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Viking Orbiter and Its Mariner Inheritance

During the closing days of 1968, the engineers at Langley, in consultation with specialists at JPL and NASA Headquarters, completed a Viking spacecraft design. Viking would have two major systems—an orbiter and a lander. While the lander would provide the means for safely delivering the scientific instruments to the surface, house, and provide the necessary power source and communications links for those experiments, the orbiter had a series of equally important functions in the Viking mission. The orbiter would transport the lander to Mars, provide a platform for the Viking imaging system so that proposed landing sites could be surveyed and certified, relay lander science information (pictures and other data in an electronic format) to Earth, and conduct scientific observations in its own right.

Despite early debates among NASA managers, it was only logical that the design and development of the Viking orbiter system be carried out at the Jet Propulsion Laboratory, where the engineering team already had an expertise in the design of planetary spacecraft. After building the Ranger lunar probes and the early Venus and Mars Mariner flyby spacecraft, the California engineers had gone on to build the Mariner Mars 69 flyby craft and were working on the Mariner Mars 71 orbiter when Viking was initiated. The Viking orbiter would borrow heavily from Mariner technology, with such specialized functions as the project demanded being added to the basic chassis.

Early plans for the Viking orbiter called for only a few modifications of the Mariner 71 craft. However, structural changes that permitted mating the lander to the orbiter and enlarging the solar panels led to significant alterations of the basic 1971 orbiter. During the long flight to Mars, the orbiter would have to provide power to the lander, especially during the periodic checkups on the lander's health and during occasional updates of the lander's computerized memory. These additional energy requirements made it necessary to increase significantly the solar panels, from 7.7 square meters to 15.4.

The decision to build a large soft-landing craft instead of a small hard-lander led to the requirement for a large orbiter. The orbiter would not only have to transport the lander, it would also have to carry an increased supply of propellant for longer engine firings during Mars orbit insertion, longer than those planned for the 1971 Mariner mission.[1] And an upgraded attitude control system with greater impulse, plus a larger supply of attitude control propellant, would be required to control the combined spacecraft. Table 26 categorizes the Viking orbiter subsystems as compared to Mariner 71, listing subsystems from Mariner requiring only minor changes, subsystems from Mariner requiring extensive modifications, and completely new subsystems designed for Viking.

Table 26
Sources of Viking Orbiter Subsystems

Mariner	Mariner Adaptations	New
Radio	Structure	Computer/command
X-band transmitter	Attitude control	Data storage
Pyro control	Propulsion	Relay link
Omni antenna	Scan platform	High-gain antenna
	Temperature control	Science instruments
	Packaging	
	Data system	

A brief review of the Mariner 69 and Mariner 71 spacecraft will provide a better understanding of the technological relationships between the Mariner and Viking projects.

MARINER MARS 69

Born in the winter of 1965, Mariner Mars 69 was supposed to be only a modest improvement over *Mariner 4*. Early plans for a 1969 orbiter and hard-lander mission had been scrapped, and in its place a flyby craft had been substituted that would approach Mars at a distance of about 3200 kilometers, rather than the 13 800-kilometer pass made by *Mariner 4* in 1965.[2] The 1969 spacecraft would also carry more weight (381 kilograms) than earlier Mariners (*Mariner 2*—203 kg, *Mariner 4*—261 kg), because of the performance capability of its Atlas-Centaur launch vehicle. (Detailed information on the Mariner flights is given in appendix C.) Building on Project Ranger and Project Mariner experience, JPL engineers borrowed a number of fundamental mission and systems features for use with Mariner Mars 69. The most important of these was three-axis stabilization (roll, pitch, and yaw), provided by gyroscopes and celestial sensors, switching amplifiers, and cold-gas jets. This attitude control system permitted orientation of the solar panels and thermal shields, which provided temperature control, relative to the sun. The high-gain communications antenna could be aimed toward Earth to improve communications, and the scientific instruments could be directed toward the objects of their study. The attitude control system also permitted the craft to be maneuvered more precisely.[3] Other characteristics of the Mariner spacecraft included an extensive ground command capability and a large number of engineering and scientific telemetry measurements. The ground command capability was used primarily as a backup to the onboard central sequencer, a mini-computer that also reacted to commands from Earth.

Mariner Mars 69 followed the general design pattern of *Mariner 4*. The central body was octagonal with a magnesium framework (127-centimeter diagonal, 46-centimeter depth), with electronic assemblies and onboard propulsion system fitted into the equipment bays on all sides. Four hinged solar panels radiated from the body. On the side of the spacecraft opposite the solar panels was a platform for mounting the television camera, an infrared radiometer, an ultraviolet spectrometer, and an infrared spectrometer. The omnidirectional antenna and the fixed, high-gain, reflector antenna were attached on the side generally oriented toward the sun. Ground stations could communicate with the spacecraft continuously for tracking and the return of scientific data. Images would be stored by an onboard tape recorder for relay to Earth at a reduced play-back rate, since the cameras necessarily acquired imaging data at a rate much higher than the telemetry channel could accommodate.

As they worked on early Mariner and Ranger spacecraft, specialists at JPL had also evolved systems for tracking and controlling spacecraft from Earth, recognizing the requirement for a highly sensitive, steerable antenna (radio telescope) for communication with deep space probes. For continuous long-range coverage, a network of three stations, about equidistant in longitude, was normally sufficient. The first stations were at Goldstone, California; Johannesburg, South Africa; and Woomera, Australia. By the time Mariner 69 was ready to fly, there were eight 26-meter radio antennas and one 64-meter antenna in the Deep Space Network. Signals from the Space Flight Operations Facility at JPL were directed to the spacecraft by the appropriate ground station.[4]

As first established, Mariner Mars 69 had three objectives. The primary goal was to fly spacecraft by Mars to investigate that planet, establishing the basis for future experiments, especially those related to the search for extraterrestrial life. While exploiting existing technology, Mariner 69 engineers also hoped to develop new technology necessary for future missions. A tentatively approved objective to investigate certain aspects of the solar system was dropped from consideration by NASA Headquarters managers in April 1966. Mariner 69 would concentrate its efforts on Mars-related science. Experiment proposals were solicited and received by the Space Science Board, which acted as an advisory body to the NASA Office of Space Science and Applications. As had been proposed several times before, an atmospheric entry probe was suggested, but it was also rejected as before, because it would have significantly increased both the time required to develop the craft and the budget for the project. Scientific payload selection was announced on 26 May 1966.

By mid-1966, the design of the mission and the spacecraft was well under way. Money was the problem faced by N. William Cunningham, program manager at headquarters, and Harris M. Schurmeier, project manager at JPL, and their Mariner 69 team. Successive budget cuts each fiscal year forced the team to defer delivery of certain parts and components, which repeatedly required the engineers to reschedule the assembly and testing of the spacecraft. The budget reductions also forced the deletion of some spare parts and tests and led to several mission design changes. Despite financial constraints, the Mariner project staff was able to expand the scope and effectiveness of the spacecraft. An increase in mission science, for example, affected the planetary encounter phase of the mission. JPL specialists developed an improved telemetry transmission system that would return information at a higher rate than previously possible, increasing the overall volume of scientific return substantially. Since scientists would be using their instruments more frequently, the central control computer and sequencer through which ground controllers talked to the science instruments and manipulated the instrument scan platform would experience greater demand.

As early as September 1966 at the second project quarterly review, it became apparent that the 1969 mission was going to be much more than just a repeat of the *Mariner 4* flight. The instrument scan platform alone had grown in weight from 9 kilograms to 59. Throughout 1967 and 1968, as work progressed on the spacecraft and Earth-based systems, Schurmeier reported to NASA Headquarters that experimenters would be able to take more pictures of the Martian surface with the Mariner 69 equipment than previously anticipated. The accumulated improvements in telecommunications—increased telemetry data rates, expanded communications network, and better computer processing—would lead to a rate of data transmission 2000 times better than anything they had received before.[5] For the scientists associated with the television experiment, this was exciting news. Instead of taking only 8 television pictures during the last day of the spacecraft's approach to Mars, Robert B. Leighton and his colleagues on the television experiment team could gather some 160 images, starting two or three days before encounter with the planet. These approach pictures of the entire planet would bridge the gap between photos taken from Earth and closer images gathered by Mariner 69 craft as they passed by Mars.[6]

Engineers and technicians at JPL assembled components supplied by about a dozen subcontractors into four spacecraft—a proof-test model (PTM), two flight craft (M69-3 and M69-4), and one assembled set of spares (M69-2). While the proof-test model would never fly, it was a very important part of the 1969 project because it had to endure simulated conditions worse than any that were expected during the flight to Mars. The other three units were tested more gently on the vibration table to rehearse the launch and in the thermal-vacuum space-simulation chamber to practice the mission through deep space.

Following several visits to the test bench and much rebuilding and repairing, the craft were pronounced ready for their voyage. While the proof-test model remained behind in Pasadena to continue its service as a test article, the other three craft were sent to the Kennedy Space Center during December 1968 and January 1969. All went well with the preflight checks of Mariner F and Mariner G (preflight designations) until about 10 days before the scheduled launch. On 14 February while the Atlas-Centaur-Mariner F vehicle was standing on the pad undergoing unfueled simulation of launch, the Atlas began to collapse like a punctured tire. Most of the structural strength of the Atlas is provided by the pressure in its fuel tanks. While this balloon-like structure saves a great deal of weight, it means that the pressure must be maintained at a constant level. On this day, a faulty relay switch had opened the main valves, permitting the pressurizing gases to escape. As the Atlas began to sag on its launch tower, two alert ground crewmen sprinted to the scene and shut off manual valves inside the launch vehicle. Pumps restored tank pressure, and the big rocket resumed its original shape. The terrible scar in the thin stainless steel skin of the Atlas made it clear, however, that another launch vehicle would have to be used in its place.

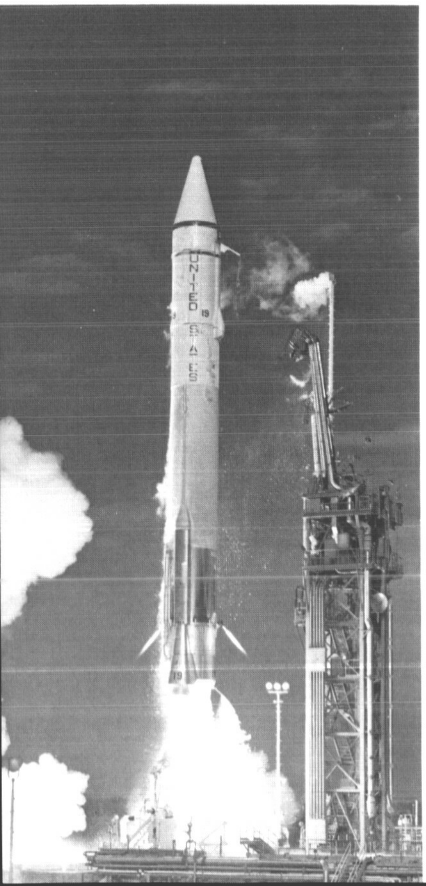
The Centaur and Mariner components were unharmed, and on 18 February KSC personnel moved the Mariner F craft and the Centaur upper stage to the Atlas originally scheduled for Mariner G. Six days later, 24 February, *Mariner 6* began its journey to Mars. After being mated to a new Atlas shipped from San Diego by General Dynamics/Convair, the second Mariner 69 craft was launched on 27 March.[7] As *Mariner 6* and *7* were en route, another group of JPL specialists was at work preparing for the next mission to Mars.

MARINER MARS 71

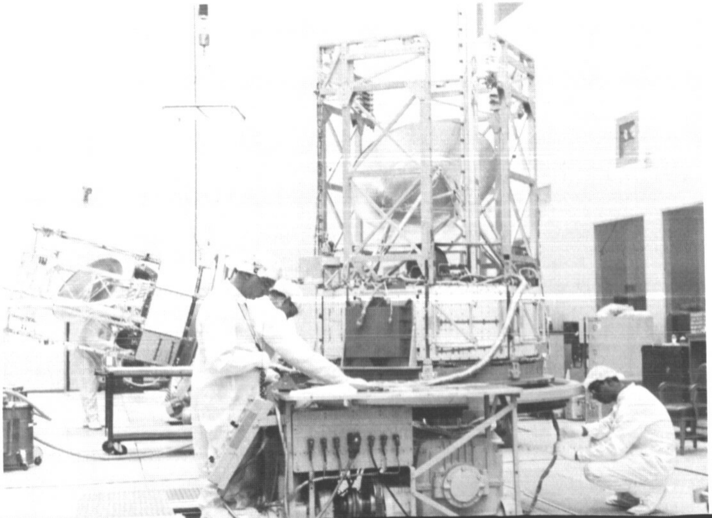
The battle over NASA's budget during the summer of 1968 had caused the agency's leadership to postpone beginning work on a Mariner Mars 71 project. NASA had begun the year by asking for $4.37 billion for fiscal 1969, or $218 million less than appropriated the preceding year. After the budget cycle was completed, President Lyndon B. Johnson signed an appropriation bill for $3.995 billion on 4 October 1968, the lowest since 1963. This figure, more than half a billion dollars less than the fiscal 1968 budget, sent NASA planners groaning back to their drawing boards.[8]

Despite the tight budget, $69 million was earmarked for the planetary program, to support Mariner Mars 69's flight and preliminary study of Mariner Mars 71 and Viking 73. Two and a half months after the project approval document for the 1971 mission was signed, NASA Headquarters announced on 14 November 1968 that Jet Propulsion Laboratory had been authorized to begin work on the project. Dan Schneiderman was appointed project manager at JPL, and Earl W. Glahn was named program manager at NASA Headquarters.[9]

Mariner Mars 71 was described as part of a continuing program of planetary exploration. Unlike the previous Mariner flights, however, the 1971 mission was designed to orbit the planet with two spacecraft for a minimum of 90 days each. At a December 1968 meeting of the American Institute of Aeronautics and Astronautics, Oran W. Nicks, deputy associate administrator for space science and applications at NASA Headquarters, spoke of the value of orbiter flights and future orbiter-lander missions for the examination of Mars. He noted that *Mariner 4, 6,* and *7* had given "snapshot views of the planet." The two 1971 orbiters would "provide powerful new tools for our survey of dynamic Mars." They were scheduled to "arrive at a time in the Mars cycle when the most striking seasonal changes are evident in the southern hemisphere." A combination of different orbits for the two 1971 craft would provide a complete survey of the entire planet. "The life-times expected from these orbiters will allow observations of the dynamic changes in clouds and surface features over a period of several months."[10] In addition to the improved observations, the two orbiters would meet several other scientific objectives.



