner IV

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 flight, while Mariner IV has indicated well over 100 in the first five months of its journey. 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.

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 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.

The Weight Watchers

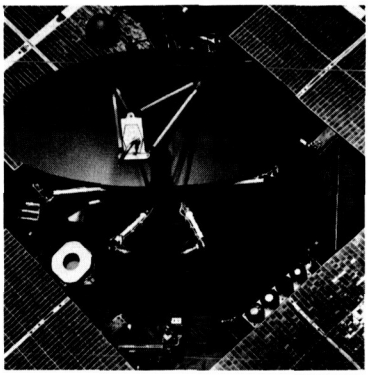
Mariner's planners early decided they would need more spacecraft weight than the 450 pounds that the Atlas/Agena B vehicle had launched to Venus in 1962. A new version of the second stage of the launch vehicle, Agena D, basically a collection of improvements from better propellant utilization to lightweight materials, added up to 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.

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.

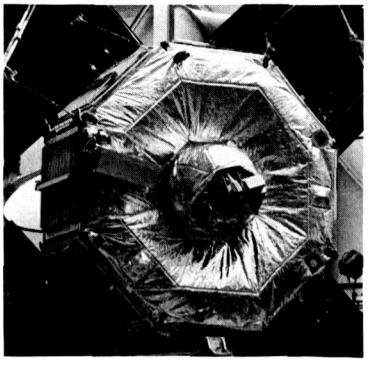
For example, the bones of birds and the I-beams of girders indicate that nature and man have found ways to get more strength for less structural weight. Mariner's structural designers went further; they nearly eliminated the skeletal structure. Mariner's forebears were built around a hexagonal skeleton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



Above: Spacecraft upper deck is covered with black-surfaced thermal shield. Ionization chamber is mounted on low-gain antenna tube (top of picture); below elliptical high-gain antenna, at left, are trapped-radiation, cosmic-dust, and plasma-probe sensors. Primary sun sensor is near bottom of picture; four disks at lower right are absorptivity standards for thermal engineering test. Below: Spacecraft lower deck has aluminized thermal shield, with Canopus sensor at left, TV scan platform protruding in center.



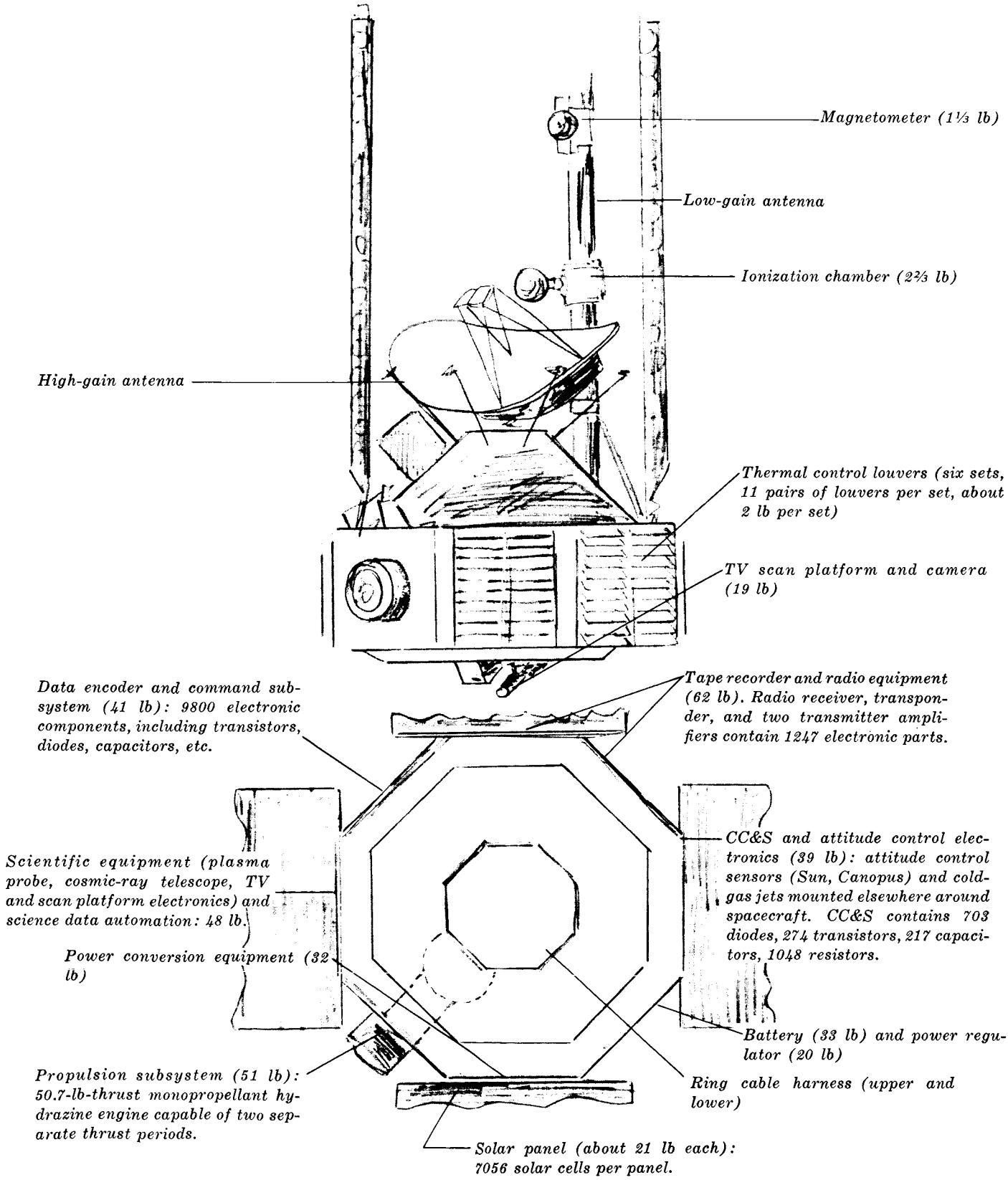
Controlled Temperatures

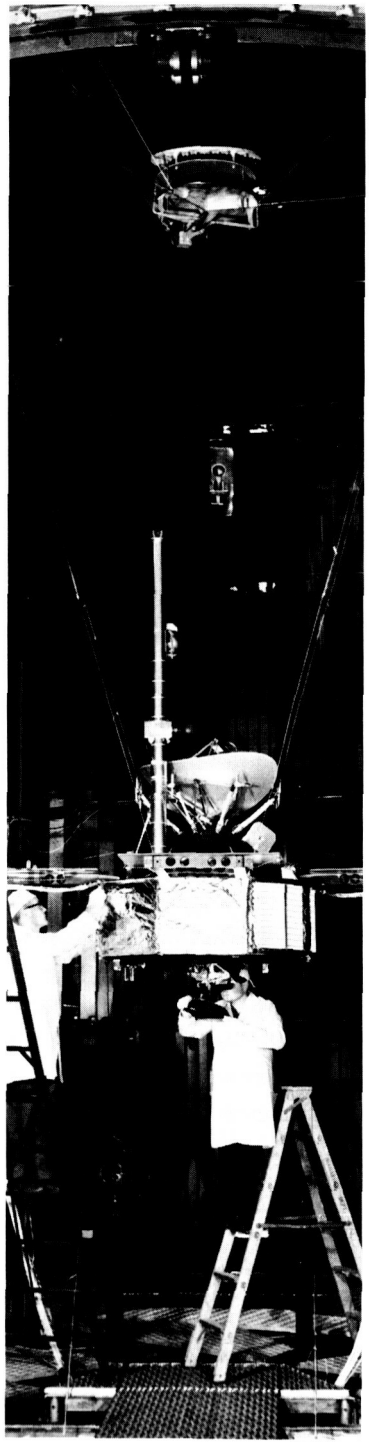
An object in space will be warmed by the rays of the Sun, and cooled by its own radiation to the black sky around it, at a rate dependent on its temperature. It will thus eventually stabilize at a temperature primarily dependent on its distance from the Sun: near Earth it would be about 125°F warmer 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 black stripes (radiating 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.


