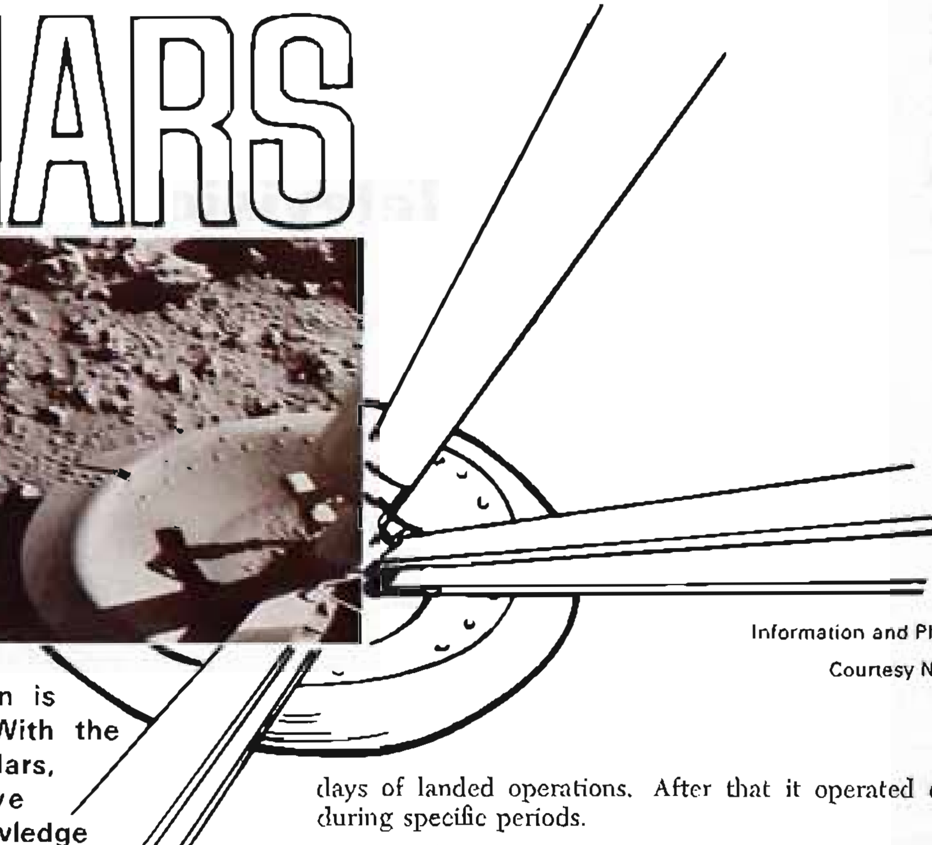
SIGNALS FROM MARS



Information and Photos
Courtesy NASA

Interplanetary exploration is no longer science fiction. With the touchdown of Viking 1 on Mars, American scientists have opened new avenues to knowledge of the physical universe. And it's all possible because of communications.

Viking 1 and 2 signal systems represent the newest in technology, and suggest many possible applications for defense communications. Let's look at just a few of those systems.

Lander Subsystems

COMMUNICATION EQUIPMENT

The Lander transmits information directly to Earth with an S-band communications system, or through the Orbiter with an ultrahigh frequency (UHF) relay system. The Lander also receives Earth commands through the S-band system.

Two S-band receivers provide total redundancy in both command receiving and data transmission. One receiver uses the high-gain antenna, a 76-cm. (30-in.) diameter parabolic reflector dish that can be pointed to Earth by computer control. The second receiver uses a fixed low-gain antenna to receive Earth commands.

The UHF relay system transmits data to the Orbiter with a radio transmitter that uses a fixed antenna. The UHF system operated during entry and for the first 3 days of landed operations. After that it operated only during specific periods.