Mariner F and G spacecraft (below)—to be christened Mariner 6 *and* 7 *on launch—are tested in preparation for their five-month journeys to Mars to investigate the planet's atmosphere and surface. Solar arrays are not yet installed. At left, an Atlas-Centaur launch vehicle thrusts* Mariner 7 *toward space from Cape Kennedy, Florida, on 27 March 1969, following the* Mariner 6 *launch in February.*



Scientists had four general objectives for the 1971 missions, including the search for "exo-biological activity, or the presence of an environment that could support exo-biological activity." They hoped to gather information that might help answer nagging questions about the origin and evolution of the solar system. A third goal was to collect "basic science data related to the general study of planetary physics, geology, planetology, and cosmology." The specialists were also interested in information that would assist in planning and designing a Viking lander mission on Mars, especially data that would affect landing site selection.

Five specific investigations also demanded the attention of the planetary scientists. The orbiter cameras would provide imagery that could update topographic maps of the planet's surface. The television team, led by Harold Masursky of the U.S. Geological Survey, anticipated photographs of a much higher quality (better resolution) than those taken by the 1964 and 1969 spacecraft. These images, and other orbiter sensors, would also allow the scientists to examine time-variable surface features. Some specialists thought the most obvious of these features—the "Wave of Darkening"—was seasonal. Were the variations the results of moisture, vegetation, or the movement of air-borne dust?[11] The long stay in orbit also would permit study of the composition and distribution of the Martian atmosphere, to gain clues about the planet's weather. A fourth area of study included temperature, composition, and thermal properties of the planet's surface; scientists would be looking for warm spots where life forms might have had a chance to survive. And the Mariner investigators wanted a closer look at the seasonal waxing and waning of the polar caps.[12] Besides studying these five areas, scientists would also be getting information on the internal activity, mass distribution, and shape of the planet.

To meet the objectives, the Mariner Mars 71 mission plan called for two spacecraft to perform separate but complementary missions. Mission A was designed primarily as a 90-day reconnaissance. The orbital path would give the spacecraft instruments a look at a large portion of the planet's surface. Orbiting the planet every 12 hours, the flight path would permit communication with the Goldstone tracking station during a lengthy portion of every alternate orbit. Mission B would study more closely the time-variable features of the Martian atmosphere and surface for at least 90 days, moving in a wide, looping orbit around the planet once every 32.8 hours.[13] Nicks believed that the Mariner 71 orbit missions and the 1973 Viking orbiter-lander flights would be powerful study tools, permitting man to gain at least partial answers to several important questions: "Is there life elsewhere? Has life existed on nearby planets and disappeared for any reason? Can nearby planets be made suitable for life?"[14] But before they could begin to look for answers, the NASA-contractor team had to build the hardware.

Engineers at JPL had a basic philosophy about incorporating changes into each new generation of spacecraft: modifications would be included to

(1) adapt the previous design to unique requirements for the new mission,

(2) overcome difficulties demonstrated in the previous mission, and
(3) incorporate new technology when a major improvement would provide a significant benefit in cost, weight, or reliability.[15]

The Mariner 71 spacecraft designers wanted to carry over as much of the design of the early Mariner spacecraft and ground equipment as possible. As they were quick to point out, the repeated use of experienced personnel, procedures, documentation, and facilities was a benefit to the project during tests, launch, and flight operations. The Mariner 71 spacecraft grew in size, weight, and complexity, however.

Table 27
Mariner 69 and 71 Spacecraft Comparisons

Spacecraft Feature	Mariner 69	Mariner 71
Shape	Octagonal magnesium frame	Octagonal magnesium frame
Size	127 cm diagonal; 45.7 cm depth	138.4 cm diagonal; 45.7 cm depth
Solar panels	112 cm x 90 cm (4); 4.0 sq m	215 cm x 90 cm (4); 7.7 sq m
Launch weight	412.8 kg	997.9 kg

Besides growing much larger than its predecessors, Mariner 71 was also taking on a new major task, orbiting the planet Mars, not just passing by. As a consequence, the *propulsion subsystem* had to be completely redesigned to provide the necessary propulsion capability—a 1600-meter-per-second velocity change—to inject the spacecraft into Mars orbit. The 1971 design incorporated a 1335-newton (300-pound-thrust) engine, instead of the 225-newton (51-pound thrust) engine on Mariner 69. Nearly all the components needed for the 1971 propulsion subsystem (valves, regulators, and the like) had been used on previous spacecraft, but they had not been used in this particular combination. Although the propulsion subsystem was a new design, some inheritance from earlier Mariner systems was realized at the parts level by using flight-proven components.

Mariner 71's *data storage subsystem* was a completely new design, too. This all-digital, reel-to-reel tape-recording unit was, however, derived from earlier development activities at JPL. It incorporated selectable playback speeds of 16, 8, 4, 2, and 1 kilobits* per second, with an eight-track capabil-

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**Bit* is the abbreviation for *b*inary dig*it* and stands for the smallest unit of computer-coded information carried by a single digit of binary notation. This form of notation is a system of expressing figures for use in computers that use only two digits, one and zero. A kilobit equals 1000 bits.

ity using two tracks at a time. High-packing density for this electronic information provided a total storage capability of 180 million bits on a 168-meter tape. Data could be recorded at 132 kilobits per second. In this subsystem, there was little or no design-hardware carry-over from previous programs.

Design of the *central computer and sequencer* was altered to increase this onboard system's memory from 128 words to 512 words.* The modification provided the operational flexibility required for orbital operations, permitting repetitive sequences to be carried out. Other changes in the central computer and sequencer led to improved operations between the computer and the sequencer, better checks on stored information, and generally improved control over the spacecraft.

Of the four Mariner 71 onboard science instruments—television, infrared radiometer, ultraviolet spectrometer, and infrared interferometer spectrometer—only one was new to the Mariner series. The *infrared interferometer spectrometer* (IRIS) had been flown on the Nimbus weather satellites. It would provide information on the composition of the Martian atmosphere—measuring water vapor, temperatures at the surface, and the temperature profile of the atmosphere—and would examine the polar caps. Although the instrument was an adaptation of a previous design, many changes had to be made in it so that it worked on Mariner. To Mariner systems engineers, IRIS was a new instrument that they had to incorporate into their spacecraft design.

Television was another subsystem that was extensively modified. Installing two cameras on Mariner 71, the engineers could use circuitry, optics, and vidicon components from other systems. But there were difficulties. The Mariner 69 television equipment had developed background noise problems; a considerable amount of processing had had to be done to both analog and digital signals to convert them into usable video images. And the 1969 system had less dynamic range and was not as adaptable as the scientists needed for the orbiter mission. The Mariner 71 team developed an all-digital television system with eight selectable filters in the wide-angle camera, automatic and commandable shutter speeds, and picture sequencing. Another improvement reduced the effects on the optics of long exposure to the harsh space environment. Relying on existing technology minimized development costs and risks and provided the Mariner 71 scientific team a high-performance television system.

Major changes were made in the *attitude control subsystem* to adapt it to the requirements of orbital flight. To accommodate a new autopilot and computer logic changes, the Mariner 71 engineers designed new attitude control electronics and redesigned the inertial reference unit (a device that

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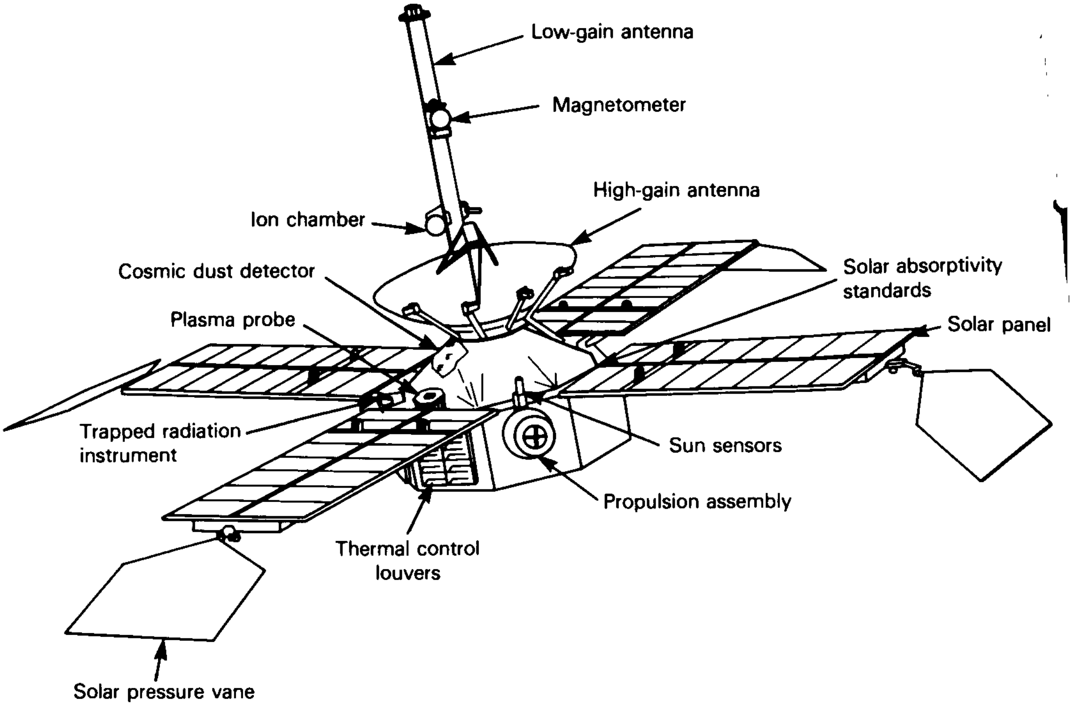
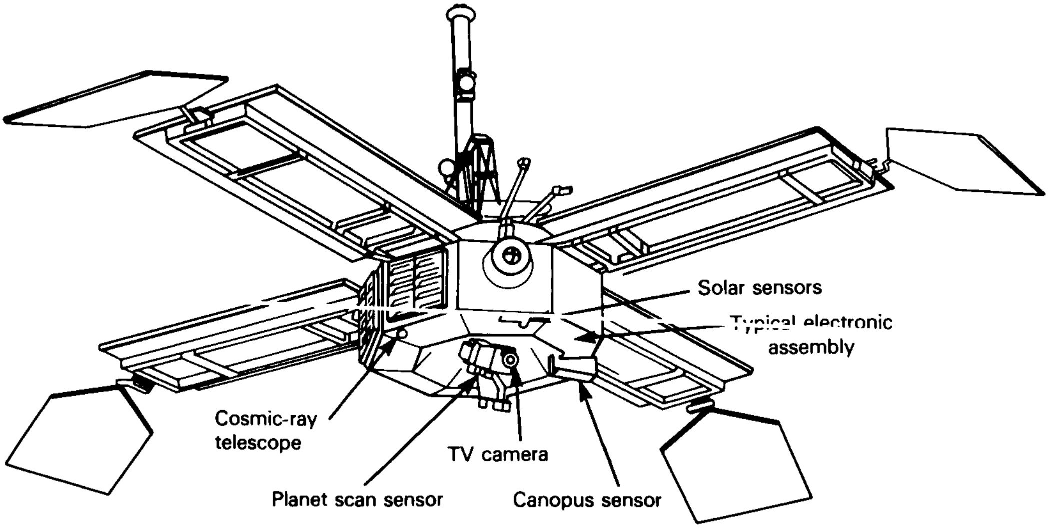
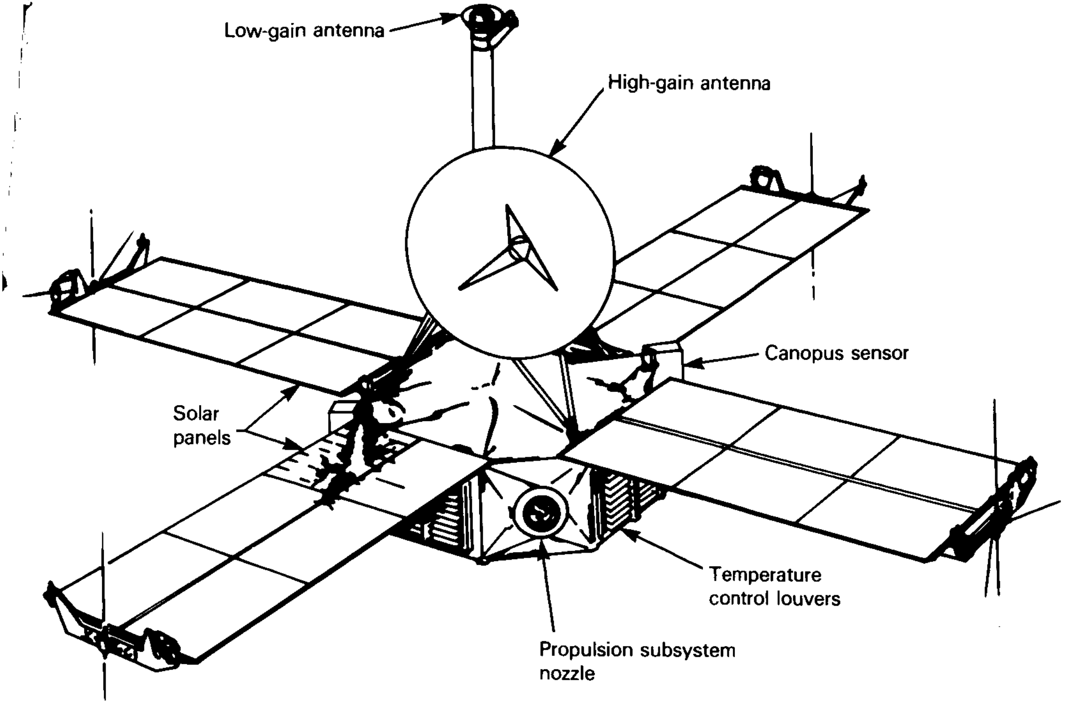
*A *word* in a computer memory is a binary number containing a specific number of bits and is used as the unit of meaning.