Magnetometer (1⅓ lb)
Low-gain antenna
Ionization chamber (2⅔ lb)
High-gain antenna
Thermal control louvers (six sets, 11 pairs of louvers per set, about 2 lb per set)
TV scan platform and camera (19 lb)
Data encoder and command subsystem (41 lb): 9800 electronic components, including transistors, diodes, capacitors, etc.
Tape recorder and radio equipment (62 lb). Radio receiver, transponder, and two transmitter amplifiers contain 1247 electronic parts.
CC&S and attitude control electronics (39 lb): attitude control sensors (Sun, Canopus) and cold-gas jets mounted elsewhere around spacecraft. CC&S contains 703 diodes, 274 transistors, 217 capacitors, 1048 resistors.
Scientific equipment (plasma probe, cosmic-ray telescope, TV and scan platform electronics) and science data automation: 48 lb.
Power conversion equipment (32 lb)
Battery (33 lb) and power regulator (20 lb)
Propulsion subsystem (51 lb): 50.7-lb-thrust monopropellant hydrazine engine capable of two separate thrust periods.
Ring cable harness (upper and lower)
Solar panel (about 21 lb each): 7056 solar cells per panel.



Mariner Mars temperature model preparing for test in JPL's 25-foot space simulator.

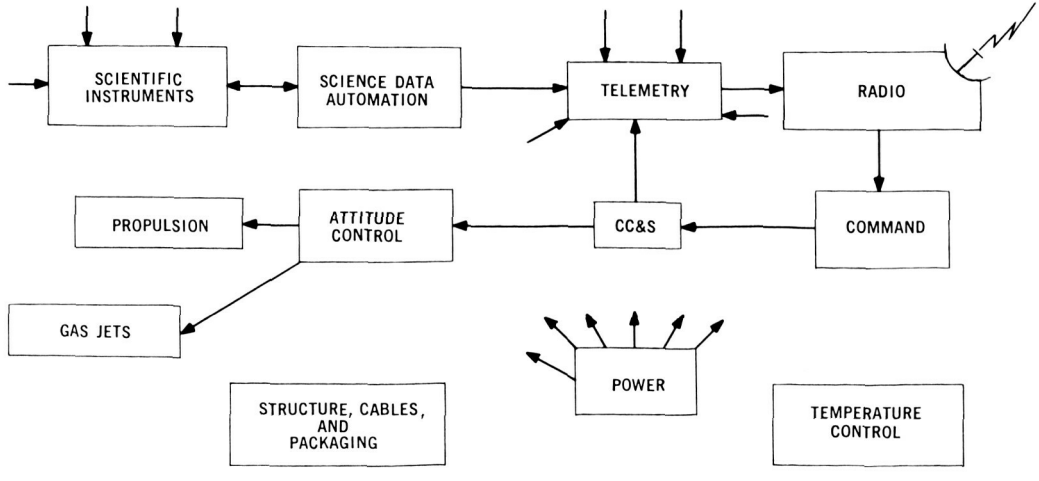
A sophisticated thermal-control device, a set of polished aluminum shutters which could open to expose a radiating surface beneath, was tested on one compartment of Mariner II in its flight to Venus. The shutters are activated by bimetallic strips, like inexpensive dial thermometers or the thermostat 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

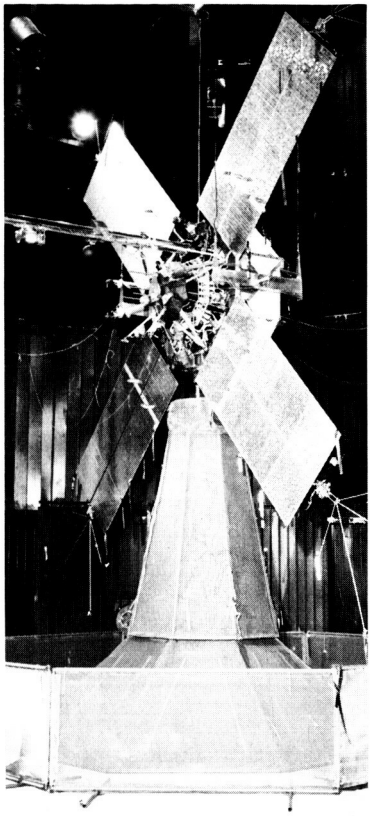
Some philosopher has remarked that you can't get from "1 + 1" to "2" just by understanding the "1." Systems engineering might be likened to the "+" sign. It started with a job to be done. Each of the Systems of the Mariner Mars 1964 Project (Launch Vehicle, Spacecraft, Deep Space Net, and Space Flight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

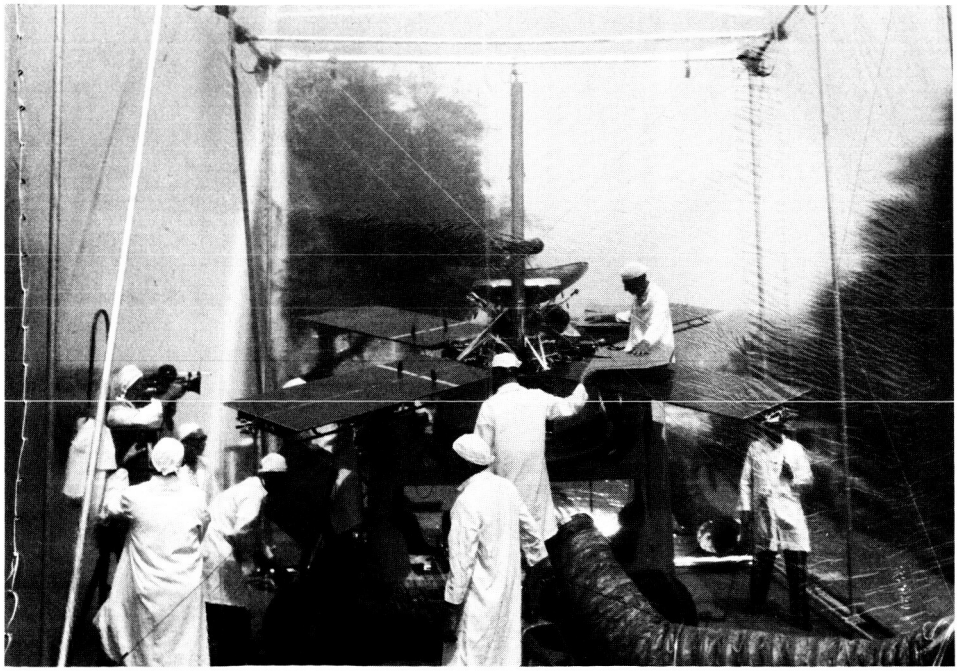


Outer Space on Earth

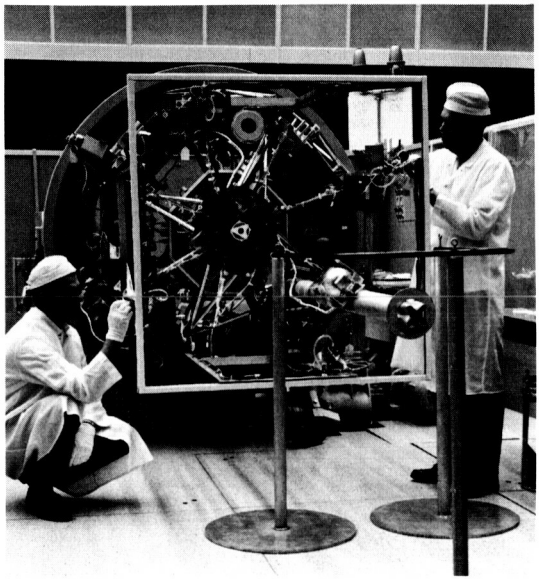
Though space exploration serves experimental science, it is not itself purely experimental; this is evidenced by the distaste with which spacecraft developers brush off such labels as "cut and try," "file to fit," "shoot and hope." With the exception of extremely long missions such as Mariner IV, most 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