LANDING RADARS

The radar altimeter (RA) measured the Lander's altitude during the early entry phase, alerting the Lander computer to execute the proper entry commands. The RA is a solid state pulse radar with two specially designed antennas: one is mounted beneath the Lander and one is mounted through the aeroshell. Altitude data were received from 1,370 km. down to 30.5 m. (740 mi. to 100 ft.).

The aeroshell antenna provided high-altitude data for entry science, vehicle control and parachute deployment. The Lander antenna switched into operation at aeroshell separation and provided altitude data for guidance and control, and for terminal descent engine ignition.

The terminal descent landing radar measured the horizontal velocity of the Lander during the final landing phase. It is located directly beneath the Lander and is turned on at about 12 km. (4,000 ft.). It consists of four continuous-wave doppler radar beams that can measure velocity to an accuracy of plus or minus 1 meter per second. *[See THE ARMY COMMUNICATOR, Winter 1976, page 48, for a discussion of doppler navigators.]*

GUIDANCE AND CONTROL

The "brain" of the Lander is its guidance control and sequencing computer. It commands everything the

Lander does through software (computer programs) stored in advance or relayed by Earth controllers.

The computer is one of the greatest technical challenges of Viking. It consists of two general-purpose computer channels with plated-wire memories, each with an 18,000-word storage capacity. One channel is operational while the other is in reserve.

Among other programs, the computer had instructions stored in its memory that could have controlled the Lander's first 58 days on Mars without any contact from Earth. These instructions were updated and modified by Earth command once communication was established.

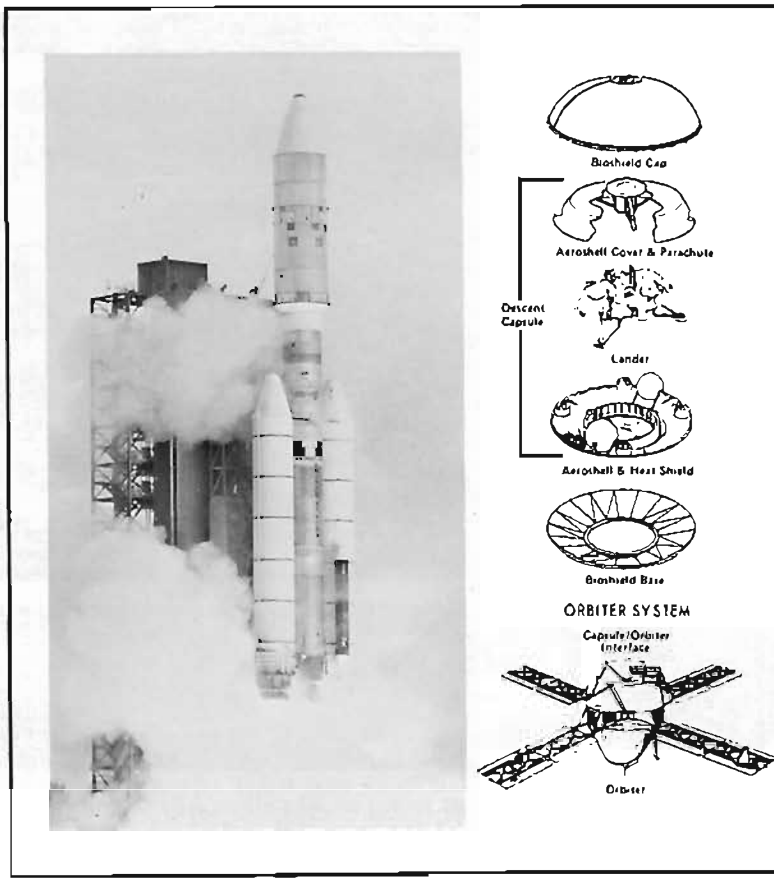
POWER SOURCES

Basic power for the Lander is provided by two SNAP 19-style 35-watt radioisotope thermoelectric generators (RTG's) developed by the U.S. Energy Research and Development Administration. They are located atop the Lander, and are connected in series to double their voltage and reduce power loss.