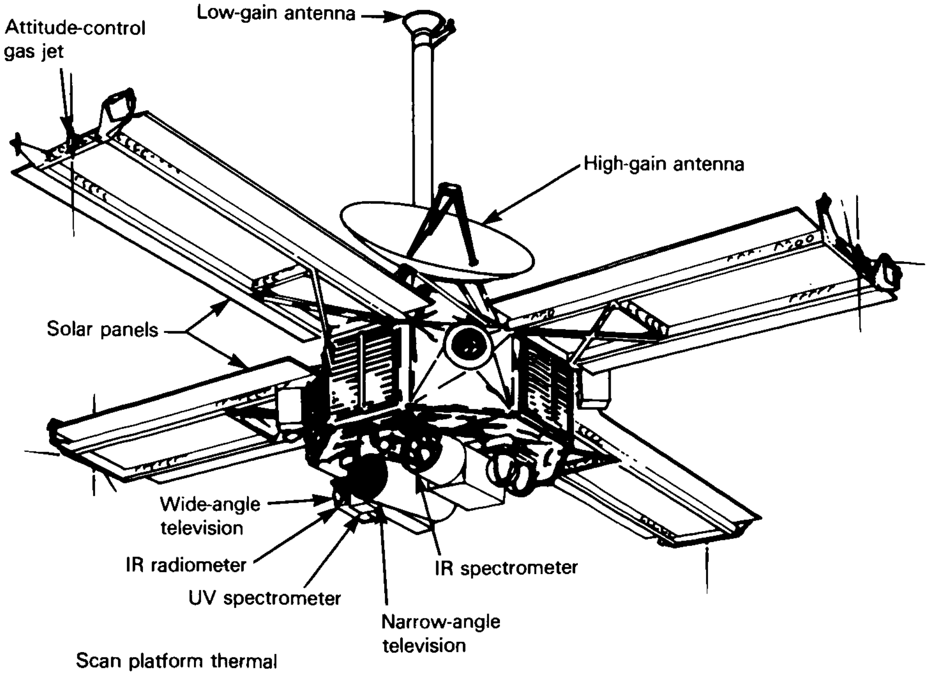
Mariner Mars 1964





Mariner Mars 1969





Scan platform thermal
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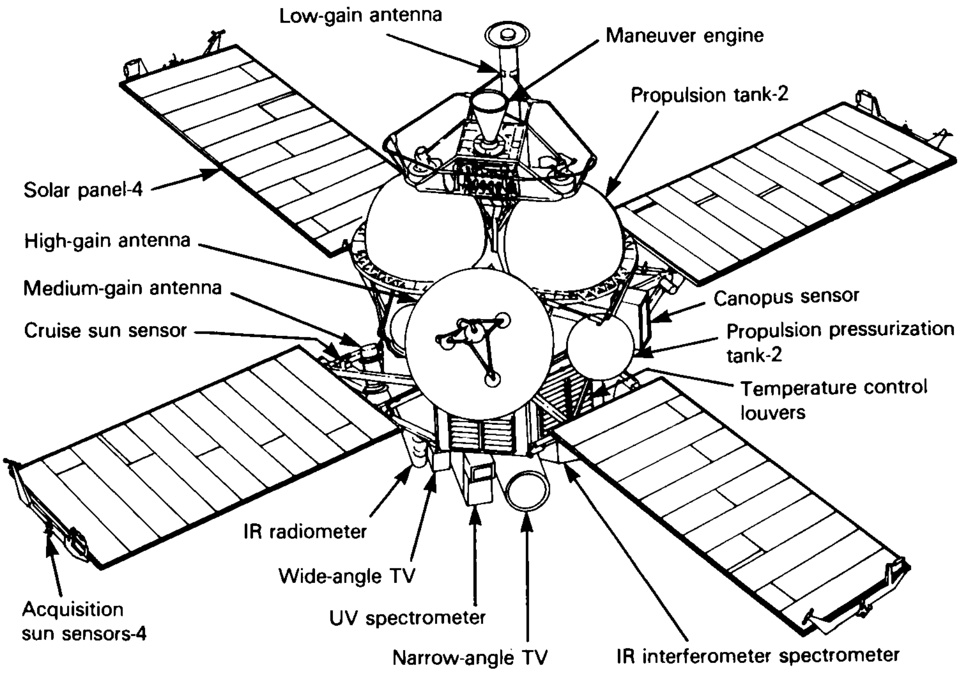
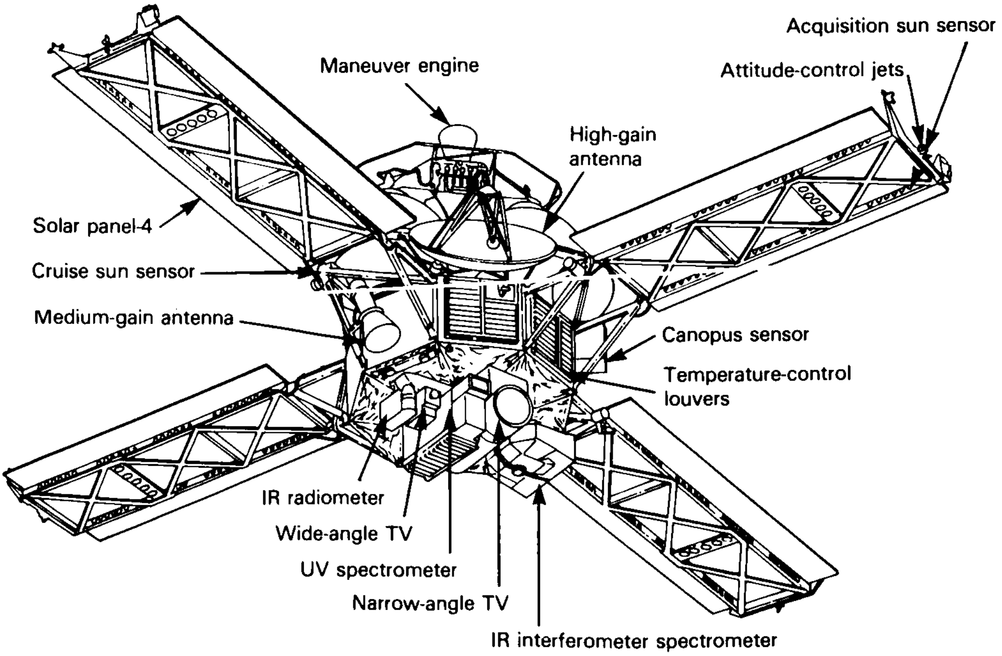
Mariner Mars 1971





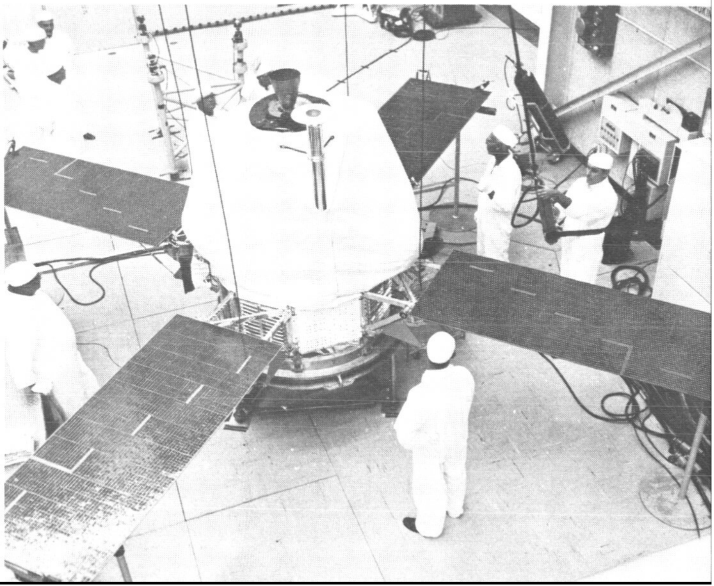
Note: Propulsion module and scan platform insulation blankets not shown.

gives continuous indication of position by integration of accelerations from a starting point). They included an acceleration sensor (accelerometer) that would control the firing duration of the propulsion-subsystem rocket engine. To maintain spacecraft attitude stability, gyroscopes were modified from Mariner 69 hardware. Sensors, both solar and star, which help determine the spacecraft's location in space, were considerably altered for the orbital flight. Mariner 71's attitude-control gas-jet system was similar to the 1969 subsystem with only minor modifications.

The *data automation subsystem* was designed to contain a new logic function to accommodate the requirements of the scientific instruments and orbital flight. Integrated circuitry and packaging techniques were directly borrowed from Mariner Venus 67 and the 1969 Mars craft. The *structural subsystem*, or the basic chassis of the spacecraft, was a successful adaptation of the 1969 octagonal frame. Electrical energy requirements were provided by an adapted *power subsystem*, which used new nickel-cadmium batteries and enlarged solar panels like those used in 1969. The *radio subsystem*, which borrowed technology from the Apollo program was altered to eliminate earlier problems. Other systems requiring only minor changes included command, telemetry, antennas, scan platform control, infrared radiometer, and ultraviolet spectrometer. The Mariner 71 final project report notes, "The design changes which were incorporated underwent considerable review and debate prior to approval so that the maximum inheritance could be realized," keeping the total number of changes the engineers had to make in the Mariner hardware to a minimum.[16]

FIRST PHASE OF VIKING ORBITER PLANNING

Working within this milieu that stressed building on proved technological concepts, the engineers at Langley and JPL also made maximum use of earlier subsystems for the Viking orbiter. First considerations for a design of a Titan-Mars 1973 orbiter mission had begun even before the 1971 Mariner or 1973 Viking flights had been approved. A Titan-Mars orbiter



Assembly of Mariner 9 *at Jet Propulsion Laboratory. The spacecraft's solar panels are spread.*

design team led by Casper F. Mohl was established at JPL in August 1968, with Dalton D. Webb, Jr., as the group's Langley representative.

Casey Mohl was an advanced mission planner at the California lab. He had worked on *Explorer 1* and on several lander capsule studies for Ranger. During the Voyager effort, he had participated in the capsule systems advanced development activities, part of JPL's hard-lander studies. When the laboratory began to work with Langley's Advanced Spacecraft Project Office on the 1973 mission, JPL Director Pickering assigned Mohl and a group of his colleagues to the "pre-project effort," and the men began to study the diameters and weights of possible 1973 orbiters.[17] As they worked, they discovered that every time the Langley people "did something to the lander, it ricocheted back to the orbiter, especially into the [propellant] tank sizing."

Orbiter size was limited by the diameter of the Centaur launch shroud, which was 3.65 meters. Weights considered during the fall of 1968 ranged from 454 to 680 kilograms for the orbiter and 590 to 907 kilograms for the lander. At this early stage in the planning, many suggestions for the mission design were made, including one by JPL engineer Robert A. Neilson that the 1973 flight be made using a 1971 orbiter without scientific instruments or scan platform. Later, of course, such an idea would be unthinkable, but during the mission definition period one of the alternatives called for using the orbiter simply as a bus to deliver the lander to Mars.[18] The two JPL orbiter proposals presented to the Langley Research Center Advanced Space Projects Office on 9 and 30 October did not include any scientific instruments for the orbiting vehicle, as the JPL planners wanted to consider initially only the minimum number of modifications in the 1971 orbiter, just then beginning to take shape on the drawing board.[19]

By mid-November 1968, the JPL advanced planners had gone about as far as they could with the design of an orbiter for 1973 without approval of the project by Congress and the president. But at a 5 December meeting, a very pleased Casper Mohl told the "out-of-orbit" design team that the Titan-Mars 73 project had received the approval of the Bureau of the Budget; they could proceed with the development of an orbiter design while Langley worked on the lander. Although the orbiter science payload would not be defined until the Mariner 69 results were known, John Naugle said that, for planning purposes, the candidate experiment hardware in descending order of priority would include: Mariner 71-style television camera, high-resolution infrared radiometer, infrared interferometer spectrometer, near-infrared mapper, x-ray spectrometer, three-channel ultraviolet photometer, and polarimeter. Projected weights for the orbiter at launch were 1880 to 2130 kilograms, and the lander would weigh between 680 and 920 kilograms, with approximately 70 kilograms allocated for orbital science instruments.[20]

Between mid-November 1968 and mid-February 1969, JPL worked on a "baseline orbiter conceptual design" for the Viking mission, while the project office at Langley concentrated on staffing key management positions. In Pasadena 13–14 February, JPL hosted a review of its conceptual design for the orbiter. The Viking spacecraft (orbiter and lander) was to be launched by a Titan IIID-Improved Centaur, which could lift a combined weight of 3330 kilograms (2513 kilograms for the orbiter and 817 kilograms for the lander). The orbiter and lander would have a minimum life of 90 days after touchdown on Mars. The lander would have communications links directly with Earth stations and through the orbiter, which would serve as a relay satellite.

A key element of the February presentation was the technology that would be borrowed from Mariner 71. For electricity, the Viking orbiter power subsystem was essentially the same as for Mariner 71, providing lander power during transit and early orbital cruise periods. For 50 days of solar occultation during the 1973 mission, the spacecraft would be without the benefit of the sun's energy for one-half to three and one-half hours in each orbit. The increased distance of Mars from the sun during the Viking mission and the revised science instruments also led to some new requirements for the power system. New solar panels were designed, along with a new battery and battery charger. Minor changes were made in the power distribution circuitry, but the core of the entire system was borrowed from Mariner design.[21]

Industry representatives would later write to James S. Martin, Viking project manager at Langley, complaining about JPL's conservative orbiter design. L. I. Mirowitz, director of planetary systems at McDonnell Douglas Astronautics Company in St. Louis, believed that "spacecraft performance could be judiciously improved by considering" some newer components; "for example, the [central computer and sequencer] has a 512 word sequencer weighing [12.5 kilograms], the current state of the art permits use of a lander computer and sequencer that has a 6000 word capacity and weighs [11.3 kilograms]."[22] A. J. Kullas at the Denver Division of Martin Marietta Corporation also believed that weights could be reduced and performance improved by being less conservative than JPL had been in its engineering. In one instance, Kullas suggested that newer kinds of electrical cabling would permit a weight reduction from about 49 kilograms to 39, a saving of 20 percent.[23] While there was no doubt that the JPL baseline orbiter design could be improved, the conservative engineering was not unreasonable in an era of stringent budgets and equally tight schedules. Building on previously proved hardware concepts helped to ensure spacecraft reliability within the budget and on time. The specialists at JPL evaluated alterations to the basic design, and the orbiter did change over time, but conservative engineering prevailed.[24]

Organizing Orbiter Management

Early in April 1969, a formal Viking Orbiter Office was set up at JPL to replace the ad hoc arrangements that had existed since the official initiation of the 1973 landing project. Pickering announced the establishment of the management office on the 17th and named Henry W. Norris Viking orbiter manager. Casey Mohl's team went out of business at about the same time, and some of the members of that group joined Norris. A native Californian and graduate of UCLA, Norris had worked in aviation and space activities at General Precision Inc. before joining JPL at the age of 41 in 1963. During the Mariner Mars 69 mission, Norris served as spacecraft systems manager. Kermit S. Watkins, deputy to Norris, came to the Viking project from the JPL Office of Flight Projects, having also been assistant program manager for the Surveyor lunar landers.[25]