Above: Mariner's on-board rocket motor was fired in a space-simulator test of system interaction (proof-test model). Left: Mariner's solar panels power the spacecraft at the bottom of Earth's atmosphere in a unique test.



System testing in JPL's Spacecraft Assembly Facility.

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.

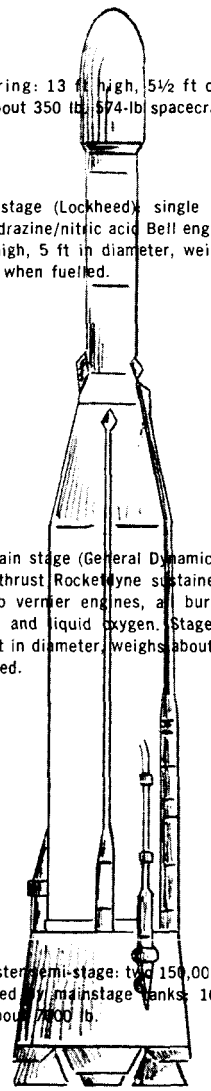
MARINER LEAVES PORT

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/Agena 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 two 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

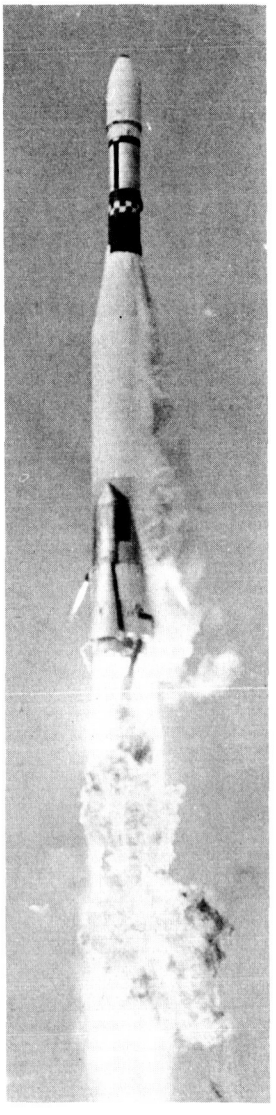
Unlike a conventional aircraft, a spacecraft spends most of its time falling. The first few minutes of the flight, and then, a day or a week later, a few more seconds, are all the powered flight it ever has. Accordingly, its captain must plot his course before the ship leaves port; the charting is more 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 practical 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 (24 degrees south from due East) for Cape Kennedy 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 mission, push Mariner about 10,000 miles away from the Sun.

Mariner III: 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.

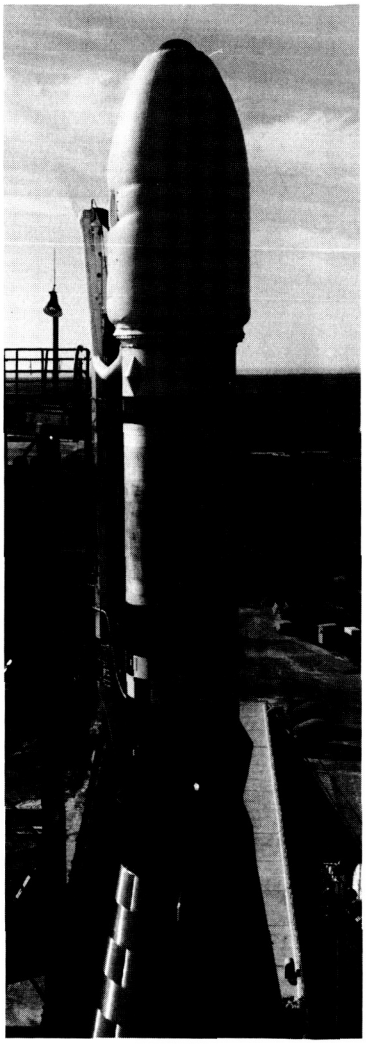
Nevertheless, within minutes the mission was doomed, though it took nearly nine hours for it to die. The cylindrical fiberglass-honeycomb nose fairing, or shield, designed to protect the spacecraft during the smashing thrust up through the atmosphere and then to be jettisoned, failed during the climb 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 drag 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 three weeks after the launch of Mariner III, another Mariner/Atlas/Agena stood ready on the pad, with the new metal nose shield installed.



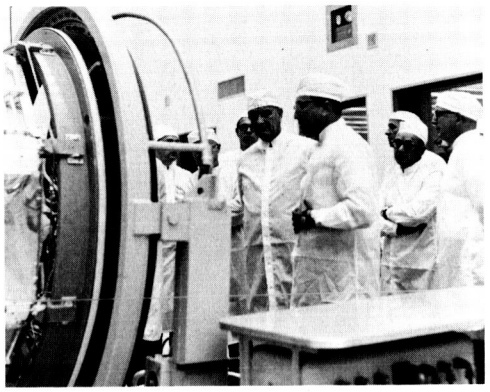
Mariner IV: A Good Sendoff

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.

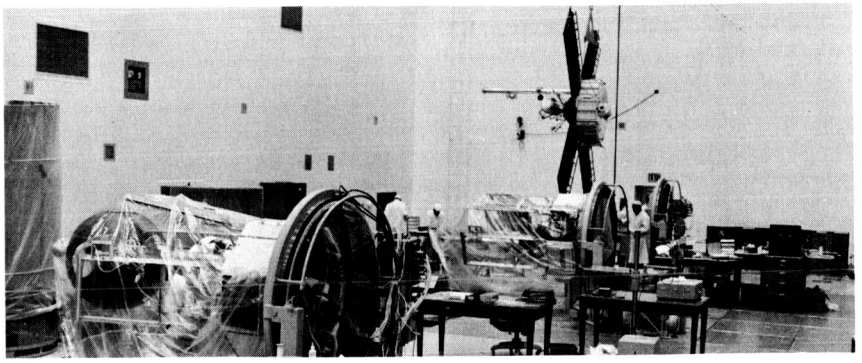
As it rose, the space vehicle rolled to an azimuth of 91.4 degrees, just South of due East, and began to pitch over from its vertical ascent. Shedding its two massive booster engines, Atlas carried on with the single sustainer. A ground computer fed guidance commands to the vehicle until the sustainer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

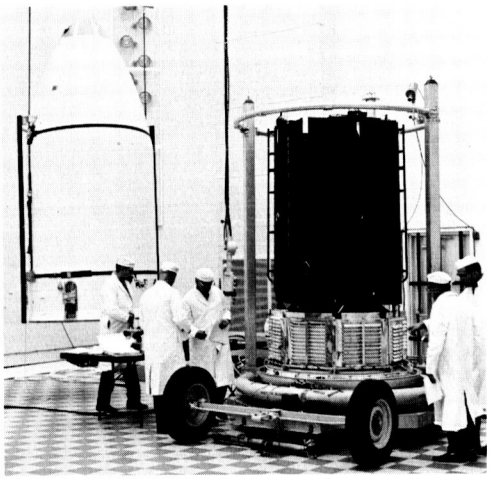
Launch operations were described as nominal; it was a good shot.