The first isotopic space generator was put into service in June 1961, on a Navy navigational satellite. Advances in SNAP systems were made with the development and flight of SNAP 19 aboard Nimbus III, launched in April 1969. This use of SNAP 19 represented a major milestone in the development of long-lived, highly reliable isotope power systems for space use by NASA. The SNAP 27 generator was developed to power 5 science stations left on the Moon by the Apollos 12, 14, 15, 16, and 17 astronauts. The continuing operation of these generators is providing new dimensions of data about the Moon and the universe. Four SNAP 19 nuclear generators are providing the electrical power for each of the two NASA pioneer Jupiter flyby missions (Pioneers 10 and 11) currently in space.

The generators will provide a long-lived source of electricity and heat on Mars, where sunlight is half as strong as on Earth, and is nonexistent during the Martian night, when temperatures can drop as low as minus 120 degrees C. (minus 184 degrees F.).

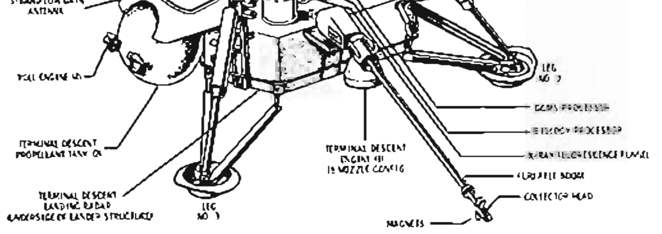
The generators use thermoelectric elements to convert heat from decaying plutonium-238 into 70 watts of electrical power.



"Waste" or unconverted heat is conveyed by thermal switches to the Lander's interior instrument compartment, when required. Covers over the RTG's prevent excess heat dissipation into the environment.

Four nickel-cadmium rechargeable batteries help supply Lander power requirements in peak activity periods. The batteries, mounted in pairs inside the Lander, are charged by the RTG's with power available when other Lander power requirements are less than RTG output.

VIKING LANDED CONFIGURATION



DATA STORAGE

Data storage equipment collects and controls the flow of Lander scientific and engineering data. It consists of a data acquisition and processing unit (DAPU), a data storage memory, and a tape recorder.

The DAPU actually collects the science and engineering information and routes it to one of three places: to Earth through the S-band high-gain antenna, to the data storage memory, or to the tape recorder.

Information is stored in the data storage memory for short periods. Several times a day the memory transfers data to the tape recorder or back to the DAPU for further transmission. The memory has a storage capacity of 8,200 words.

Data are stored on the tape recorder for long periods. The recorder can transmit at high speed back through the DAPU and the UHF link to an Orbiter passing over-

head. It can store as many as 40 million bits of information, and it can record at two speeds and play back at five.

LANDER CAMERAS

The first pictures taken by Lander 1 were panoramic surveys and regions of particular interest. They were imaged in high resolution, in color, and in infrared.

Stereoscopic views were obtained by photographing the same object with two cameras, providing photos in which three-dimensional shapes can be distinctly resolved. Putting together this information, scientists can tell much about the character of the Martian surface and the processes that have shaped it.

Used as photometers, the cameras yield data that permit inferences about the chemical and physical properties of Martian surface materials. Color and infrared diodes will collect data in six different spectral bands. Reflectance curves constructed from these six points have diagnostic shapes for particular minerals and rocks.

Another area of camera investigation is atmospheric properties. Pictures taken close to the horizon at sunset or sunrise help determine the aerosol content of the atmosphere. Some pictures were also taken of celestial objects: Venus, perhaps Jupiter, and the two Mars satellites, Phobos and Deimos. The brightness of these objects will be affected by the interference of the atmosphere, and the cameras can provide a way to measure aerosol content.

The cameras can also be used in the same way as more conventional surveying instruments. Pictures of the Sun and planets can be geometrically analyzed to determine the latitudinal and longitudinal position of the Lander on Mars.