Other key personnel members appointed to the orbiter team by Director Pickering included Allen E. Wolfe, spacecraft systems manager, and Conway W. Snyder, Viking orbiter scientist. Wolfe had been spacecraft systems manager for Project Ranger and for the *Mariner* 5 Venus mission in 1967. A nuclear physicist by education, Snyder had worked at the California Institute of Technology on Navy rocket research projects during World War II. He joined the JPL physics staff in 1956 and was principal investigator on three space experiments that studied the solar wind, becoming *Mariner* 5 project scientist.[26] While Norris, Watkins, Wolfe, and Snyder were essential, highly visible members of the orbiter staff at JPL, they represented only the top of a large pyramid. When the orbiter management held its first weekly staff meeting on 1 April 1969, Norris told the participants that their sessions were not designed to resolve problems, but to discuss them "in sufficient depth to understand and identify items for separate action."[27]

One of the immediate concerns of the project managers was the growing cost of the orbiter as projected in periodic estimates. Early in February, Charles W. Cole, manager of the Advanced Planetary Missions Technology Office at JPL, informed Martin that the hardware for the total orbiter system (two flight craft, spares, and test models) would cost nearly $147 million, while the total amount needed by the California laboratory to get the orbiters ready for flight, with test equipment and facilities, would be $161 million. Cole attributed the high figures to recent increases in hardware requirements, accelerated delivery schedules, and more extensive test procedures. The Viking orbiter would require several major pieces of new hardware (table 28), and the designers at JPL had based their cost projections for this equipment on the master schedule given them by the Viking Project Office. But the people in California did not believe that the schedule was realistic. For example, the JPL engineers were convinced that such an early delivery date for the engineering test model of the orbiter would require a major acceleration of orbiter system and subsystem design plans, which in turn would demand an earlier selection and design of scientific

Table 28

Major Test and Flight Hardware to be Developed by JPL for the Viking Orbiter

Equipment	Purpose or Function of Equipment	Scheduled Delivery Dates As of 10 Feb. 1969	As of 13 Mar. 1969	As of 7 Aug. 1969
Orbiter structural test model (STM)	Also called development test model (DTM). For qualification testing of basic orbiter structure, including vibration, static modal, and separation of orbiter from lander tests.	mid-Feb. 1971	15 Sept. 1971	15 Aug. 1971
Thermal control test model (TCM)	For thermal qualification of orbiter systems. During tests, TCM to be mated with lander capsule thermal effects simulator to test effects on orbiter of lander heating. Both STM and TCM to be returned to JPL by 1 Aug. 1971 for laboratory testing.	1 Mar. 1971	1 Dec. 1970	1 July 1971
Engineering test model (ETM)	To validate physical and functional interfaces between orbiter and lander capsule and between spacecraft and people, procedures, and facilities associated with combined systems tests. To be assembled from early production components for orbiter; flight-qualified parts not necessary. Could be updated after tests for use in Deep Space Network compatibility testing and launch center testing.	1 Aug. 1971	1 Dec. 1971	1 Feb. 1972
Proof-test model (PTM)	To demonstrate orbiter design adequacy by performance of qualification tests, including vibration, shock, and thermal/vacuum. Also to be used for propulsion-system-interaction tests.	1 Feb. 1972	15 July 1972	1 Aug. 1972
Flight orbiters	Three flight-ready orbiters to be fabricated by JPL, two to be launched, and third to be held as backup before launch and as systems test vehicle during mission.	1 Aug. 1972 1 Sept. 1972 1 Oct. 1972	15 Oct. 1972 15 Nov. 1972 15 Dec. 1972	1 Jan. 1973 1 Feb. 1973 1 Mar. 1973

SOURCE: "Viking Project Performance and Design Requirements Specification," n.d., encl. to S. R. Schofield, "Minutes of the 17th Viking Orbiter Design Team Meeting Held 20 March 1969," memo, 24 Mar. 1969; Charles W. Cole to James S. Martin, "JPL Resource Requirements for Viking Project," 10 Feb. 1969; Langley Research Center, "Viking Project Orbiter System (VOS) Master Working Schedule," 13 Mar. 1969; and LaRC, "Viking Project Orbiter System (VOS) Master Working Schedule," 7 Apr. 1969.

instruments and related equipment than JPL had planned. These schedule changes would have to be translated into direct dollar increases. But even extra dollars could do only so much toward relieving the problems imposed by the increased tempo. Cole wrote to Martin, "In JPL's opinion, the significant schedule risk . . . is not further reducible by bringing additional money and manpower to bear." What they would need was close coordination among the Viking Project Office at Langley, the lander contractor, and the JPL orbiter team to minimize the risks if they were to build a program that was "suitably balanced and mutually acceptable."[28]

During the spring months of 1969, the orbiter schedules were revised by the project office to give Pasadena teams some more time and the budget a little breathing room. Rising expenditures, however, continued to be a major concern of Viking personnel on both coasts, although evaluating the budget promised to become a more comprehensible, concrete process once the agency selected an industrial contractor to design and build the lander. Only then would they be able to determine a firm figure for the cost of the entire project.[29] In late February 1969, NASA had issued a request for proposals for the lander and, on 29 May, selected Martin Marietta Corporation from the three bidders for the contract. With this choice made (discussed in chapter 7), the Viking project entered a new phase.

Early in June when Jim Martin and his colleagues met with representatives from the new lander contractor and JPL, nine working groups were established. Of these, one of the most important, from the perspective of the budget and scheduling, was the spacecraft interface and integration working group. Formed as the "common ground" for discussion between the Viking Project Office at Langley and the spacecraft builders at JPL and Martin Marietta, this working group allowed the three organizations to exchange information and ideas on spacecraft construction and hardware interface. Donald H. Kindt at JPL was named the Viking orbiter/lander capsule integration engineer. The interface-integration working group met for the first time on 10 and 11 June and, after their sessions, representatives from all three organizations took "action items" home to consider before they met again.[30]

Another aspect of the increased tempo was the further proliferation of committees and working groups. By the end of June 1969, the amount of paperwork reaching Henry Norris's desk at JPL was growing dramatically. All managers in NASA programs, whether government or contractor employees, had to become accustomed to reading thousands of letters, memoranda, telexes, meeting minutes, reports, and other documents in the course of a project. Besides the meetings of the orbiter design team, 28 other conferences had been held by the end of June. The Viking orbiter project staff had held 12 meetings by 2 July, and the Viking orbiter mission design team started a new series of work sessions on 30 June. By the time the orbiter was ready to fly, the personnel of the orbiter design team (and its successor, the orbiter system design team), who oversaw the spacecraft's design and fabrication would meet formally more than 250 times. The mission planners who worked out the flight details for the orbiter—navigation and tracking—met 143 times before the Viking launches.

Although Kermit Watkins noted as early as August 1969 that "we are beginning to become inundated with documentation," all the meetings and paper allowed Norris and his orbiter team to keep abreast of the myriad of details that went into planning and building the spacecraft. At the Viking Project Office in Hampton, Virginia, Jim Martin used similar tools to keep tabs on the progress or lack of progress of the lander. Viking was not brought to fruition by paperwork alone, but the mountain of documents the teams left behind provides some clues to the enormous number of man-hours that went into getting the project off the ground.[31]

During the remainder of 1969, the Viking orbiter personnel worked on a number of key tasks in defining the design of the spacecraft and the nature of its scientific payload. Norris participated in the first meetings of the Viking Project Management Council; Norris, Watkins, and their colleagues worked out the second and third versions of the "Viking mission definition" document; orbiter staff members received a briefing on the preliminary science results of Mariner Mars 69; and the staff took part in the first quarterly review of the whole project. These activities were typical of activities during the next five years.

Viking Project Management Council

Jim Martin formed the Viking Project Management Council* in March 1969. Since Viking was the first planetary project in which several NASA centers and contractors would be participating in the design, development, and operation of major spacecraft elements, the project manager believed that a management council would "facilitate common understanding of the overall project objectives and provide a forum where technical and management problems can be freely discussed." At the first meeting, 18-19 August at the Martin Marietta factory outside Denver, each of the systems managers gave a brief status report on his organization's work to the 50 persons attending.

Henry Norris outlined the orbiter design, covering such topics as the relationship between the orbiter and lander during the cruise phase of the trip to Mars, the orbiter's weight budget, and communications equipment for the Viking spacecraft. Noting that orbiter and lander weights were a recurring concern, he told Martin and the other participants at the council meeting that a system of weight bookkeeping must be established between Langley and JPL. By this time, the entire spacecraft was projected to weigh

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*Membership in the council included J. S. Martin—chairman, W. J. Boyer, H. E. Van Ness, I. Taback, F. W. Bowen—secretary, and E. A. Brummer, Langley; R. H. Gray, Kennedy Space Center; W. Jakobowski, NASA Headquarters; E. R. Jonash, Lewis Research Center; A. J. Kullas, Martin Marietta; and H. W. Norris and N. A. Renzetti, JPL.

3316 kilograms, with the weight of the orbiter at 605 kilograms without propellants. Jim Martin agreed; someone from the Viking Project Office would be assigned to the problem. Norris also reported that procurement had begun for the orbiter components and work was already under way on tasks that would require a long lead-time. The spokesman from JPL noted in summary that additional orbiter personnel at the laboratory would be selected shortly, including some persons that were finished with their Mariner 69 activities.[32]

Once all the systems managers gave their reports, 13 working group chairmen presented information about their work. Norris later told his colleagues at the Jet Propulsion Laboratory that the sessions "proved to be very beneficial in helping to identify and clear the air on a number of interface concerns." In particular, the two days of discussion helped to clarify the roles and responsibilities of individuals and organizations.[33] Equally significant, it gave the managers from scattered geographic locations an opportunity to meet with one another. Face to face, they could take the measure of their colleagues as they worked on problems of mutual interest. This and subsequent meetings of the management council would force the men to work with other human beings, not faceless signatures on memos. The council was just one part of Jim Martin's strategy for forging a team from a group of disparate individuals and organizations.

VIKING MISSION DEFINITION NO. 2

The Viking project definition document was another element in Jim Martin's attempt to create a viable Mars exploration activity. Revised several times, the document gave project participants a general description of the Viking missions. By August 1969, the document had been updated five times, the latest edition being called "Viking Project Mission Definition No. 2." This 21-page paper was prepared by a group working under A. Thomas Young, the science integration manager, at Langley. Three men had to approve it before it was released 11 August 1969—Gerald Soffen, project scientist; Israel Taback, engineering manager and deputy project manager; and Jim Martin. "Viking Project Definition No. 2" contained a more nearly complete description of the entry and lander science experiments that would be included in the lander capsule and the lander. These experiments had been defined through the work of the Science Steering Group, chaired by Jerry Soffen.[34]

In August 1969, there were eight science instrument teams: orbiter imaging, biology, molecular analysis, meteorology, entry science, radio science, seismology, and ultraviolet photometry. Each of the lander experiments was further described in the "Viking Lander Science Instrument Teams Report," which served as an important reference on the state of instrument design, the scientific rationale for the experiments, and for studies that might lead to ways of increasing the scientific capability of the instruments. The instrument team report and "Viking Project Definition

No. 2" provided the basis for spacecraft design negotiations with Martin Marietta and the starting point for "early Project activity including the initiation of mission, spacecraft and operations design."[35] Although the mission definition was geared toward getting lander hardware design and fabrication started, it also had significant impact on the orbiter design team.

Henry Norris told his people at a 27 August staff meeting that the mission definition had been distributed to all the JPL division representatives. Since this was a controlling document for the project, Norris's team would have to reconcile its "resources," or budget, with its baseline definition of the orbiter. Some differences existed, for example, between the communications requirements as stated in the definition document and as pursued by the JPL engineers. "The main requirement causing a significant impact is that of the orbiter having the capability to communicate with either lander." Norris asked division representatives "to flag any other areas of disagreement."[36]

As Norris and his staff worked on the orbiter design, the mission definition continued to evolve. A number 3 edition would be ready in January 1970 after the final selection of science investigators by NASA Headquarters in December. The number 4 version would be prepared in the early spring of 1971, reflecting any changes that came from the Viking project critical design review. Finally, some time after June 1972, "Viking Project Mission Definition No. 5" would be issued to reflect lessons learned from the Mariner 71 mission. From October 1969 onward, the mission definition documents would be used in conjuction with "project specification" documents to monitor the effort.[37] Meanwhile, the science results from *Mariner 6* and *7* had to be incorporated into the Viking plans.

MARINER 69 SCIENCE RESULTS

Scientific investigators from the Mariner 69 team presented a series of briefings and press conferences on their findings from the Mars flyby missions. The first major briefing and press conference were held on 11 September 1969, the day the preproposal briefings for prospective Viking science investigators were scheduled in Washington. While less tentative than the results presented at a 7 August press meeting, John Naugle indicated that the September briefings were really only progress reports. The final meeting of the scientists was scheduled for spring 1970, and more detailed accounts of individual experiments would be published in various journals.

Robert Leighton described the results of the television experiment at the September science briefing. "Before the space age, Mars was thought to be like the Earth, polar caps, seasons, . . . rotates in 24 hours, etc." This view of the Red Planet "was largely the legacy of Percival Lowell who popularized the idea of reclamation projects to get the water supposedly from the polar caps down to the equator where the farmers were." Although scien-

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tists had rejected the Lowell ideas of an inhabited Mars long before *Mariner 4*, they were not prepared for the stark, lunarlike images acquired during that mission. Pictures from *Mariner 6* and 7, according to Leighton, showed that Mars was "like Mars," with its own characteristic features, "some of them unknown and unrecognized elsewhere in the solar system."[38]

Leighton noted during the press conference that areas to be photographed by the Mariner 69 missions had been chosen to "cover as many different kinds of classically recognized features on Mars as possible, dark and light areas, oases." *Mariner 6*'s track traversed the equatorial zones and crossed a great many light areas, such as the circular great desert of Hellas, and dark areas, like the region called Hellespontus. *Mariner 7* took a sweep of pictures along a meridian (north to south) that included the south polar cap. The 60-fold increase in the data transmission rate produced for the 1969 spacecraft yielded many more pictures than the scientists had originally hoped.