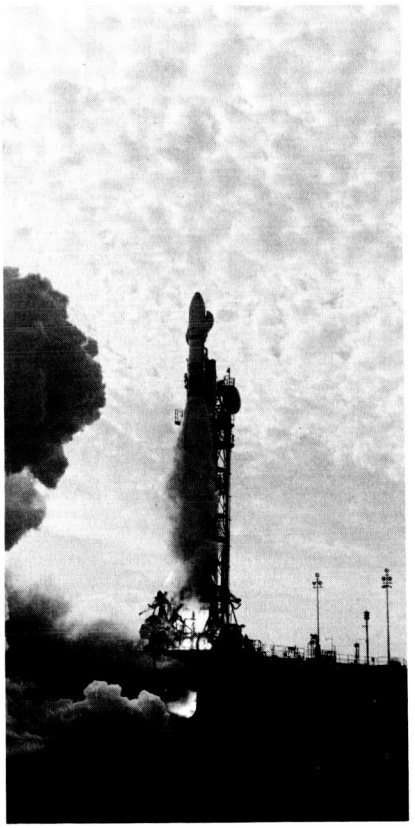
2



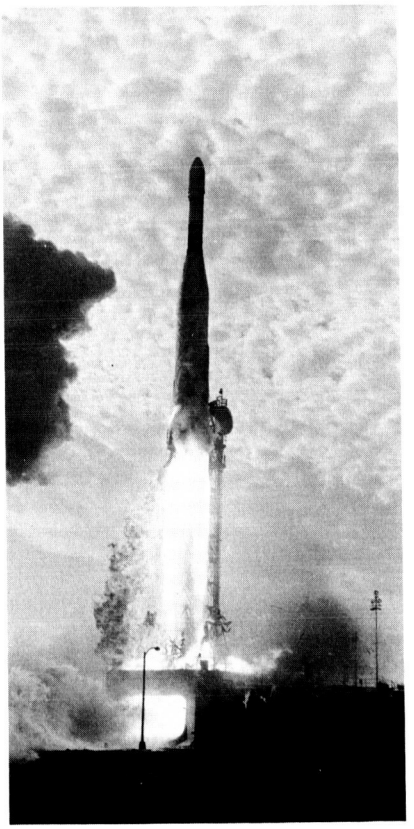
1



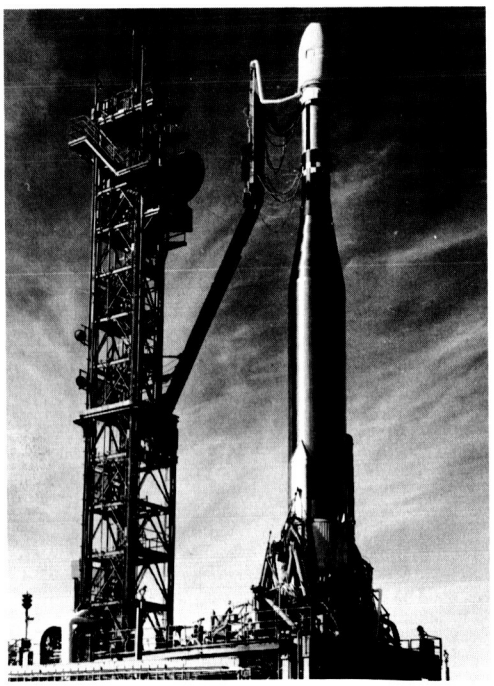
3



8

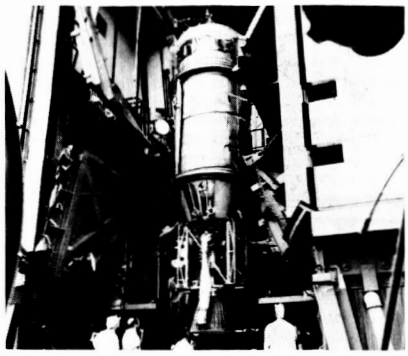


9

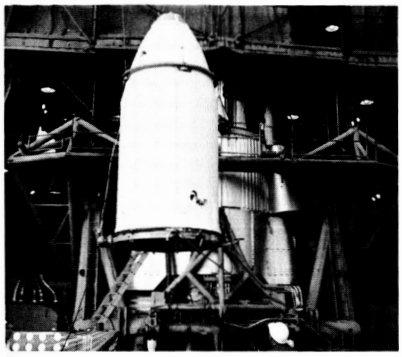


6

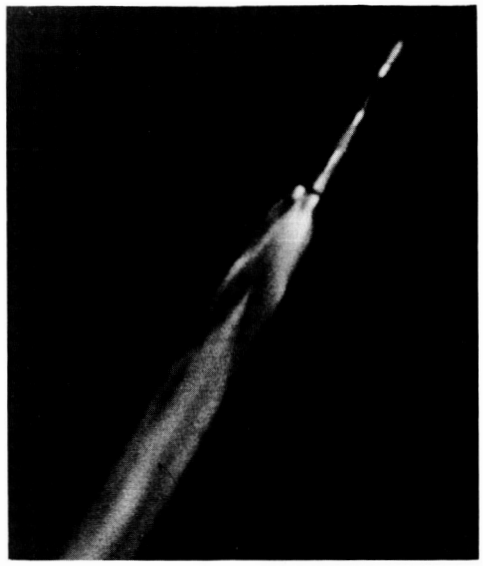
7



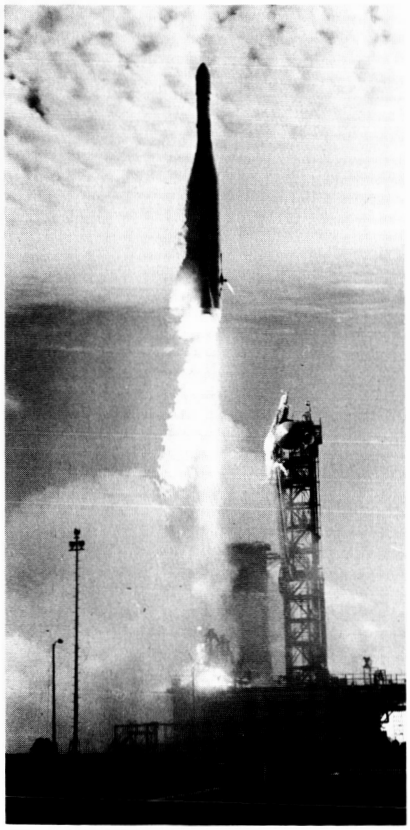
4



5



12



10

11

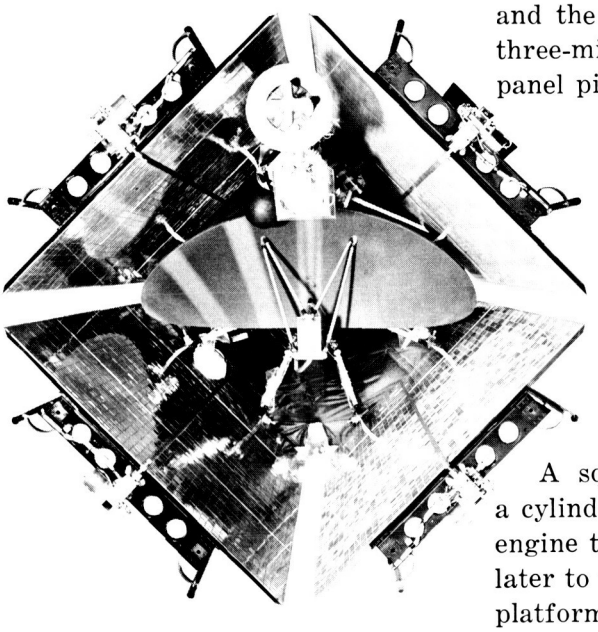
At the Cape, two flight spacecraft and a spare were assembled and tested (1). President Lyndon B. Johnson (2) inspected the spacecraft during assembly; then (3) Mariner IV was installed in its nose fairing, ready for the launch vehicle. Meanwhile, the Agena D vehicle was mated to the Atlas D booster (4). Then the encapsulated spacecraft was mounted (5) on the launch vehicle; the assembled space vehicle (6) was tested thoroughly, while JPL engineers in the spacecraft building monitored the performance (7). The Mariner IV launch (8–12) was controlled from the spacecraft mission director's area (13) and the launch complex blockhouse (14).

13

14

IN-FLIGHT EVENTS

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 three-minute timer was started, and, simultaneously, the spacecraft radio power was switched up and the interplanetary scientific instruments were turned on. When the three-minute timer ran out, electric current was applied across the solar-panel pin-puller squibs.



Mariner's four solar panels are folded for launch.

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.

Power From the Sun

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 com-

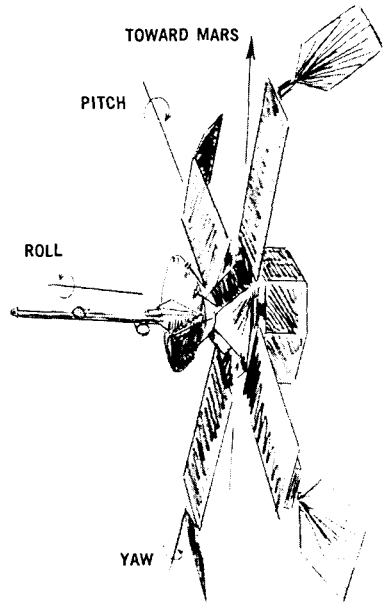
mands (such as Sun search, star search, and midcourse maneuver), and conducts complex maneuvers in accordance with instructions sent from Earth.

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 fifteen 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.

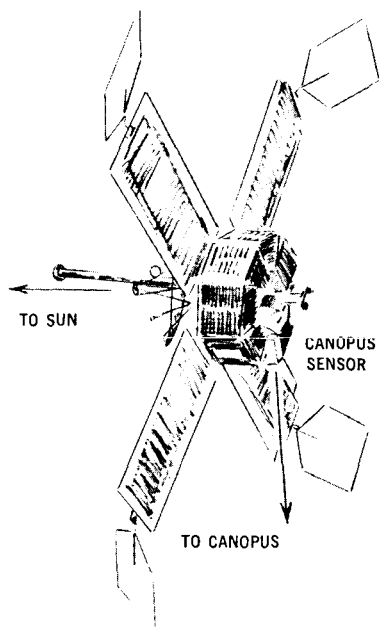


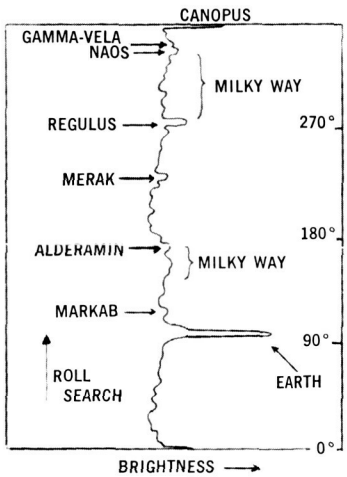
Lock on Canopus

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. As the spacecraft moves around the Sun, the angle between the Sun line and the Canopus line changes slowly; one of the tasks of the CC&S is to alter the sensor's angle four times during the flight to keep the star in view.





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 seven 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 six. 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.

Trajectory Adjustment

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 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.

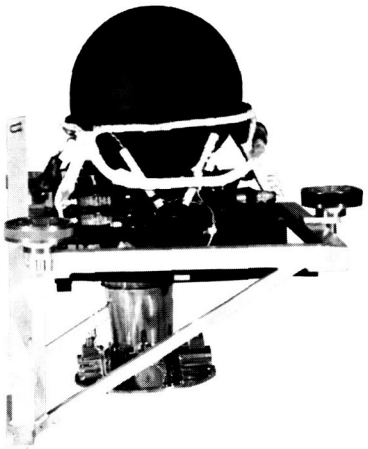
After about a week of tracking to determine the flight path and Mars arrival time, the thrust maneuver was scheduled for December 4. All the necessary ground commands had been received by the spacecraft, when it suddenly "lost lock" with Canopus, though Sun lock was not disturbed.