Each Lander is equipped with two identical cameras, positioned about 1 m. (39 in.) apart. They have a relatively unobstructed view across the area that is accessible to the surface sampler. The cameras are on stubby masts that extend 1.3 m. (51 in.) above the surface.

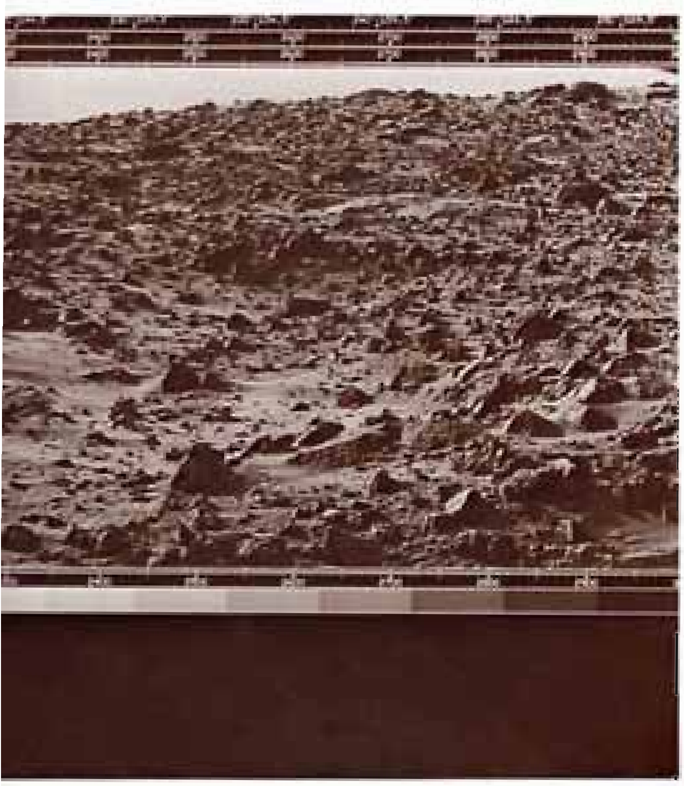
The imaging instruments are facsimile cameras. Their design is fundamentally different from that of the television cameras that have been used on most unmanned orbital and flyby spacecraft. Facsimile cameras use mechanical instead of electronic scanning.

In a television camera the entire object is simultaneously recorded as an image on the face of a vidicon tube in the focal plane. Then the image is "read" by the vidicon through the action of an electron beam as it neutralizes the electrostatic potential produced by photons when the image was recorded. In a facsimile camera, small picture elements (called pixels) that make up the total image are sequentially recorded.

In a facsimile camera an image is produced by observing the object through sequential line scans with a nodding mirror which reflects the light from a small element of the object into a diode sensor. Each time the mirror nods, one vertical line in the field of view is scanned by the diode. The entire camera then moves horizontally by a small interval, and the next vertical line is scanned by the nodding mirror. Data that make up the entire picture are slowly accumulated in this way.

Because each element (spot) in the field of view is recorded on the same diode, opposed to different parts of the vidicon tube face, the facsimile camera has a photometric stability that exceeds most television systems. Relatively subtle reflectance characteristics of objects in the field of view can be measured.

There are actually 12 diodes in the camera focal plane; each diode is designed to acquire data of particular spectral and spatial quality. One diode acquires a survey black-and-white picture. Three diodes have filters that