Table 29
Pictures from Mariner Mars 69

Mission	Original Projection		Pictures Returned		Total Useful Pictures
	Far Encounter	Near Encounter	Far Encounter	Near Encounter	
Mariner 6	8	25	50	26	428
Mariner 7	8	25	93	33	749
Total	16	50	143	59	1177

Because of the large number of craters, the television team described Mars as more moonlike than Earthlike. In the *Mariner 6* near-encounter frame 21, which covered a territory of 625 000 square kilometers, there were 156 craters ranging in diameter from 3 to 240 kilometers. There were many hundreds more that were 500 meters across or smaller. The classical area Nix Olympica (18°N, 133°) was identified as a very large, "white-rimmed" crater some 500 kilometers in diameter, with a bright spot in the center. Cratered terrain, the parts of the Martian surface on which craters are the dominant topographic form, were widespread in the southern hemisphere. Although knowledge of cratered terrain in the northern hemisphere was limited, since fewer photographs were available, some cratered areas appeared as far north as 20°. Two kinds of craters were seen in the pictures, large and flat-bottomed and small and bowl-shaped. Flat-bottomed craters were most evident in *Mariner 6* frames 19 and 21, and their diameters ranged from a few kilometers to a few hundred. Shallow, they had a diameter-to-depth ratio of 100:1. The smaller, bowl-shaped craters, best seen in *Mariner*

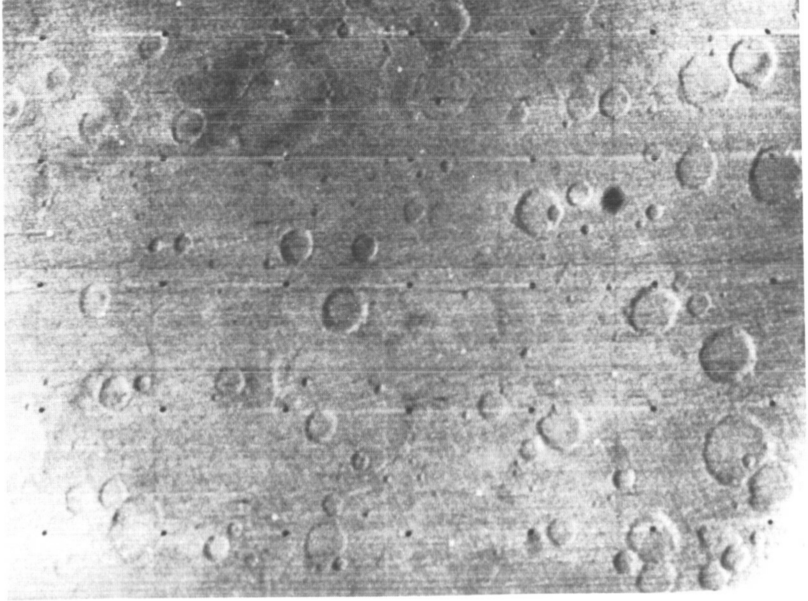
6 frames 20 and 22, resembled lunar primary impact craters, and some of them had interior slopes steeper than 20 degrees. The flat-bottomed craters were of interest to the Mariner 69 investigators because they were unlike most craters discovered on the moon.

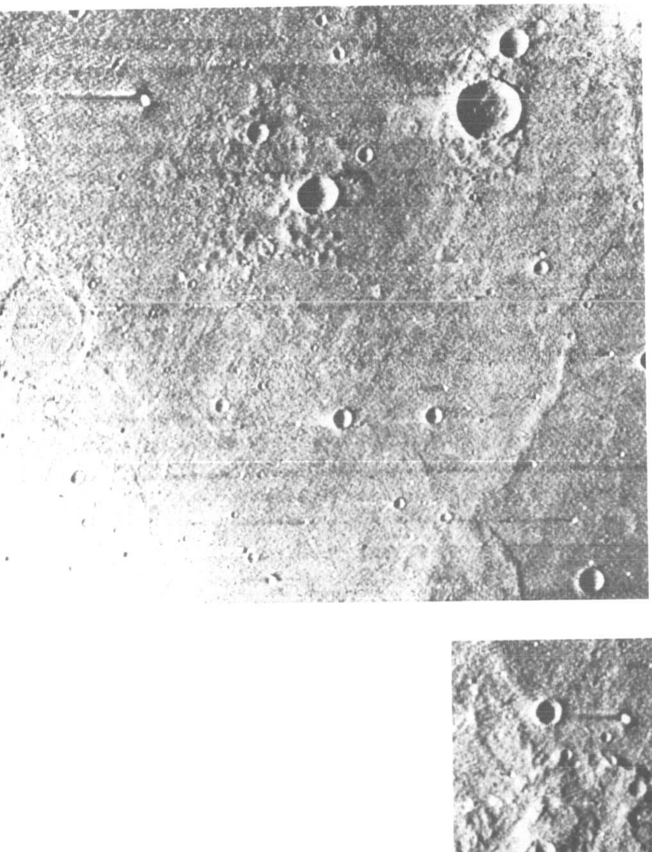
The chaotic terrain was a puzzle. *Mariner 6* frames 6, 8, and 14 illustrated "two types of terrain—a relatively smooth cratered surface that gives way abruptly to irregularly shaped, apparently lower areas of chaotically jumbled ridges." A belt of the latter terrain lay within a band 1000 kilometers wide and 2000 long at about 20° south, between the dark areas Aurorae Sinus and Margaritifer Sinus. Perplexing the scientists because it was nearly craterless, this region of short ridges and depressions was unlike anything on the moon.

Hellas, centered at about 40° south, was the best example of the so-called featureless terrain. At the resolution limit of the 1969 cameras (the cameras could not see objects smaller than 300 meters in diameter), this desert area appeared devoid of craters. Leighton and his colleagues noted: "No area of comparable size and smoothness is known on the moon. It may be that all bright circular 'deserts' of Mars have smooth floors; however, in the present state of our knowledge it is not possible to define any significant geographic relationship for featureless terrain."

Especially bothersome was the fact that pictures taken during the *Mariner 7* traverse showed that the dark area Hellespontus, west of Hellas, was heavily cratered. "The 130- to 350-kilometer-wide transitional zone is also well cratered and appears to slope gently downward to Hellas, interrupted by short, en echelon scarps and ridges." Once the flat floor of Hellas was reached, the craters disappeared. "Craters are observed within the transitional zone but abruptly become obscured within the first 200 kilometers toward the center of Hellas." The possibility of an obscuring haze was rejected because in *Mariner 7* frame 26 "the ridges of the Hellas-Hellespontus boundary are clearly visible, proving that the surface is seen; yet there are virtually no craters within that frame. Thus the absence of well-defined craters appears to be a real effect."[39]

In seeking to explain the relationship of these various kinds of terrain to the light and dark markings noted in telescopic observations, Leighton and his colleagues had a number of thoughts. First, the contrast of light and dark markings on Mars varied with wavelength, as had been known for a long time from telescopic photography. In the violet range of light, "bright" and "dark" areas were essentially indistinguishable since they have approximately the same reflectivity. With increasing wavelength, contrast was enhanced as redder areas became relatively brighter. The distinction between bright and dark areas on the surface was usually more obvious in far-encounter views than in near-encounter views. The clearest structural relationship between a dark and a bright area was that of Hellespontus and Hellas. Chaotic terrain appeared lower in elevation and at the same time more reflective than the adjacent cratered areas. Whether chaotic





Mariner 6 *took near-encounter photos of Mars on 31 July 1969. Frame 19 (above), 3613 kilometers from the surface, shows flat-bottomed craters a few kilometers to a few hundred wide. High-resolution frames 20 (left) and 22 (below) show smaller, bowl-shaped craters, resembling primary impact craters found on the moon.*

terrain was extensive enough to include previously identified bright areas remained to be determined. Still, some of the areas traditionally thought of as oases were being identified with large, dark-floored craters such as Juventae Fons or with groups of craters such as Oxia Palus. In addition, at least two classical "canals" (Cantabras and Gehon) coincided with the quasi-linear alignment of several dark-floored craters. Other canals, showing up as irregular dark patches, would probably on closer inspection be associated with a variety of physiographic features. Leighton and his colleagues reported another correlation with earlier observations. Some drawings and "maps" of Mars portrayed a circular bright area within the dark region south of Syrtis Major and east of Sabaeus Sinus. In the Mariner 69 pictures, the investigators found a large crater in approximately the same place. The experimenters hoped to devote many hours to a comparison of these new Mariner pictures with earlier maps and photographs in an attempt to identify topographical features.

Clues to Evolution of Mars

What did the *Mariner 6* and 7 pictures tell scientists about the evolution of the planet's surface? The absence of Earthlike tectonic forms indicated that in recent geologic time the crust of Mars had not been subjected to the kinds of internal pressures that have modified and continue to modify the surface of Earth. Since the larger craters probably had survived from a very early time in the planet's history, the scientists inferred that Mars' interior is, and probably has always been less active than Earth's. The TV experimenters noted that one theory argues that Earth's "dense, aqueous atmosphere may have been formed early, in a singular event associated" with the creation of the planet and its core. Tectonic features, therefore, might be related in origin to the formation of a dense atmosphere, and "their absence on Mars independently suggests that Mars never had an Earthlike atmosphere."

Building their case further for the unearthly nature of Mars, the television specialists commented on the age of the cratered terrains, comparing Martian surface features with similar features on the moon. Both bodies showed heavily cratered and lightly cratered areas, evidently reflecting regional differences in meteoroid bombardment, or response to it, over the life-span of the surfaces. The thin atmosphere on Mars (contrasting with no atmosphere on the moon) possibly had produced recognizable secondary effects in crater form and size distribution. Also, the scientific community generally accepted that the number of craters on the moon could not have been produced in its 4.5 billion years at the estimated present rate of impacts. An early era of high bombardment must have been followed by a long period at a greatly reduced rate. A rate per unit area as much as 25 times that on the moon was estimated for Mars. Since even the most heavily cratered areas seemed to have aged relatively uniformly, "this again suggests an early episodic history rather than a continuous history for cratered Martian terrain, and increases the likelihood that cratered terrain is primordial."

The existence of primitive, undisturbed terrain on Mars would have a number of important ramifications, especially for scientists looking for extraterrestrial life:

> If areas of primordial terrain do exist on Mars, an important conclusion follows: these areas have never been subject to erosion by water. This in turn reduces the likelihood that a dense, Earth-like atmosphere and large, open bodies of water were ever present on the planet, because these would almost surely have produced high rates of planet-wide erosion. On the Earth, no topographic form survives as long as 10^8 [100 million] years unless it is renewed by uplift or other tectonic activity.[40]

Extrapolating further from this line of reasoning, the scientists found that the Martian environment apparently had not changed much during the life of the planet; thus, there was little possibility of a dense atmosphere or water that could have aided the evolution of primitive life forms.

Norman Horowitz, a biologist at Cal Tech and long-time participant in NASA exobiology studies, thought nothing in the new data encouraged the belief that Mars harbored life. "But the results also don't exlude this possibility." This was essentially what the exobiologists had expected, since Martian life was almost certainly microbial if it existed and would not be easily detected from flyby missions. "We have certainly seen no signs of the noble race of beings that built the canals or launched the satellites of Mars. I'm pretty sure they don't exist." *Mariner 6* and 7 data did strengthen the earlier conclusion that water was extremely scarce on Mars and that was a seriously limiting factor for the search for life. While no clouds, frosts, or fogs had been seen in the new pictures, minute amounts of water vapor had been detected in the atmosphere. "Mars is a cold desert by terrestrial standards. If there is life on Mars, it must be a form of life that can utilize water in the form of water vapor or ice." Horowitz added that it was possible that "extensions of our own terrestrial life, evolutionary adaptations," could live under such conditions. The exobiologist repeated what he had said many times: "The search for life on Mars is not sustained by optimism about the outcome. Anyone who is carrying on this work because he is sure he is going to find life, I think, is making a mistake. The search is sustained by the tremendous importance that a positive result would have, scientifically and philosophically, and until then we are obliged to continue the search." One of the major reasons they were exploring the Red Planet for life was to test their current notions about the origin of life. "We don't want to fall into the logical trap of using these notions to disprove in advance the possibility of life on Mars. We want to get there and make a direct test."[41]

Effects on Mariner 71 and Viking

Leighton, during the 11 September 1969 press conference, said that each Mariner spacecraft had "in its turn revealed a new and unexpected, no doubt significant kind of terrain. . . . Now I leave it to you to figure out how many new surprises there are still waiting for us on Mars." While Mars spacecraft evolved from one mission to the next, Leighton believed that he and his colleagues should not "fight the last war" with the Viking spacecraft. Instead, they must realize that they were still only in the initial stages of exploring Mars. "Flexibility in design [and] adaptability in execution" were incredibly important.[42]

The distinctive new terrain revealed in the Mariner 69 pictures emphasized the importance of "an exploratory, adaptive strategy in 1971 as opposed to a routine mapping of geographic features." Very early in the first 90-day Mariner 71 mission, all of the planet should be examined with the A-camera, and selected targets should be studied with the higher-resolution B-camera, to correlate the extent and character of cratered, chaotic, and featureless terrains, and any new kinds of terrain, with classical light and dark areas, regional height data, and so on. Leighton and colleagues thought that a second objective should be the search for and examination of areas that indicated the possible presence of local water. The complex structure found in the south polar cap called for close investigation, particularly to separate the more permanent features from those varying daily or seasonally. A look at the north polar cap also promised to be "exceedingly interesting."

"If the effects of the Mariner 6 and 7 results on Mariner '71 are substantial, they at least do not require a change of instrumentation, only one of mission strategy. This may not be true of the effects on Viking '73." The Mariner 69 television specialists believed the discovery of so many new, unexpected properties of the Martian surface and atmosphere added a new dimension to selecting the most suitable landing site for Viking. Viking might be even more dependent on the success of Mariner 71 than had been supposed. From the improvement in the image resolution obtained by the 1969 B-cameras, scheduled also for use on Mariner 71, the team thought that an improved system might profitably be included in the Viking orbiter, designed to examine the fine-scale characteristics of terrains even more closely before choosing a landing site.[43]

At its 11 September meeting, the Viking Science Steering Group agreed that a joint meeting of Mariner 69, Mariner 71, and Viking 73 scientists would be useful. Jerry Soffen suggested that such a session would permit a more thorough examination of the *Mariner 6* and *7* information. At the same time, the science strategies for later flights to Mars could be more widely discussed. Plans called for the joint meeting to be held in early 1970 after the final selection of Viking investigators. Generally, Viking interest in the polar regions as a target for primary investigation diminished after hearing the early Mariner 69 reports.[44]

The Viking orbiter science briefing on 12 September concentrated largely on the orbiter imaging system and its role in providing pictures that would help find landing sites. Orbiter science objectives included:

- obtaining information for landing site selection for Viking,

- obtaining repeated coverage of landing sites during the lifetime of landers on the surface,
- obtaining information for selecting landing sites for future missions,
- making scientific investigations using the orbiter radio system, and
- obtaining information for studying the dynamic characteristics of the planet and its atmosphere.