Flight telemetry is monitored closely before midcourse maneuver.

Since the spacecraft had no baseline from which to orient its rocket motor, the maneuver was postponed with another ground command until Canopus lock could be re-established.

It was theorized that a dust particle of pin-point size, floating a few feet from the Canopus sensor and shining fiercely in the sunlight, might have so increased the brightness registered in the attitude-control system that the spacecraft released its lock on Canopus and began to track the dust particle. As the particle drifted out of the field of view of the sensor, the spacecraft was left in a star-searching mode. After several days of observation — the phenomenon repeated itself a number of times — the excessive-brightness reaction was removed by ground command. The reaction had been intended to prevent Earth-lock, and Earth was moving well out of the way.

On December 5, 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 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.



Midcourse motor

Maneuver successfully completed!

LONG-DISTANCE COMMUNICATION

A fundamental characteristic of the Mariner class of mission is the physical separation of the spacecraft performing the flight from the operators who conduct it. Unique to Mariner IV is the extent of the separation —up to 150 million miles. This great distance imposes, at encounter, a communications delay of about 12½ minutes each way. In spite of the delay, the spacecraft must be able to maneuver, to switch from one operational sequence or equipment chain to another, and to interrupt or cancel an operation on command from its "crew" on Earth. Furthermore, details of its operating performance and condition, its precise position and motion, and the outputs from its scientific equipment must be readily and frequently available to the operating team. This vital function is carried out by the telecommunications subsystems of the spacecraft and, on the ground, by a worldwide network of tracking stations and a complex of computers, data displays, and other equipment.

Keeping in Touch

Starting before liftoff at the Cape and throughout its flight mission, Mariner IV has been and will be sending a steady stream of information back to Earth. Its radio, putting out about 10 watts of power at about 2300 megacycles in the "S-band," has two transmitting amplifiers (a Mariner-II-type cavity amplifier and a longer-life traveling-wave tube), and two antennas: a low-gain, omnidirectional broadcast antenna and a high-gain, narrow-beam elliptical reflector dish. Either antenna can be used for command reception as well as transmission; the dish, whose direction is fixed on the spacecraft, was switched into the transmission link on March 5, when the range became extreme for the "omni" and the Earth entered the narrow beam of the reflector.