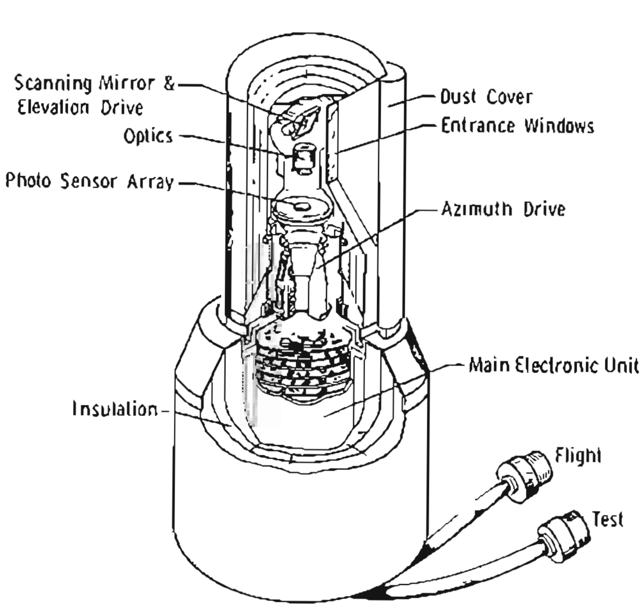


transmit light in blue, green, and red; together these diodes record a color picture. Three more diodes are used in essentially the same way, but have filters that transmit energy in three bands of near-infrared.

Four diodes are placed at different focal positions to get the best possible focus for high-resolution black-and-white pictures. Objects the size of an aspirin can be resolved. The twelfth diode is designed with low sensitivity so it can image the Sun.

The survey and color pictures have a fixed elevation dimension of 60 degrees; high-resolution pictures have a fixed dimension of 20 degrees. The pictures can be positioned anywhere in a total elevation range of 60 degrees below to 40 degrees above the nominal horizon. The

LANDER CAMERA SYSTEM DIAGRAM



azimuth of the scene is adjustable; it can vary from less than 1 degree to almost 360 degrees to obtain a panorama.

The facsimile camera acquires data relatively slowly, line by line. Rapidly moving objects, therefore, will not be accurately recorded. They might appear as a vertical streak, recorded on only one or two lines. This apparent liability can be turned into an asset.

If the camera continues to operate while its motion is inhibited, the same vertical line is repetitively scanned. If the scene is stationary, the reflectance values between successive lines will be identical, but if an object crosses the region scanned by the single line, the reflectance values dramatically change between successive scans. The single-line-scan mode of camera operation, therefore, provides an unusual way of detecting motion.

Orbiter Subsystems

The Viking Orbiter is a follow-on design to the Mariner class of planetary spacecraft with specific design changes for the Viking mission. Operational lifetime requirements for each Orbiter are 120 days in orbit and 90 days after the landing.

The combined weight of the Orbiter and Lander contributed to an 11-month transit time to Mars. A lighter Mariner mission payload permitted a 5-month transit time. The longer flight time then dictated an increased design life for the spacecraft, larger solar panels to allow for longer degradation from solar radiation, and additional attitude control gas.

Two 30-ampere-hour, nickel-cadmium rechargeable batteries provide power when the spacecraft is not facing the Sun during launch, correction maneuvers, and periods when Mars blocks out the Sun.

The Orbiter is stabilized in flight by locking onto the Sun for pitch and yaw reference and onto the star Canopus for roll reference. The attitude control subsystem keeps this attitude with nitrogen gas jets located at the solar panel tips. The jets fire to correct any drift. A cruise Sun sensor and the Canopus sensor provide error signals. Before Sun acquisition four acquisition Sun sensors are used and then turned off.

Two on-board general-purpose computers in the computer command subsystem (CCS) decode commands and either order the desired function at once or store the commands in a 4,096-word, plated-wire memory. All Orbiter events are controlled by the CCS, including correction maneuvers, engine burns, science sequences, and high-gain antenna pointing.

The main Orbiter communications system is a two-way, S-band, high-rate radio link providing Earth command, radio tracking, and science and engineering data return. This link uses either a steerable 1.5-m. (59-in.) dish high-gain antenna (HGA) or an omnidirectional low-gain antenna (LGA), both on the Orbiter. The LGA was used to send and receive near Earth, the HGA as distances increased. An X-band link is used for radio science through the HGA.