Of the 57 kilograms alloted for orbiter science instruments, more than half (32 kilograms) was set aside for the imaging system. For many months, the specialists would discuss alternative approaches to the design of the camera system, as technical and fiscal issues affected the final design of this important piece of Viking hardware.[45]

QUARTERLY REVIEW

As another step toward regularizing the management of the Viking project, Jim Martin arranged for the first of a series of project-wide quarterly reviews at the end of the first week of October 1969. Each systems manager was given 90 minutes to summarize progress in his area of responsibility. Henry Norris noted that this process was less detailed than the reports he had given in similar reviews at JPL in the past; instead his presentation was "delivered in tutorial style."[46] What is the orbiter? What is its function? How does it work? What is the progress to date? Are there any problems? If so, do they affect other systems and what steps are being taken to solve the difficulties? Over two days, many, many topics were covered.

The JPL presentations on the orbiter were typical of those given during the quarterly review. Norris opened with a brief overview of the schedule for the orbiter and his projected activities for the next three months. Richard K. Case of the orbiter design team reported on the configuration of the orbiter as it had evolved to date, summarizing telecommunications plans for the orbiter, lander, and Earth stations and briefing the group on steps being taken to integrate scientific experiments. Peter T. Lyman told his colleagues about the orbiter guidance and control propulsion subsystem, a complex subject to master. Lyman, a new member of the orbiter team, was the perfect man to tackle it. After 10 years at the University of California at Berkely, he had worked on Mariner 64 and helped plan hardware for the ill-fated Voyager. During Mariner 69, Lyman had been the project engineer from the Engineering Mechanics Division, overseeing much of the construction of the two successful Mariner craft. G. P. Kautz, in his turn, reviewed the manpower and funding JPL would need to develop the orbiter, closing with a list of the problems it faced.[47]

The quarterly review was followed up by two additional meetings in October. Langley Director Edgar Cortright held a session for the other center directors and key Viking project personnel, and Jim Martin convened a Viking Project Management Council meeting. The consensus was that the project was off and moving at a reasonable pace. Fewer problems seemed to have surfaced than might have been expected at this stage. Harris Schurmeier, the Mariner 69 project manager, noted that Viking was more complex than earlier projects because so many more partners were in the game. With all the different groups involved and with the limited dollars available, he thought the participants needed to establish clearer channels for handling problems.

Jerry Soffen also commented on the need for better communications. Although the quarterly review had been held to secure the participation of the many constituencies in the decision-making and reporting process, many of the scientists had left the meeting before the second day's discussions. Soffen's observation triggered a 45-minute session on how best to integrate the scientists into the project. Nearly everyone agreed that the investigators had to understand the fiscal and technical aspects of Viking so that they could appreciate the relationships of their own activities to the whole enterprise. The scientists would have to learn that their experiments were only a part of a very large undertaking.[48] As the specialists returned to

Table 30
Viking Project Orbiter System:
Critical Schedule Activities, 1969

Activity	Required Date
Project spec approved	1 Dec. 1969
Orbiter investigators identified	15 Dec. 1969
Concepts approved and first drafts covering orbiter-lander interfaces	1 Nov. 1969 to 2 Jan. 1970
Orbiter system design concepts and general configuration established to allow subsystem function and design requirements to be prepared	15 Jan. 1970
Critical problems	
1. Many activities must start with preliminary data, requirements	
2. Schedules must be achieved	
3. Little or no recovery time	

SOURCE: Martin Marietta Corp., Denver Div., "Viking Project Quarterly Review Held October 7 & 8, 1969 at Langley Research Center; Presentation Material," PM-3700005, Oct. 1969. Since events were to alter the Viking's project's calendar, the systems management offices would be forced to revise their plans many times. This is one early schedule.

Table 31
Viking Project Orbiter System: Baseline Conceptual Design Changes, Expected Weights, 1969

Item Changed	Baseline Weight (kg)	Expected Weight (kg)	Cause
Orbiter (less propulsion)	627	606	1. Design to "flight loads" analysis 2. Use of lightweight solar cells 3. Reevaluation of expected subsystem weights
Propulsion (inerts and residuals)	385	302	1. Substitution of helium for nitrogen as pressurant 2. Reduction of required ΔV = 1575 mps to ΔV = 1420 mps 3. Increase in nozzle expansion ratio from 40:1 to 60:1
Usable propellant	1420	1263	4. Use of selected injectors for I_{sp} = 289 sec
Lander capsule adapter	22	21	1. Design to "flight loads" analysis
Lander capsule	816	995	
Spacecraft adapter (includes destruct package and transition adapter)	149	130	1. Design to "flight loads" analysis
Viking spacecraft launch weight	3419	3317	

SOURCE: Martin Marietta Corp., Denver Div., "Viking Project Quarterly Review Held October 7 & 9, 1969 at Langley Research Center: Presentation Material," PM-3700005, Oct. 1969.

their various tasks after the saturating experience of the review at Langley, storms began to gather on the project's horizon.

During the remainder of 1969, one of the questions that nagged NASA managers who were looking for ways to pare the budget was, Is the orbiter essential to the Viking mission? This was an especially difficult question because eliminating the orbiters would obviously save a great amount of money, $100-165 million. For project personnel at headquarters and Langley who thought that the direct- versus out-of-orbit delivery issue had been settled nearly a year before, the revival of this question was disturbing.

On 13 September 1969, NASA's Lunar and Planetary Missions Board, an advisory group, agreed that the orbiters should be preserved, as they would give greater mission flexibility and a higher chance of mission success. When released from orbit, the landers could be expected to touch down in an elliptical area (called a footprint) 180 by 530 kilometers; with a direct entry that footprint would be increased to 500 by 900 kilometers. An orbiter-based mission would use the orbiter cameras to survey potential landing sites, which although not guaranteeing success would permit the Viking team to assess and eliminate obviously hazardous landing regions. But most significant, an orbit relay link would allow two-thirds more information to be sent to Earth than the lander alone could manage. With these considerations, the Lunar and Planetary Missions Board drafted the following resolution:

> A balanced program to develop a deeper understanding of man's neighborhood of the universe should remain a goal of NASA's lunar and planetary program. After examining Mariner 6 and 7 results, the [Lunar and Planetary Missions Board] emphasizes that landing of scientific instruments on Mars in 1973 remains a task of major importance.
>
> The cost of the Viking program now represents a substantial part of the funds at present available to the planetary program. Nevertheless, the [Lunar and Planetary Missions Board] considers the Viking program should go forward as planned.
>
> A Mercury-Venus flyby, the continued exploration of Venus, the introduction of a small planetary orbiter program, and the initiation of a major program to explore the outer planets are all essential to an orderly exploration of the solar system. NASA should develop those programs as required for this exploration.[49]

Although there would be several delays and unexpected twists and turns along the way, this resolution described the basic strategy NASA's planetary programmers would follow during the 1970s. Before it could be implemented, however, Walt Jakobowski and his team in the Viking Program Office at NASA Headquarters had to fight many battles just to preserve the basic Mars orbiter-lander mission. All of their work would be affected by a worsening budget crisis in Washington.

MONEY PROBLEMS AT NASA

The summer of 1969 was a time for triumph and despair. *Apollo 11* landed on the moon in July, but at almost the same time NASA's budget was cut severely. Despite being an enthusiastic supporter of the Viking project and wanting to pursue an aggressive program of unmanned planetary exploration, Thomas O. Paine, appointed administrator in March, began to preach fiscal restraint to the Viking managers as early as June 1969. He told John Naugle, his associate administrator for space science and applications, that Viking and the other advanced planetary projects would have to be managed wisely because NASA was living in an era of great pressures to reduce the budget. The space agency's expenditures were being subjected to considerable public scrutiny and debate.[50]

Paine's worries were well founded. When the House Committee on Appropriations reported 19 June on the NASA budget request, the projected fiscal 1970 funds were nearly $300 million less than the previous year.

Five days later, the Senate Committee on Aeronautical and Space Sciences recommended a further reduction of $250 million. Late in July, Paine talked with President Richard M. Nixon about the space program as they flew to the Pacific splashdown site of *Apollo 11*. The president said that he personally was very enthusiastic about American space activities, but his administration could not direct large amounts of resources to the space program until the war in Vietnam had been ended. Nixon was reflecting the budget-cutting mood of Congress and the lack of public support for new space initiatives. Reactions to the report of the president's Space Task Group also affirmed the need for a fiscally responsible space program.[51]

To develop goals for the post-Apollo period, President Nixon had appointed a special Space Task Group* in February 1969. Although acknowledging that a new rationale for the American space program had to be sought—competition with the Soviet Union was no longer a realistic justification for NASA's activities—the task group rejected the idea that a manned mission to Mars in the 1980s should be the next great challenge accepted by the United States. The negative responses made on Capitol Hill and in the press to the manned Mars goal reinforced the group's decision. A July 1969 Gallup Poll, for instance, found 39 percent of 1517 persons polled nationally favored attempts to land a man on Mars; 53 percent opposed. Of the 21- to 29-year-olds, 54 percent favored the project and 41 percent opposed, but 60 percent of those over 50 opposed.[52]

As delivered to President Nixon on 15 September, the Space Task Group's report, *The Post-Apollo Space Program: Directions for the Future*, had backed away from an early manned landing on the Red Planet. The focus for the next decades in space was on the development of hardware and systems that would ultimately support a manned mission to Mars at the close of the 20th century. After a presidential briefing on the report, Nixon's press secretary said that the president agreed with the group's rejection of an overly ambitious program aimed at an early landing on another planet but also with its refusal to propose a program that would terminate all manned space activities in the post-Apollo years.[53] Six months were to pass before President Nixon personally reacted to the task group's findings, and by that time Congress, through the appropriation process, had shaped the immediate future for NASA's programs by restricting the agency's budget even further.

As the budget for fiscal 1970 went through successive parings and the public enthusiasm for space projects continued to dwindle, Naugle and his associates at NASA Headquarters grew more and more concerned about the continuing increases in costs for Viking. On 26 August 1969, Naugle wrote Ed Cortright and other top Viking managers to review his "personal

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*The membership included Vice President Spiro T. Agnew, chairman; Secretary of the Air Force Robert C. Seamans; Administrator Thomas O. Paine; Science Adviser to the President Lee A. Dubridge; and, as advisers, Under Secretary of State for Political Affairs U. Alexis Johnson, Atomic Energy Commission Chairman Glenn T. Seaborg, and Bureau of the Budget Director Robert P. Mayo.

philosophy" on the subject. Naugle told the Langley director that "current indications of an increase over earlier estimates are of concern; particularly in light of the need to minimize Federal expenditures." He was especially worried about "cost overruns which in times of tight budgets, will inevitably result in disruption to the Viking Project or to other projects." While the associate administrator recognized the importance of the Mars mission and while he did not care to "establish arbitrary or unrealistic cost ceilings" that could also jeopardize the success of the effort, he did want everyone in the Mars project to ensure "that Viking [was] tight, efficient, well-engineered, and well-managed." Every effort had to be made to use existing technology "to minimize development risks and associated costs." Naugle recommended a very careful study of the proposed test program to determine if any paring could be done in that area. "While we cannot omit necessary development and tests, neither can we tolerate frills."[54]

But the costs for Viking continued to grow. When first presented to Congress in March 1969, the Viking price tag had read $364.1 million, an unsound estimate. At the time, the design of the spacecraft had not been clearly defined. By August, the expected cost had risen to approximately $606 million, with an additional $50 million for the launch vehicles. In testimony before the Subcommittee on Space Science and Applications of the House Committee on Science and Astronautics in October, Naugle admitted that the total cost of Viking would run about $750 million. Representative Charles A. Mosher of Ohio asked Naugle what he meant when he said that the $750 million "included an allowance for a minimum number of changes." The NASA spokesman responded that past experience with planetary programs indicated that the agency could expect a 15 to 20 percent increase in the cost of a given project. "So, in the case of Viking, we are including in this $750 million estimate about $100 million for mandatory changes or for trouble that we may get into in the project." NASA was using $650 million as its target, but Naugle told the congressmen that "we are only so wise and only so able to foresee into the future."

Representative Thomas N. Downing of Virginia expressed his concern about these projections since they had already grown more than 30 percent in little more than a year. Naugle noted that the figures presented in 1968 were based on a still poorly defined spacecraft. "What we have found . . . is that we underestimated the weight of both the orbiter and the lander." The additional weight could be translated into more man-hours of labor, which in turn could be translated into more dollars. On top of that, the cost of those man-hours had also increased. All the congressmen were disturbed. Joseph E. Karth, the subcommittee chairman, pointed out that his group had to sell these cost escalations on the House floor and it would not be easy. Naugle's statements that everything was being done to keep costs in line were not all that reassuring to Karth, who believed that NASA had "so far failed miserably in that regard." After trying to convince the subcommittee that the agency had "made a substantial effort to accurately determine funding requirements before beginning hardware development," Naugle and his staff renewed their attempts to control the project managers. Since Congress would not suffer another project with a huge cost overrun, Don Hearth and others working for Naugle sought to establish controls over Viking that would prevent sudden and unexpected expenditures by the engineers in the field.[55]

For all their concern and activity, the men at NASA Headquarters could not prevent the budget crisis. When President Nixon signed the fiscal 1970 appropriations bill on 26 November, the total amount—$3.697 billion—was $299 million less than appropriated the previous year. At the same time, the Bureau of the Budget was already beginning to chip away at the dollars the space agency was seeking for 1971. Robert P. Mayo, director of the Bureau of the Budget, found himself in an awkward position; he had promised President Nixon a balanced budget, but finding places where he could reduce expenditures was very difficult. Throughout the fall of 1969, a stiff debate ran between the space agency and the budget people, and some of the meetings Paine, Mayo, and their staffs held were not pleasant.