The 10 watts transmitted by Mariner IV has shrunk to as little as .0000000000000000001 watt (10^{-19} watt) as measured at the input to the receiver. Signals of such low power call for extremely sensitive receiving equipment on the ground. The Deep Space Stations, spotted at about 120-degree intervals around the globe, are equipped with steerable reflector antennas 85 feet in diameter. The heart of the traveling-wave-maser receiving amplifier fed by each of these antennas is a synthetic ruby crystal immersed in liquid helium; this radical design keeps the internal or "system" noise low enough that the faint spacecraft signal can be heard.

The direction or angular position of Mariner in its flight is calculated from the pointing angles of the narrow-beam ground antennas. The velocity

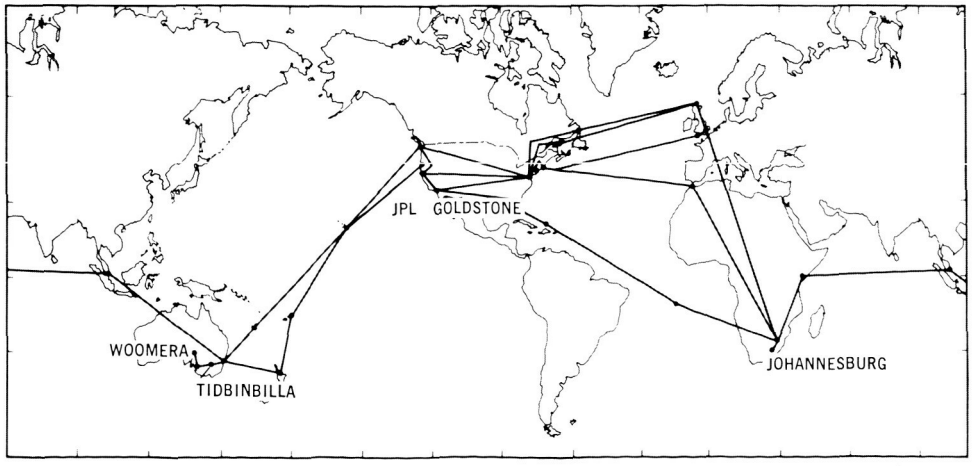
of the spacecraft is determined by tracking the radio carrier frequency very precisely and then measuring the amount of "stretching" of the frequency due to the doppler effect. The operating frequency is controlled either by an oscillator on the spacecraft or, for more precise determination, a stable oscillator on the ground, which generates a signal that is transmitted to the spacecraft, multiplied by a known factor (240/221), amplified, and sent back to Earth.

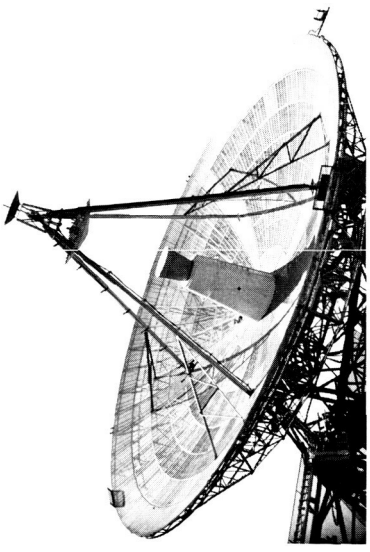
Listening Post: Earth

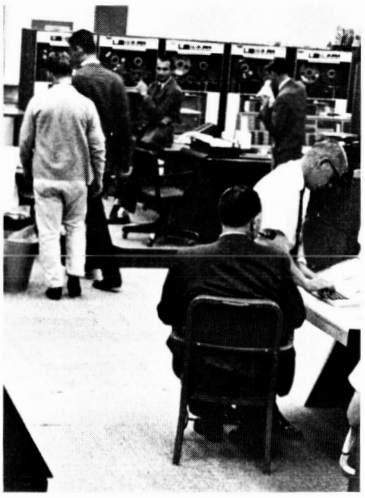
In 1958 and 1959 the first Deep Space Station was constructed in the Southern California desert near Goldstone Dry Lake. Its huge 85-foot-diameter reflector antenna is mounted like a telescope so that it can track a spacecraft at planetary distance. This Pioneer Station, modified with the advances of technology, is in service today, tracking Mariner IV almost 12 hours per day. There are two more stations at Goldstone now, capable of handling multiple missions (in February and March, Ranger and Mariner missions were tracked simultaneously) and carrying out research and development in telecommunications.

In Australia there are two stations. The one at Woomera tracked Mariner until it was converted to another frequency to support two Ranger flights in February and March. A brand-new station at Tidbinbilla, near the capital city of Canberra, stepped into the breach, and has covered Mariner IV since that time.

The first Deep Space Station to track Mariner IV was the one near Johannesburg, South Africa. Johannesburg tracked Mariner 10 hours a day until the Ranger missions were flown. After the Ranger flights, Johannesburg reconverted to the S-band, and Mariner was again in touch with Earth 24 hours a day. A new station being built in Spain will alleviate such conflicts in the future.







SFOF computers

The international tracking network is woven together by means of land lines, undersea cables, and radio links; at the hub of the net, in Pasadena, is the Space Flight Operations Facility, whose computers and data-handling and control equipment support Mariner's crew. Here operations teams specializing in the flight path, spacecraft performance, and space science monitor the information received from Mariner IV and translated by the computers. From these data the command decisions are made. The scientific information is converted into tabular and graphic form for analysis and interpretation by the scientists.

Dropping the Lens Cover

One of the major events that took place during Mariner's flight was the removal of the television camera lens cover, originally scheduled for the latter part of the mission. Because of the problem with the Canopus sensor, the engineers believed that removing the cover might release dust particles, which, in turn, might drift past the sensor and cause an abnormal reaction. To prevent such an occurrence just before encounter, they decided to play it safe. By conducting the "clear-for-action" earlier, closer to Earth, they would gain more time to absorb and rectify any possible after-effects. The operation was rescheduled for February 11, during the Goldstone tracking shift. First, a "verification" series of five commands was taped, proofread, and sent from Goldstone; the spacecraft's reaction to each was carefully monitored before the next was sent. The telemetry mode was shifted, and power distribution in critical areas was checked. With all systems *go*, the operational series of five commands went off, leaving the lens uncovered, the shutter closed, and the scan platform aimed in the best direction for encounter—ready for action.

Space Flight Operations Director

SFOF Mission Control

The commands were sent to the spacecraft in the form of binary words, each word consisting of an arrangement of 26 zeroes and ones (bits). The command signal was superimposed on the radio-frequency carrier; when it reached the spacecraft, it was "demodulated" from the carrier and sent to the particular subsystem for which it was intended. By means of electronic logic circuits, the commands could activate various mechanisms aboard the spacecraft, and the results could be determined by monitoring the telemetry signals received back on the Earth.

Goldstone Control

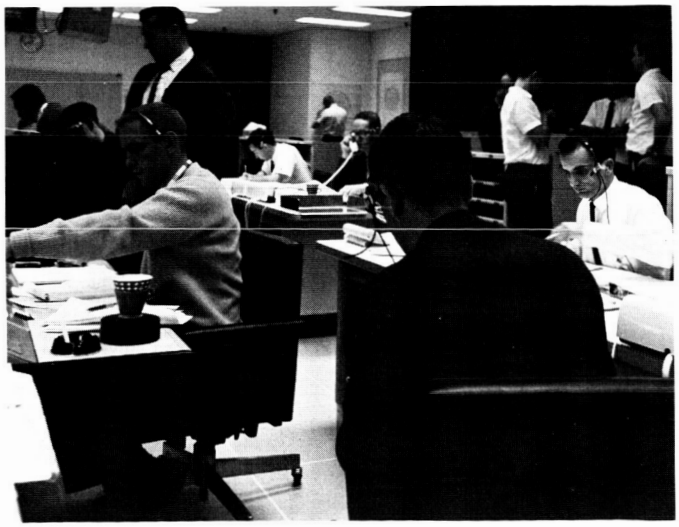
Engineering Telemetry

Mariner's signals back to Earth outnumber Earth's infrequent words of command. Exclusive of scientific data (packaged separately by the data automation system for transmission), Mariner reports almost 90 spacecraft measurements: temperatures, voltages, currents, pressures, angles, and the like, described in a seven-bit word each. There are four event counters, which note receipt of commands and the passage of time. Up to January 3, the spacecraft chattered away at 33⅓ bits per second; on that date, the rate was slowed down by a factor of four, due to the lengthening range to Earth (about six million miles).