S-band transmission rates vary from 8.3 or 33.3 bits per second (bps) for engineering data to 2,000 to 16,000 bps for Lander and Orbiter science data.

Relay from the Lander is through an antenna mounted

A near-360 degree picture taken by Lander 1. The added drawing completes a full-circle image.

on the outer edge of a solar panel. It was activated before separation to receive from the Lander through separation, entry, landing, and surface operations. The bit rate during entry and landing is 4,000 bps; landed rate is 16,000 bps.

Data are stored aboard the Orbiter on two eight-track digital tape recorders. Seven tracks are used for picture data, and the eighth track is for infrared data or relayed Lander data. Each recorder can store 640 million bits.

Data collected by the Orbiter, including Lander data, are converted into digital form by the flight data subsystem and routed to the communications subsystem for transmission or to the tape recorders for storage.

Five days before the Mars Orbit Insertion maneuver, Viking started optical navigation and science experiments directed to Mars. TV images were obtained of the whole disc of Mars, of star fields, and of Deimos, one of two moons of Mars. Infrared scans of the planet give gross determinations of surface temperatures and concentrations of water vapor in the atmosphere in preparation for more precise measurements to come.

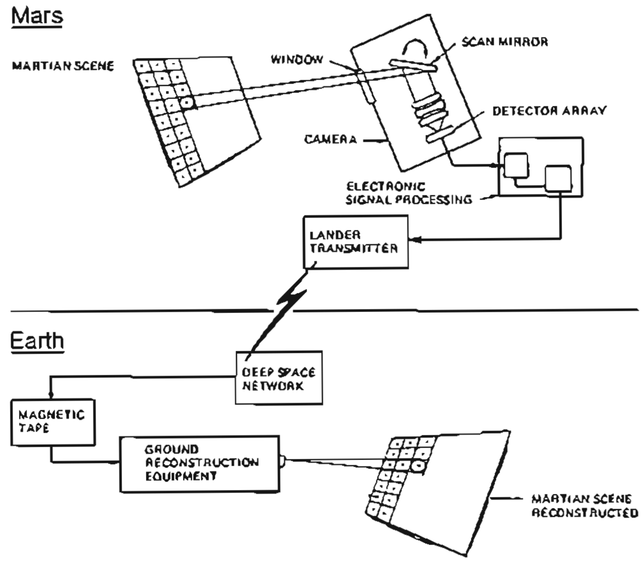
Every 20 days the Orbiter photographed the whole disc of Mars from high altitude and in color. Toward the end of the first Lander's planned mission, on Sept. 7, the Orbiter rocket engine fired a trim maneuver to cause the spacecraft to orbit the planet slightly out of synchronization with the Mars rotational period. The Orbiter then "walked" around the planet so all of its surface could be imaged in great detail. Orbital surveillance of Mars can continue through a whole Martian year, until June 1978.

Thermal mapping also continued after separation. The IRTM instrument is extremely sensitive to the presence of dust in the Martian atmosphere and can follow the development and progress of dust storms. Atmospheric dust can be detected even when it is not visible to the cameras.

Volcanic activity might also be detected, and another experiment will try to obtain details of grain sizes of material along the bottoms of the Martian canyons.

Viking Radio Science

Radio investigations will use signals from the Landers and Orbiters throughout the mission. Radio signals from



Viking 1 on the surface of Mars will be used to determine, with great precision, the distance from Earth to Mars. Other tests will provide new and improved determinations of the gravity field, figure, spin axis orientation, and surface density of Mars; pressure, temperature, and electron profiles in the planet's atmosphere; and properties of the solar system.

Radio science characteristically deals with small disturbances or changes in spacecraft orbits, deduced from tracking data analysis, and with small variations in frequency, phase, or amplitude of received signals. The investigations are intimately involved with data analysis, using complicated analytical procedures and associated computer programs to determine the physical effects that produce the observed variations. Data must sometimes be collected for an extended period to produce results.