In light of the Space Task Group's report, Paine reasoned that he could not recommend a budget of less than $4.25 billion for NASA. He told Mayo in a letter: "This is a difficult time. Please do not think me unfeeling toward the many claimants for your scarce budgetary resources." But Paine thought that inefficient agencies were being rewarded with increased budgets while NASA was being penalized. "The people of NASA have produced outstanding results . . . while reducing costs and personnel more than any other area of government. . . . Space offers the President now a highly productive program and his greatest leadership opportunity." Unfortunately, the dollars did not go to the successful.[56]

For Viking, the budget cut was devastating. Before Congress had a chance to consider the budget, Nixon's administration cut $20 million from the amount requested for the Mars lander project for 1971. The picture was unpleasant. With the decline in resources, aggravated by inflation, Administrator Paine had to reduce expenditures.[57]

Table 32
NASA Appropriations, FY 1968-1971

(in billions)

Budget Item	FY 1968	FY 1969	FY 1970	FY 1971
Total NASA budget	$4.5889	$3.9952	$3.6967	$3.3126
Lunar & Planetary Programs	.1250	.0923	.1388	.1449
Mariner Mars 71	—	—	.0454	.0296
Viking 73	—	—	.0400	.0350
Mariner Venus Mercury 73	—	—	.0030	.0211

Paine was convinced that the only alternative to the delay of Viking was its cancellation. At noon on 31 December 1969, Paine told John Naugle that further analysis of the federal budget for 1971 by the Bureau of the Budget had disclosed a $4-billion problem; NASA had been asked to reduce its request by $225 million. The administrator and his associates considered three ways to cut dollars—delay Viking from 1973 to 1975; cut the Viking orbiter completely and reduce further the Office of Manned Space Flight budget; or eliminate manned flights after the final Skylab flight in 1973. The second and third options would not provide the necessary reduction, and the Bureau of the Budget, with President Nixon's agreement, thought that deferral of Viking was the best step. Naugle spent the rest of that day working out the details of Viking's slip, taking time out to note for the record: "I left at 4:30 pm to welcome the New Year and the new decade in a bleak mood—feeling that two years of careful planning for Viking had been wiped out in four hours by a combination of a budgetary error and the article in the [Washington] Post on Monday, 29 December, by Cohn stating that scientists at the [American Association for the Advancement of Science] Meeting had advocated a reduction in the NASA science program." NASA's space projects were under criticism as part of a general outcry against federal spending that did not contribute to the solution of social problems like pollution and feeding the poor. While scientist Carl Sagan pointed to the Defense Department as the real source of budget misallocations, other "authorities" questioned NASA's current proposals to send manned missions to Mars. Caught in the midst of the antimilitary, antitechnology furor was Viking. During the last hours of 1969, NASA nearly lost another opportunity to land on Mars at all.[58]

After two weeks of scrambling to reorganize the space agency's programs, Tom Paine made a public statement of the changes the 1971 budget would require. Mindful of recent criticisms, he commented:

> We recognize the many important needs and urgent problems we face here on earth. America's space achievements in the 1960's have rightly raised hopes that this country and all mankind can do more to overcome pressing problems of society. The space program should inspire bolder solutions and suggest new approaches. . . . NASA will press forward in 1971 at a reduced level, but in the right direction with the basic ingredients we need for major achievements in the 1970's and beyond.

While NASA diminished its total activities, the agency would "not dissipate the strong teams that sent men to explore the moon and automated spacecraft to observe the planets." Paine listed the following actions as being consistent with the requirements of the 1971 budget:

> 1. We will suspend for an indefinite period production of the Saturn V launch vehicle after the completion of Saturn V 515.
> 2. We will stretch out the Apollo lunar missions to six-month launch intervals, and defer lunar expeditions during the [Apollo Applications

> Program] space station flights in 1972 [actually flown in 1973, as Skylab flights.]
>
> 3. We will postpone the launch of the Viking/Mars unmanned lander from 1973 to the next Mars opportunity in 1975.

With the closing of the Electronics Research Center in Cambridge, Massachusetts, these actions would reduce the number of persons (including contractors) working on NASA projects from 190 000 at the end of fiscal 1970 to about 140 000 at the end of fiscal year 1971.[59]

Although Viking survived, there was considerable confusion at first over what the modified project would be. Henry Norris and his orbiter teammates officially learned about the change in plans on 12 January 1970.[60] At the Viking Orbiter Staff meeting in Pasadena the next day, Norris explained that they had been asked to examine two alternatives for 1975 Viking missions—the basic 1973 orbiter-lander mission rescheduled for 1975, or a direct-entry lander mission. This renewed debate over what was called "Options A and B" brought a sense of *deja vu* among the working people.[61]

Besides an additional direct dollar cost of about $102.2 million, JPL learned from the program office at headquarters, other problems were associated with deferring Viking to 1975. Steps would have to be taken to bolster morale among the scientists and engineers. The several false starts on Viking's predecessors and the cancellation of Voyager had already discouraged many. As with all complex projects, a strong and highly motivated team was essential for success, and a limited sum of money would have to be made available during fiscal 1970 and 1971 to hold the existing team together and permit some meaningful work on the aspects of the mission that would pose the greatest technical challenges. The balance of the Viking project would be budgeted at 1970 levels, but slipped two years. An additional five percent would be added to compensate for possible inflation.

William J. Schatz of the JPL Propulsion Division pointed out two other problems caused by the delay. A mission in 1975 would require a longer flight time; Mars's position relative to Earth would require a different trajectory. Previously, the mission analysis and design people had used Voyager 1973 work to plan for the 1973 Viking flight. A 1975 launch would require the specialists to start trajectory and flight path analyses from scratch. New calculations would demand more manpower and computer time, both of which cost money. Hardware alterations would also be required. Changes in the materials used for the propulsion systems might be necessary to ensure their reliability, and the use of helium as a pressurant would have to be reevaluated. But beyond these technical considerations was the economic impact of the stretchout. "Of prime importance," said Schatz, was the retention "of a qualified team of engineers at the rocket engine contractor during the stretchout period." The engine manufacturer, Rocketdyne, a division of North American Rockwell, was already laying off personnel, "jeopardizing their ability to support our development program." Other vendors were either closing their doors or dropping assembly lines for certain components because of the general poor condition of the economy. JPL was planning to procure many items it needed for Viking as soon as possible and place them in bonded storage until it was ready to assemble the spacecraft.[62]

During late January and early February, NASA Headquarters, Langley, and JPL personnel continued to evaluate the future course of Viking. After receiving a 28 January briefing by various Viking staff members, John Naugle decided on 10 February that the agency would pursue its original plan to fly an orbiter-lander combination. Positive words of support for the Viking team were put on record by George M. Low, NASA deputy administrator, and Naugle. Both men knew that the real work had just begun, but they appreciated the teamwork displayed during the latest crisis. Low told his colleagues, "Viking holds the highest priority of any project or program in NASA's Planetary Program. Viking holds a high priority among all of NASA's programs."[63]

The Space Science Board of the National Academy of Sciences also underscored the value of continuing with Viking, but the board's endorsement carried some reservations. Philip Handler, president of the Academy, had suggested to NASA Administrator Paine in mid-November 1969 that a Space Science Board review panel be established to evaluate the balance among the scientific disciplines supported by space agency funds. The last such review had been held in July 1966 at a time when National Academy and NASA personnel had assumed that the budget for space activities would continue to increase. Paine accepted Handler's offer, but advised him and his colleagues to weigh carefully the impact of any recommendations to shift money from one project to another. Any recommendations to cancel programs that had already gone through an elaborate approval process within NASA would, in the existing budgetary climate, "almost certainly lead to the curtailment of the on-going [programs] with little chance that additional funds [would] become available for [any] program which the Board feels should be increased."[64]

The Space Science Board team that evaluated NASA's space science activities was known as the Viking Review Panel, reflecting the amount of money being spent on the Mars project and the concern generated by the postponement of the Mars landing. The panel report issued on 24 March 1970 combined praise and concern. NASA was complimented for its work in defining a project that accurately reflected the payload recommendations of the Space Science Board's 1968 study, *Planetary Exploration, 1968–1975*. Cost projections, however, caused some division among the members of the panel. Some believed that the potential return from the Mars mission was so great that $750 million was justified. Others expressed concern that "within the extremely restricted budgetary climate, NASA must set much more limited goals for itself in order to achieve a balanced scientific effort." This latter group feared that Viking's high cost would cause the space agency to lose other "less costly but equally valuable missions."

Some participants in the review were worried about the complexity of the Viking science payload, the most sophisticated payload planned to date, with many new experiments. A two-year delay of the Viking launch might indeed be beneficial. "The additional two years can be devoted to an extensive test of the abilities of the payload, increasing confidence in [it]."

Since it appeared that future budgets for space activities would be low, the Viking Review Panel recommended that "considerably more modest planetary missions" be initiated in the years to come. Single, complicated, expensive projects like Viking were too risky—politically and technologically. Realistically appraising the Viking Review Panel's pronouncement, John Naugle told Paine, "It is, I think, in view of the talk by the scientific community these days, an accurate and as good a statement about Viking as we could expect."[65]

WORKING TOWARD JULY 1975

Money problems would always haunt the Viking project. The scarcity of dollars especially affected the development of the lander and its science payload and repeatedly tried people's patience and equanimity. Early in 1973, Joseph R. Goudy, the Langley Viking Project Office resident engineer at JPL, commented on budget cuts that led to the dismissal of about 200 employees at the California laboratory on rather short notice:

> These cutbacks have created a different atmosphere and environment, resulting in a change in attitude. Six months ago, when the [Viking Project Office] came in with a new requirement or direction that required additional or premature effort, it was generally accepted with the attitude, "We don't think it's necessary but it's their money; if they want it, we'll do it." Now, with the Orbiter having to take rather severe cuts, this is no longer considered "their" money and the attitude has become much more critical, if not down-right hostile.[66]

Henry Norris, looking for ways to keep his orbiter personnel from reacting too negatively to the repeated budget cuts, tried to convince them—and for the most part he succeeded—that the budget was just one of the many realities that a good engineer or manager had to live with and work around as he tried to do his job.

The tasks assigned to the orbiter teams were laid before them in a five-year schedule, which ended with a pair of mid-summer 1975 launches. The master plan was presented for the first time at the Viking Project Management Council meeting in February 1970, and it reflected the changes brought by the stretchout.

The pace of the work at JPL assumed a rhythm familiar to the people who had worked on other NASA projects. The determining factors, "driv-

Table 33
Viking Orbiter Schedules

Event	Proposed before 1 Jan. 1970	Proposed after 1 Jan. 1970	Actual Dates
Preliminary design review	May 1970	Jan. 1972	19-20 Oct. 1971
Critical design review	June 1971	Jan. 1973	9-10 July 1973
Start proof-test spacecraft test	Aug. 1972	March 1974	Jan. 1974
Qualification test completed	Nov. 1972	July 1974	Jan. 1975
Shipment of first flight hardware to KSC	Feb. 1973	Dec. 1974	Feb. 1975
Launch	July 1973	July 1975	20 Aug. 1975 9 Sept. 1975

SOURCE: Information on the 1970 master plan was taken from Henry Norris, "Viking Orbiter Project Staff Meeting—Minutes of January 13 and 14, 1970," memo, 19 Jan. 1970.

ers" in NASA parlance, for the designers and engineers were master schedules that determined when major hardware components had to be completed so the launch dates could be met. But the realities of designing and building the spacecraft did not always conform to calendar milestones, and the variance led to frequent revisions of the schedules. At every step along the way, the work was formally documented in a large number of Viking project documents. By cross-checking and coordinating these documents, the project manager at Langley could be assured that the orbiter, lander, science payloads, launch vehicles, ground support equipment, flight control facilities, and the tracking system would all function as required when the hardware was brought together and assembled for the launch and flight to Mars. This system of mass documentation, formal reviews, telecons, and informal conversations worked because the people associated with the effort believed in delegated management. Jim Martin's centralized responsibility and authority for Viking was a key factor to the project's success, but equally important was the esprit de corps among the Viking teams at the working level.[67]

The troops at JPL functioned within divisions responsible for specific engineering activities or disciplines. Norris and his orbiter staff allocated funds, prepared plans and schedules, assigned tasks, and received progress reports, but the divisions carried out the actual design and development of the spacecraft and experiment hardware, as well as prepared and operated such facilities as the Deep Space Network and the Space Flight Operations

Facility. Each division chief and his subordinates not only supervised their personnel but also selected the engineers who represented their divisions on the orbiter team.*[68]

The structure of management at JPL did not fit Jim Martin's management scheme. The people at Langley had always worked through a more centralized organization, in which everyone was directly responsible to the project director, and the Viking Project Office was uneasy with the JPL system. Martin knew that the organizational structure of the lab would not likely be changed just for this mission, so he went to Pasadena in the early spring of 1970 to observe firsthand how JPL worked. Specifically, he wanted to know: How had JPL dealt with hardware problems in the past? How did it plan to manage the Viking orbiter in the future? How would it control the flight phase of a mission?[69]

Henry Norris believed that the time Martin spent with division managers and Viking representatives at JPL led him to understand more clearly the lab's approach to project management. Martin was still "not entirely comfortable" with the organization, Norris reported, but at least the project director had been exposed to it and the men who filled the ranks. Likewise, the people at JPL began to appreciate the sources of Martin's concerns and continued to work with the project office to improve and strengthen JPL management control over the teams in Pasadena.[70]

Although they had adopted different approaches, the personnel at Langley and JPL were working toward the same goal. Once the baseline orbiter configuration had been established in February 1969, the next major orbiter goal was the preliminary design review (PDR). This formal review, held on 19-20 October 1971, came at the end of the conceptual phase for the design of the orbiter systems; the specialists were now ready to work on the detailed design of the hardware. Once the basic soundness of all aspects of the orbiter was approved, the teams would head for the next important milestone, the critical design review (CDR). Getting to the PDR had been a major accomplishment, made difficult by the repeated problems with the budget; but the teams at JPL had completed their design work and coordinated their efforts, attending weekly meetings and frequently using the telephone along the way. In fact, more than 60 meetings were held that directly impinged upon the design of the orbiter.

The preliminary design review gave all interested parties a look at the orbiter as JPL planned to build it. Once the conceptual design was complete, work on the design of breadboards, or first working test models, of the basic orbiter subsystems would begin. These designs would be evaluated at subsystem PDRs and, once approved, work on the breadboards would

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*Divisions and their representatives assisting the Viking orbiter staff at JPL, spring 1970: Quality Assurance and Reliability, G. E. Nichols; Project Engineering, V. R. Galleher; Data Systems, G. F. Squibb; Space Science, M. T. Goldfine; Telecommunications, J. R. Kolden; Guidance and Control, A. E. Cherniack; Engineering Mechanics, W. J. Carley; Astrionics, J. D. Acord; Environmental Sciences Simulation, N. R. Morgan; Propulsion, W. J. Schatz; Mission Analysis, P. K. Eckman; and Technical Information and Documentation, S. B. Hench.

proceed, with their suitability for conversion into flight hardware being confirmed during a series of subsystem critical design reviews. A general CDR for the entire Viking orbiter system would certify the readiness of the orbiter staff to go to the next step—building the flight-ready orbiters.

By October 1971, the orbiter had assumed the basic configuration it would have when launched in 1975. The spacecraft had grown considerably larger than its Mariner Mars 71 predecessor. Most noticeable visually were the larger solar panels and the larger high-gain antenna. But all the internal subsystems were taking on a Viking identity of their own as well. The Mariner inheritance was still there, but instead of directly transferring subsystems from one craft to another, the engineers were borrowing from Mariner experience and know-how. Still, it was this transfer of technological knowledge from Mariner Mars 71 and Mariner Venus 73 that permitted the Viking orbiter personnel to get the craft ready to fly on time with a minimum of problems and money crises.