The spacecraft data encoder gathers these measurements into "decks" of ten measurements, sampling each in turn. Most of the decks are multiplexed—time-shared, so that they are sampled every tenth, or every hundredth, or every two-hundredth time rather than each time around. Some measurements, most of them temperatures, which change very slowly, may be sampled only every 2¾ hours; others, more critical or faster-changing, come as often as once a minute. These rates are based on the encounter data rate of 8⅓ bits per second.

SFOF Space Science Area

Spacecraft Analysis Area



THE SCIENTIFIC EXPERIMENTS

Mariner IV carries eight scientific experiments, monitored by about two dozen scientists from ten universities and laboratories. The experiments are divided into two categories: the interplanetary experiments, which are performed throughout the entire journey to Mars; and the planetary experiments, which are expected to increase our knowledge of the planet. The scientific package consists both of scientific instruments and of auxiliary equipment required to process the data.

Above and below: Experimenters

Interplanetary Experiments

Six scientific instruments were turned on a few minutes after the launch of Mariner last November; the helium magnetometer, the solar-plasma probe, the ionization chamber, the trapped-radiation detector, the cosmic-ray telescope, and the cosmic-dust detector. For the past 7 months, these instruments have been gathering scientific data about the interplanetary magnetic field, the cosmic dust found in space, the solar wind, solar flares, and other deep-space phenomena. By the time Mariner reaches Mars, it will have taken approximately 18 million scientific measurements—enough to keep scientists busy for the next several years.

The interplanetary experiments will be of special interest as Mariner approaches the vicinity of the planet; they may tell us, for instance, whether Mars is surrounded by a magnetic field like the Earth is, and whether there are intense radiation belts around the planet like the Van Allen belts around Earth.

The plasma probe suffered a component failure in December, 1964, making its readings unintelligible until the telemetry rate change early in January, 1965, made a partial recovery possible. Decreasing temperature slowly made the crippled instrument unreadable again by early May. The Geiger tube, one of two sensors in the ionization-chamber experiment, failed after an apparent overdose of ionizing radiation, and the experiment stopped returning data in March.

Planetary Experiments

As Mariner IV passes Mars, it will attempt to take 18 to 21 pictures of the surface. The electrical signal, representing 64 different shades of

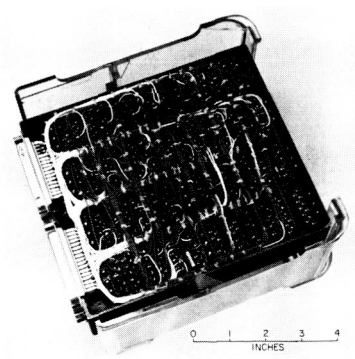
black and grey with a resolution about as good as Earth-based telescopes photographing the Moon, will be recorded on a 300-foot loop of magnetic tape. Each picture will cover an area approximately 120 miles square.

The occultation experiment is the only experiment on Mariner that does not use a special scientific instrument. It relies on the telecommunications system and on the extraordinary accuracy of the flight path. If you imagine bowling a strike in a bowling alley that reaches from Los Angeles to San Francisco, you will have a good idea of the pin-point accuracy of Mariner's trajectory.

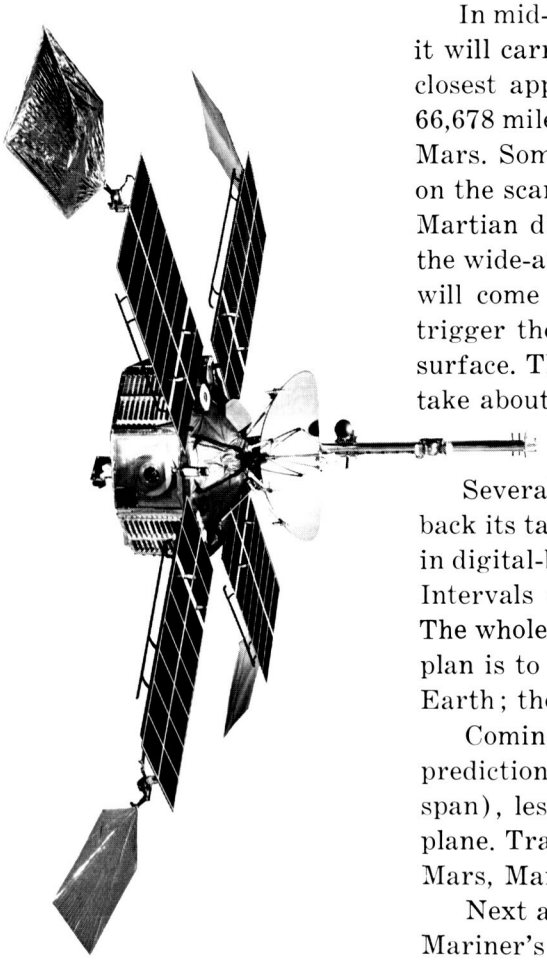
About an hour after coming within 5600 miles of the Martian surface, Mariner will seem to disappear behind the planet (as viewed from Earth), entering occultation near Mars' south pole and emerging near the north pole. As Mariner begins to disappear behind the Martian disk, its radio signals will pass obliquely through the planet's atmosphere and will be attenuated and bent, just as a stick appears to be bent when stuck into a pool of water. By measuring the changes in the characteristics of the radio signals, scientists hope to learn more about the composition and density of Mars' atmosphere.

Auxiliary Science Equipment

The science data automation system serves as a control center and data handler for the seven scientific instruments carried by Mariner IV. In the cruise mode, the science data automation system assembles data from the six interplanetary experiments, translates the information into constant-rate form, and transmits it to the data encoder, where it is passed on to the transmitter, and eventually to Earth. During the encounter, some science data will be sent directly to Earth while the picture data are being recorded.



MARS AND AFTER



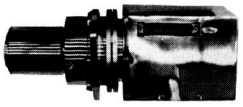
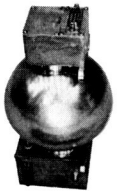
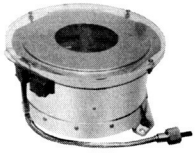
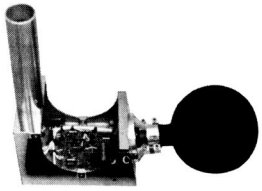
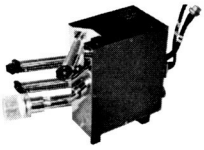
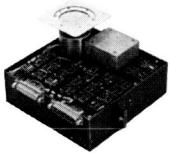
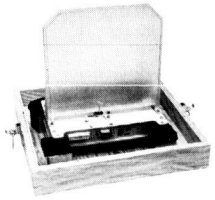
In mid-July, Mariner IV reaches its destination, and, barring accidents, it will carry out the complicated and long-awaited planetary sequence. At closest approach, it will make the historic flyby traveling at a speed of 66,678 miles per hour relative to Earth or 11,518 miles per hour relative to Mars. Some time prior to closest approach, the wide-angle sensor located on the scan platform will begin searching for the light of Mars. When the Martian disk comes into view, the scan platform will stop searching and the wide-angle sensor will begin to track the planet. Then the large red disk will come into the field of view of the narrow-angle sensor, which will trigger the tape recorder to start recording the television pictures of the surface. The pictures, taken alternately through red and green filters, will take about 25 minutes to record.