As the Orbiters rise and set with respect to the Landers, the signal amplitude received at the Orbiter on the Lander-to-Orbiter communication link is expected to vary. An attempt will be made to analyze these variations to determine dielectric properties of the regions near the Landers; these properties can be related to surface density.

After Orbiter 1 had been in Mars orbit for about 80 days, it was placed in a nonsynchronous orbit to make a global survey of the planet. Tracking data taken near periapsis will be used to determine the global gravity field and local gravity anomalies.

Several times during the missions, Mars passes near the line-of-sight between Earth and a quasar (an intense extragalactic radio source). Radio signals from an Orbiter and the quasar will then be alternately recorded at two tracking stations at the same time.

By making such observations over a period of years, in various spacecraft missions, the precise orbits of Mars and Earth can be determined. Scientists can then study the movements of Mars, thus accurately testing Einstein's general theory of relativity.

In October 1976 Orbiter 1 passes behind Mars, as viewed from Earth, during a portion of its orbit. The spacecraft signals are gradually cut off, or occulted, by the planet. Variations in signal properties (frequency, phase, and amplitude) as the spacecraft enters or emerges from occultation are used to infer atmospheric and ionospheric properties. Occultations for Orbiter 2 start in January 1977.

Mars and Earth will be in conjunction Nov. 25, 1976. As the planets approach conjunction, radio signals from Viking spacecraft pass closer and closer to the Sun and are gradually more affected by the solar corona.

Signal variations, again measured with the dual frequency downlinks, will yield new information on the properties of regions close to the Sun, including the characteristics of any timely solar storms (Sunspots) or high activity events. Spacecraft signals are also affected by the intense gravitational field of the Sun, so a precise solar gravitational time-delay test of general relativity theory will be done in the conjunction time period. This test will determine how much the Sun's mass bends radio waves coming from the Viking to Earth, delaying their passage.

Tests to resolve small differences in the Einstein formulation of general relativity, as compared with more recently proposed formulations, can have an important impact on fundamental physical laws and on studies of the Universe's evolution.

Ground Control

Nerve center of Viking operations is the Viking Mission Control and Computing Center (VMCCC), located at the Jet Propulsion Laboratory (JPL), Pasadena, CA. Housed in two buildings at JPL, the VMCCC contains all the computer systems, communication and display equipment, photo processing laboratories, and mission support areas for the science team.

By the time the first Viking spacecraft arrived at Mars, the facilities housed more than 750 flight team members, plus several hundred more VMCCC people who will operate the facilities, computers, laboratories, maintenance shops, and communications networks.

COMPUTERS

The VMCC's large and complex computer systems receive incoming Orbiter and Lander data, process them in real time, and display and organize them for further processing and analysis. Data are first received as radio signals by the Deep Space Network (DSN) stations around the world and are transmitted into the VMCCC computers, where processing begins.

Commands that cause the Orbiters and Landers to maneuver, gather science data, and do other complex activities are prepared by the flight team. Commands are introduced into the computers through the team's control and are communicated to a DSN station for transmission to the appropriate spacecraft.

Three sets of computer systems are in the VMCCC. One is a complex of UNIVAC 1530, 1219, and 1616 computers that are designed to receive, process, and display all Orbiter data in real time and do preliminary image reconstruction on video data taken from Orbiter cameras.

Another set is a system of IBM 360/75 computers that receive, process, and display in real time all Lander telemetry and tracking data from the tracking stations. They are the means through which commands are sent to the Orbiters and Landers. They also do early image reconstruction and display of video data from Lander cameras on the surface, and they provide computing capability for many programs that do command preparation, Lander data analysis, and mission control functions.

Two large UNIVAC 1108 computers are used in nonrealtime to do analyses such as navigation, science instrument data analysis, and data records production.

Exposed film from the computers is processed in the VMCCC photo processing lab. High-quality prints are quickly made available. These pictures from Mars orbit and from the surface are analyzed by scientists housed in the mission support rooms of the VMCCC.

The VMCCC system is the responsibility of JPL's Office of Computing and Information Systems.

IMAGE PROCESSING LABORATORY

JPL's Image Processing Laboratory (IPL) corrects all the images (photo products) returned from the Lander and Orbiter spacecrafts. Digital computer techniques are used to improve details of returned images and to correct distortions introduced into the images by the camera systems. Large mosaics will be constructed from the Lander and Orbiter images, using the IPL products.

Special techniques developed for Viking include a program that will display Lander images for stereo viewing. The three-dimensional images will be used to evaluate the terrain near the landing site before activating the surface sampler arm. IPL will also do the processing to obtain the best possible discriminability (details) of images acquired by the Orbiter during site certification before landing.

TRACKING AND DATA SYSTEM

Tracking, commanding, and obtaining data from the Vikings are parts of the mission assigned to the Jet Propulsion Laboratory. The tasks cover all phases of the mission, including telemetry from the spacecraft, metric data, command signals to the spacecraft, and delivery of data to the VMCCC.

Tracking and communication with Viking, from the cruise phase until end-of-mission, is done by the worldwide NASA/JPL Deep Space Network (DSN). It consists of nine communications stations on three continents, the Network Operations Control Center in the VMCCC, and ground communications linking all locations.

DSN stations are strategically located around the Earth: Goldstone, CA; Madrid, Spain; and Canberra, Australia. Each location has a 64-m. diameter (210-ft.) antenna station and two 26-m. (85-ft.) antenna stations. The three multistation complexes are spaced at widely separated longitudes so spacecraft beyond Earth orbit are never out of view.

Each DSN station is equipped with transmitting, receiving, data handling, and interstation communications equipment. The 64-m. antenna stations in Spain and Australia have 100-kilowatt transmitters; at Goldstone the uplink signal can be radiated at up to 400 kw. Transmitter power at all six 26-m. stations is 20 kw.

Low-rate data from the spacecraft are transmitted over high-speed circuits at 4,800 bits per second (bps). High-rate data are carried on wideband lines at 28.5 kilobits per second (kbps) and, from Goldstone, at 50 kbps. Commands to the spacecraft are generated in the VMCCC and sent in the opposite direction to the appropriate DSN station.

Tracking and data acquisition requirements for Viking greatly exceed those of the Mariner and Pioneer projects. As many as six telemetry streams—two from each Orbiter and one or the other Lander—will be simultaneously received. Both Orbiters, or an Orbiter and a Lander, will be tracked and commanded at any given time, although the two Landers will not be operated at the same time.

In the 16 months of the primary mission, the critical period lasts at least 5 months, beginning with Mars approach. Early in this period, two sets of antennas communicated with Orbiter 1 and Lander 1 and conducted their respective missions. A third set of antennas was required to track Viking 2, still mated and approaching at some distance. During this phase, the entire capability of the DSN was occupied with Viking.

Principal communications links between the Vikings and Earth stations are in the S-band (2,100-2,300 megaHertz). The Orbiters will also carry X-band (8,400 MHz) transmitters. Operating with the Orbiter S-band system, the X-band transmitter will allow the network to generate dual frequency ranging and doppler data and will contribute to the radio science investigation at Mars.

Commands to Viking are transmitted from the VMCCC and loaded into a command processing computer at a DSN station for transmission to the proper spacecraft. Commands may be aborted and emergency commands may be manually inserted and verified at stations after voice authorization from VMCCC.

During planetary operations the network supports celestial mechanics experiments that may use very long baseline interferometry (VLBI), using DSN and other antennas outside the network.

A time problem is caused by the extremely long transmission time required for telemetry of commands from Earth and data from Mars. One-way transmission, at the speed of light, takes from 18 to 21 minutes while the Vikings are operating on Mars.