Jack Van Ness, deputy Viking project manager, recorded in his "Viking Weekly Highlights Report" that the orbiter system preliminary design review was well organized and informative. Only 22 action items remained for solution. "This relatively small number is somewhat indicative of the clarity and thoroughness of the presentations." At the conclusion of the review, the Viking Advisory Review Panel and the Orbiter System Manager's Advisory Panel provided a favorable overall evaluation of the orbiter status. None of the evaluations turned up any critical problems that would give Martin's Viking Project Office cause for concern.[71]

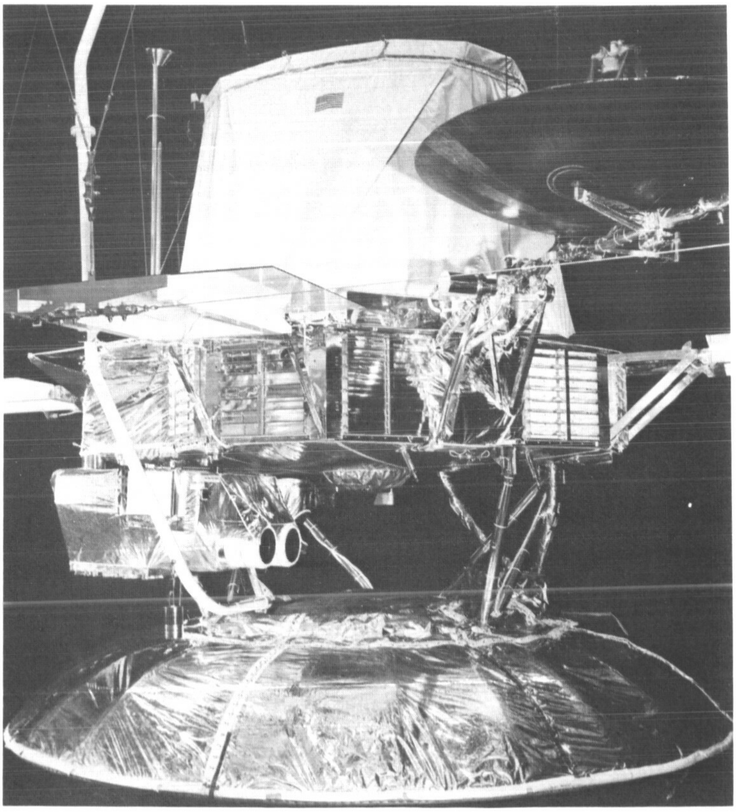
With the PDR behind them, Norris's people began to prepare the detailed designs of the 21 orbiter subsystems. Soliciting requests for proposals from industrial contractors, selecting companies to build the subsystems, and negotiating contracts occupied the months from October 1971 to July 1972. One contract was not let until July 1973. Meanwhile, the various divisions at JPL had begun to work on the subsystems that would be built at the laboratory. Preliminary design reviews for these subsystems began in January 1972 and lasted until late November.

Close on the heels of the PDRs came the subsystem critical design reviews, which spanned January to July 1973. When the subsystem CDRs were completed, a general CDR at JPL 9-10 July 1973 evaluated the entire orbiter system as it had evolved to date. The CDR panel, the Viking Advisory Panel, and the Orbiter System Manager's Advisory Panel all expressed their confidence in JPL's performance and the quality of the teams' work.[72] The technical problems being encountered by the orbiter were the routine kind that appeared during the course of most spacecraft projects—recurring difficulties with poor-quality integrated circuits and an unhappy experience when an early production propulsion tank ruptured because of a metallurgical failure.

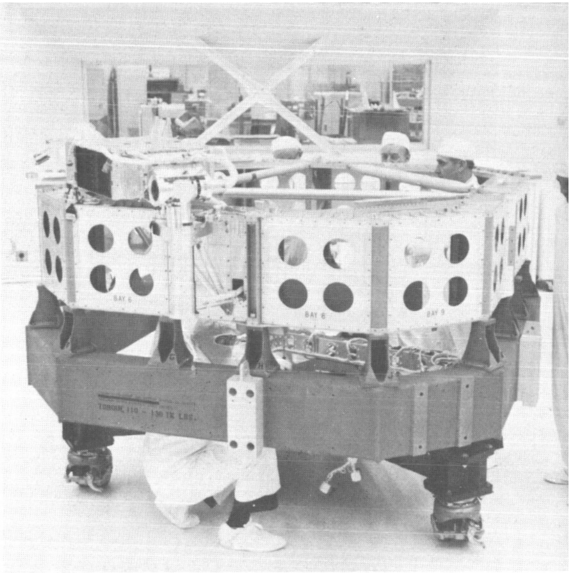
During the summer of 1973, only two subsystems caused genuine concern. The infrared thermal mapping (IRTM) subsystem was behind important lessons that would help them build Viking orbiter 2 and 3, the orbiters that would fly to Mars. One problem they encountered was the lack of sufficient work stands, particularly during the installation of the thermal insulating blanket. More stands were ordered, to avoid any bottleneck during the assembly of the flight articles. The proof-test orbiter was moved on 8 May from the Spacecraft Assembly Facility to the Environmental Laboratory, where it would go through the rigors of vibration, electromagnetic interference, pyrotechnic, thermal vacuum, and compatibility tests during the summer of 1974. At the same time, engineers would begin assembling and testing VO-2 and VO-3.[77]

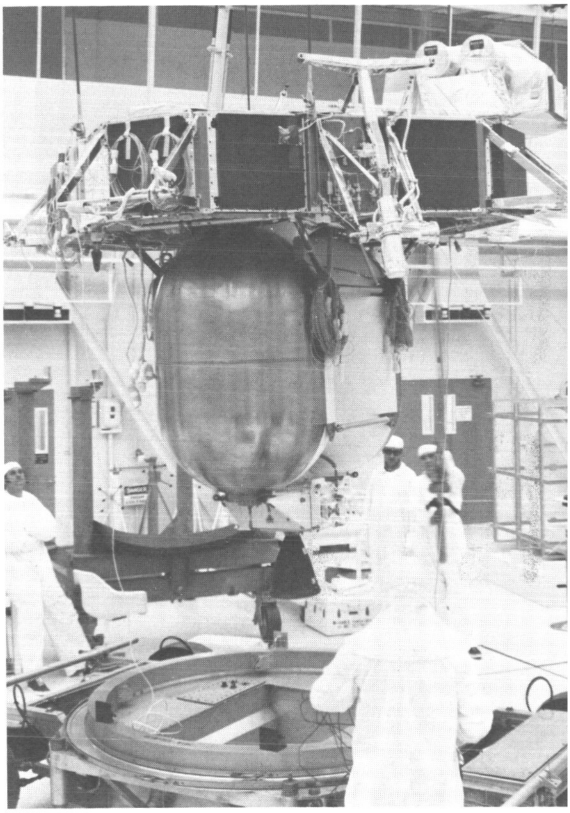
On schedule with satisfactory results, the VO-1 tests were completed in late August. As the JPL team turned its attention to readying VO-3 for early examination, however, unexpected budget problems brought a change in plans.[78] On 27 September, the orbiter staff was forced to order all testing of the third orbiter to cease. The second test team was disbanded; no money was available for testing. VO-3 was put into storage, and the proof-test orbiter (VO-1) was redesignated a flight unit. VO-1 and VO-2 would be the

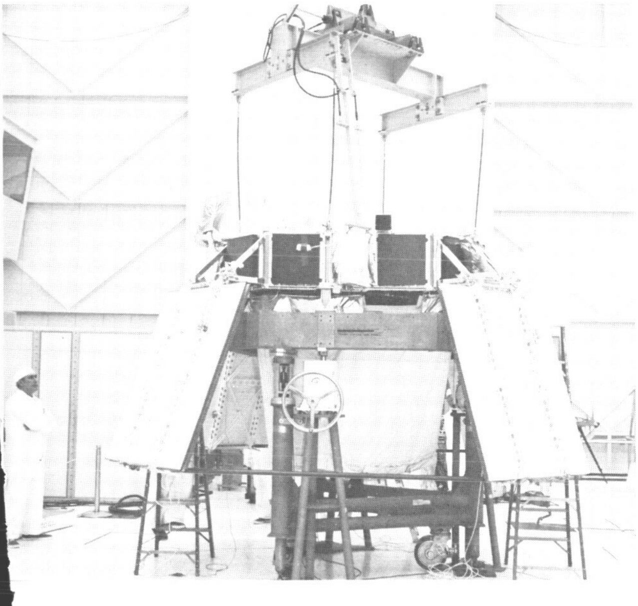
The thermal-control model of the Viking orbiter mated to the lander thermal-effects simulator was used in August 1973 to verify the effects solar radiation would have on the spacecraft. The science platform with imaging system and other instruments is attached under the orbiter.



Building the Viking Orbiter at Jet Propulsion Laboratory in 1974. Men working inside the chassis, right, fabricate the orbiter bus structure. Below right, they attach the propulsion module to the propellant tanks. Below, solar panels are in place on the nearly completed orbiter.







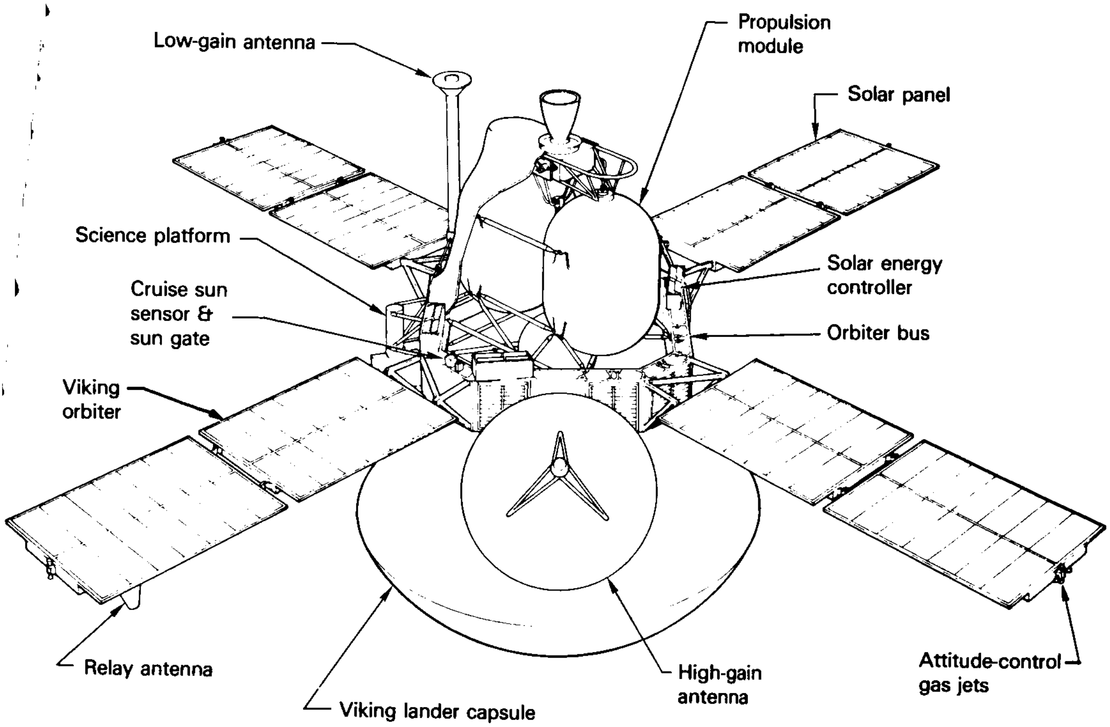
spacecraft sent to Mars. To ensure the acceptability of the proof-test hardware for flight, a series of meetings were held during the next several weeks.[79] But an orbiter design qualification review scheduled for early October 1974 lost much of its significance, since the change in plans had thrown off JPL's timing. As one participant observed, it was hard for a review panel "to determine if the Orbiter met all of its requirements in spite of all the testing that has been done."[80]

After several more months of work, orbiter VO-1 was verified for flight on 9 January 1975, and the VO-2 tests were completed on the 31st. The orbiters were shipped to the Kennedy Space Center in February, where a series of preflight checks would be made through the spring and summer.[81] The Viking orbiter, remarkably close to early weight predictions (see table 35), was a very carefully tested piece of equipment. For the teams at JPL, the design, development, fabrication, and assembly had, for the most part, gone according to plan, schedule, and budget.

Table 35
Viking Orbiter Specifications, 1969–1975

Orbiter Element	Baseline Orbiter Feb. 1969	PDR Orbiter Oct. 1971	Flight Orbiter Feb. 1975
Bus dimensions			
Long sides			139.7 cm
Short sides			50.8 cm
Height	45.7 cm	45.7 cm	45.7 cm
Distance from launch vehicle attachment points to lander attachment points		3.29 m	3.29 m
Distance across extended solar panels, tip to tip	7.80 m	9.75 m	9.75 m
Weight with fuel	2298.6 kg	2304.3 kg	2324.7 kg
Weight of fuel	1862 kg	1404.8 kg	1422.9 kg
Weight of science instruments	57.6 kg	65.4 kg	65.2 kg
Visual imaging system	21.8 kg	42.05 kg	40.05 kg
Infrared thermal mapper	13.6 kg	7.48 kg	9.30 kg
Mars atmospheric water detector		15.90 kg	15.90 kg

SOURCE: JPL, "Viking Project Orbiter System, Visual Presentation, February 13, 14, 1969" [Feb. 1969]; JPL, "Viking 75 Project Orbiter System PDR, October 19-20, 1971, Presentation Material" [Oct. 1971]; and Martin Marietta Aerospace, Public Relations Dept., *The Viking Mission to Mars* (Denver, 1975), pp. III-25, III-27, III-32, III-33.



Configuration of the mated Viking orbiter and capsule in cruise mode.

Carl D. Newby, supervisor of the Spacecraft Development/Mechanical Support Group, oversaw the assembly of the orbiters. It was the biggest spacecraft Newby and his team had built, and because it was so big it was an easy craft on which to work—they had room to move around during the assembly process. Newby pointed out that it requires a special personality to work on space hardware and a special dedication. Fabricators come to view the spacecraft as part of their lives, to care about it. Working in a closed environment, they have to learn to live with one another, as well. Spacecraft builders must be adaptable, very careful, and thoughtful. One false move, one thoughtless motion can destroy an assembly or component worth thousands of dollars or months of time. Damage to a spacecraft usually also requires requalification of the injured components or perhaps requalification of the entire craft. Workers on the Viking orbiters—many had worked on Ranger, most had worked on the Mariners—were very fond of their spacecraft. As Newby repeatedly reminded the specialists at JPL, the orbiter was a "good spacecraft to work on, it was on time and on budget."[82] Building the Viking landers, however, was a completely different story.