Several hours after it leaves Mars' vicinity, Mariner will slowly play back its tape recording through the data encoder, transmitting the pictures in digital-bit form to the Earth at the rate of more than 8 hours per picture. Intervals of engineering telemetry will be sandwiched between pictures. The whole picture-and-telemetry series will take almost 10 days to send. The plan is to repeat the series a second time to ensure receiving every bit on Earth; then Mariner will be ordered back to interplanetary investigation.

Coming so close to Mars will influence Mariner's orbit. The current prediction for the post-Mars orbit is that it will be longer (in period and span), less elongated, and more sharply tilted relative to Earth's orbital plane. Traveling in this far-flung ellipse between Earth's orbit and that of Mars, Mariner will be a satellite of the Sun forever.

Next autumn, Earth will pass from the beam of the high-gain antenna. Mariner's telemetry will go on transmitting—no one really knows how long—but we shall not receive its signal. Perhaps in 1967, when the spacecraft again approaches Earth, we shall hear from Mariner once more.

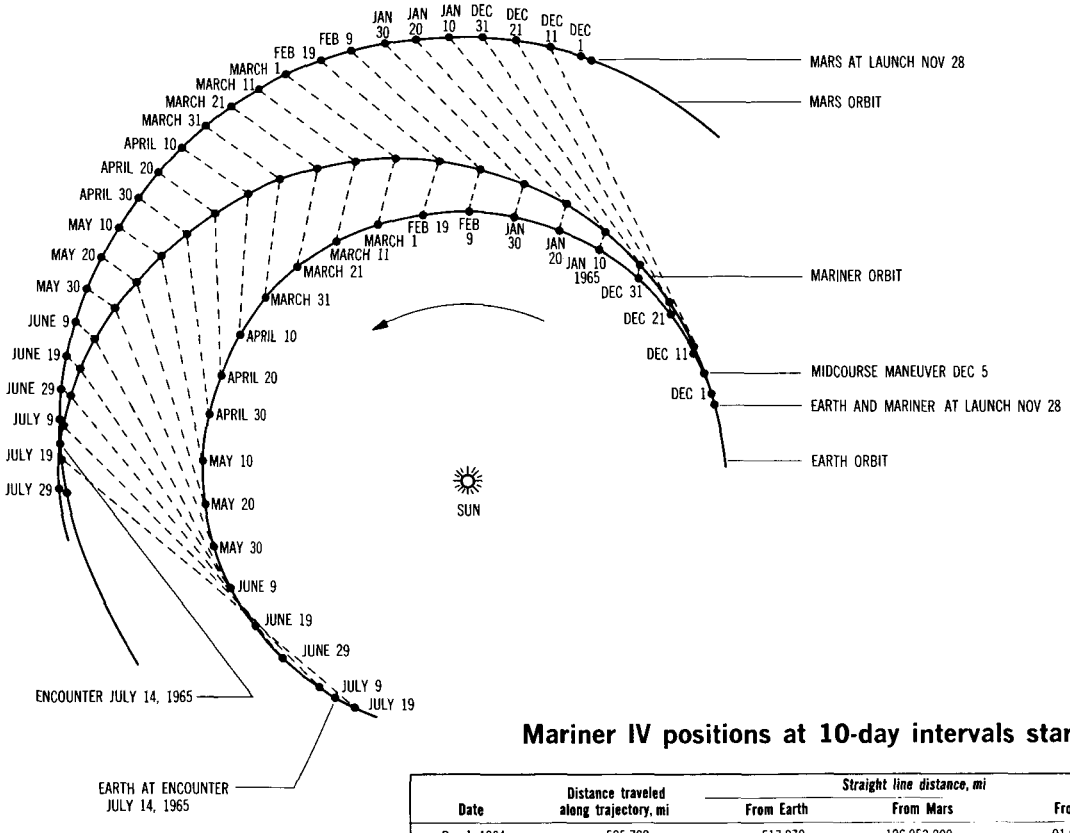
Experiment Data

	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, 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, Philadelphia
	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 of Stanford Electronics Laboratory, and F. Drake of Cornell University

*principal investigator

Orbit Data

	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	251,533,000
Perihelion distance, miles	91,342,000	128,330,000	92,000,000	92,180,000	92,230,000	104,557,000
Aphelion distance, miles	94,452,000	154,760,000	122,000,000	146,920,000	147,410,000	146,976,000
Tilt of ecliptic, degrees	0°	1° 51′		0° 8′	0° 7¾′	2° 58′
Period, days	365	687	449	528	529	570
Inclination of roll plane (equator) to orbit plane	23½°	24–25°	?	90°	90°	90°
Period of rotation	23 hr 56 min	24 hr 37 min	?	0	0	0



Mariner IV positions at 10-day intervals starting Dec. 1, 1964

Date	Distance traveled along trajectory, mi	Straight line distance, mi: From Earth	Straight line distance, mi: From Mars	Straight line distance, mi: From Sun	Velocity, mi/hr: Relative to Earth	Velocity, mi/hr: 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	325,741,140	134,398,880	5,675	144,468,580	66,678	11,518

The Log of Mariner IV

November 28, 1964	
1422:01.39 GMT	Liftoff.
1504:28	Space separation.
1510:10	Solar panels deployed.
1531:04	Sun lock completed.
November 29	
0659:03	Canopus search started.
November 30	
1102:47	Canopus lock completed.
December 4	
1305–2402	Midcourse maneuver attempted by ground command; Canopus lock lost. Maneuver cancelled from Earth; Canopus reacquired after 7 ground-commanded "star-hops."
December 5	
1305–1658	Successful midcourse maneuver (6 ground commands).
December 6	Component failure in plasma probe; scientific data unintelligible.
December 7	Canopus lock lost, Gamma-Vela acquired.
December 9	Star lock lost, Gamma-Vela reacquired twice.
December 13	Transmitting amplifiers switched (to traveling-wave tube) by ground command; star lock lost, reacquired.
December 17	Star lock lost, reacquired. "Star-hop" commanded from Earth; Canopus reacquired. Star sensor desensitized to excess brightness by ground command.
January 3, 1965	Telemetry bit rate switched by on-board command from 33⅓ to 8⅓ bits per second (most frequent readouts every 50 seconds). Plasma-probe data partly recoverable at new rate.
January 10–13	Johannesburg ground station assigned to Ranger test—6½-hour daily telemetry blackout.
February 5	Solar flare detected by science instruments.
February 7–22	Johannesburg station assigned to Ranger VIII test flight mission.
February 11	TV lens cover dropped, planetary science equipment checked and prepared by 12 ground commands.
March 5	Spacecraft transmission switched from omni to high-gain antenna by on-board command.
March 10–25	Johannesburg station assigned to Ranger IX test and flight mission.
March 17	Ionization-chamber/Geiger-tube system fails.
April 16	Solar-flare phenomena detected.
May 3	Plasma-probe data below threshold due to decreasing temperature.
May 26	Solar flare detected.
June 5	Solar flare detected.
June 15	Solar flare detected.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY