CHAPTER 6

EXPLORING THE SOLAR SYSTEM WITH SPACE PROBES

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Under the direction of the National Aeronautics and Space Administration, work has begun on a series of spacecraft intended to explore the moon and planets. These spacecraft are designed to carry a variety of instrumentation to the moon or the target planet, to conduct the required series of measurements automatically, and to return the resulting information to earth by radio link.

Eventually, human explorers will land on these other bodies to participate directly in this exploration program. However, for the first several years data will be obtained by the use of remote automatic instrument systems. It is the purpose of this chapter to describe the scientific objectives of this exploration program, some of the specialized instrumentation that is being developed to meet these objectives, and the spacecraft designed to carry these instrument systems.

6-1 THE LUNAR PROGRAM

Introduction

The surface of the moon looks quite different from the surface of the earth. The level maria are more extensive than any equally level

area on the earth's surface, and the lunar craters, the most typical of the moon's markings, are far more extensive and developed than any similar markings on the earth. On the other hand, the moon has no extensive mountain chains such as those found on earth; it is, of course, completely without liquid water on its surface, and shows no sign of any past erosion by moving water.

Origin of the lunar features has been a subject of controversy ever since they were first observed in detail by Galileo about 350 years ago. In his dialogues on the two chief world systems Galileo described the surface of the moon (1):

> The prominences there are mainly very similar to our most rugged and steepest mountains, and some of them are seen to be drawn out in long tracts of hundreds of miles. Others are in more compact groups and there are also many detached and solitary rocks, precipitous and craggy. But what occur most frequently there are certain ridges (I shall use this word because no more descriptive one occurs to me), somewhat raised, which surround and enclose plains of different sizes and various shapes but for the most part circular. In the middle of many of these there is a mountain in sharp relief and some few are filled with a rather dark substance similar to that of the large spots that are seen with the naked eye; these are the largest ones, and there are a very great number of smaller ones, almost all of them circular.

In the three centuries since the days of Galileo we have improved our astronomical techniques to the extent that we now have an order-of-magnitude better in resolution for details on the surface of the moon than was available in those first observations. Nevertheless, we are still seriously limited and cannot resolve photographically surface features smaller than approximately 1 km. (Trained observers have reported visual observations with a resolution of about half this distance.)

Most of our knowledge of the nature of the moon has resulted indirectly from an increased understanding of geophysical phenomena which affect the development of any large body. But here again our knowledge has really not progressed far in comparison with the extent of what we do not know.

The history of our understanding of the moon is well exemplified by the history of the controversy surrounding the nature of the lunar craters. For many years these craters were thought to be the remnants of massive lunar volcanoes. Although no volcanic craters on the earth ever reached such a size, there were a few formations on the [illegible]ce of the earth called "crypto volcanoes" that seemed to s[illegible] similarity in shape and size to the craters on the moon, at [illegible] one took into account the erosion effects on the earth.

[illegible]gh meteorite impact was occasionally suggested as an alternate to volcanoes for the production of lunar craters (the splashed appearance of the rayed craters has always been suggestive), the first serious discussion of the impact phenomena in crater formation on the moon was given by G. K. Gilbert (2), then director of the U. S. Geologic Survey, in 1898.

Since that time, the impact theory has steadily been gaining ground at the expense of the volcano theory. It is rather interesting to note that astronomers had always used vulcanism, a geologic process, to account for lunar craters; but when this geologist came into the field he used an astronomical process, the fall of meteorites, for his explanation.

In recent years the impact theory has gained even more ground by the study of meteorite impact sites on the surface of the earth. The most famous is Canyon Diablo or Meteorite Crater near Winslow, Arizona. Not only have numerous pieces of meteoritic iron been found in the vicinity of this formation but also the high-pressure silicate mineral coesite has been discovered in many of the shattered rocks near the crater.

Several other less obvious impact craters have been found around the world, several of which were shown up by analysis of airplane photographs. In fact, many of the "crypto volcanoes," once used to help justify a volcanic explanation for the lunar craters, are now being identified on earth as the result of meteorite impact. It is interesting to note that many of these crypto (or "hidden") volcanic structures occur in sedimentary rock—a situation that has always been difficult to explain.

In the vicinity of these meteorite craters on the earth coesite and shatter cones (or "astroblemes" as Dietz has identified them) have been reported (3, 4).

Of course, there are still some formations on the moon that appear to require a volcanic origin. For example, there are linear arrays of small craters that might be difficult to explain as the result of random meteorite impacts and might more sensibly be described as volcanoes along a surface crack. There are small rounded domes (small compared to other resolvable lunar formations, i.e., 5 km across or less), some with a visible indentation in the top, which appear to be volcanoes. But even in these cases explanations have been offered to show how these formations could be the result of impact phenomena (5, 6).

Even though our attitude toward lunar craters has changed, beginning with Gilbert, this change has not resulted from more detailed observations of the moon but rather from a more thorough investiga-

tion of geophysical processes and geologic materials here on the earth. Our observations of the moon are constrained not only by the 240,000 miles of distance separating us but also by the turbulent blanket of atmosphere which limits the resolution of even our most strategically placed telescopes. Thus the spacecraft that will be flown to the moon in the NASA Lunar Program will have an essentially unexplored region to work in.

The Ranger spacecraft

The program of lunar exploration will be initiated with the Ranger series of spacecraft. The first two (Ranger 1 is shown in Figure 6-1)

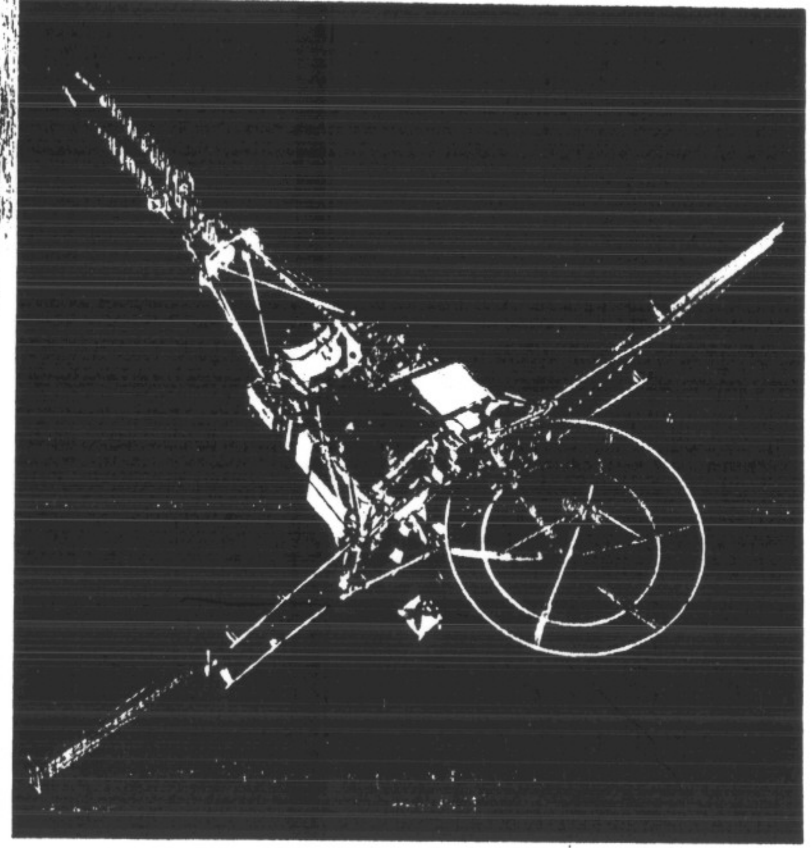

Figure 6-1 The Ranger 1 spacecraft in its open preflight condition.

were built for development flights of the many engineering innovations involved in the Ranger design. The Ranger is an attitude-controlled vehicle which derives its electrical power from solar batteries and communicates with the earth by means of a 4-ft parabolic directional antenna on the spacecraft and the 85-ft diameter receivers of the deep space instrumentation facilities at Goldstone, California, Woomera, Australia, and Johannesburg, South Africa.

The first two Rangers were launched during the third quarter of 1961. Malfunctions in the second stage of the launching rocket prevented these spacecraft from achieving the intended orbit with an apogee at a distance from the earth of approximately 1 million km. Nevertheless, both spacecraft behaved properly under the more limiting conditions of the obtained near-earth orbit at an altitude of between 100 and 200 miles above the surface.

In its structural concept, the Ranger is divided into two major portions. First is the hexagonal-base structure (Figure 6-2), to which are attached the solar cell panels and the directional antenna. Around

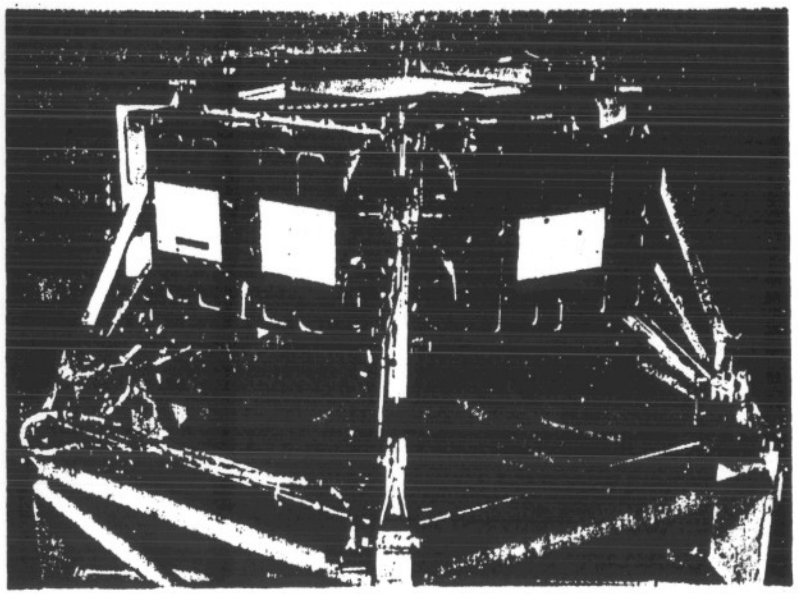

Figure 6-2 The hexagonal base structure of the Ranger spacecraft showing the electronic equipment boxes with surfaces plated and painted to maintain radiative temperature control. Two sets of proportional counters mounted in cylindrical "telescope" arrays can be seen on the upper surface of the right-hand box.

this hexagonal base are six boxes containing electronic components of the several subsystems of the Ranger. The exterior surfaces of these boxes are treated with the appropriate paint or plating to maintain proper temperature control. Attached on the forward or upper section of this hexagonal base is a superstructure (Figure 6-3) which contains most of the scientific experiments and carries on its forward end an omnidirectional antenna designed to give telemetered data on the behavior of the system in case the attitude-control subsystem should fail to point the directional antenna at an earth-based receiver. Several scientific experiments (7) were carried on the first two Rangers designed to take advantage of its intended distance from earth and comparatively long flight time (2 or 3 months). Of course, the near-earth orbit actually achieved by the launching rocketry prevented the gathering of useful information from these experiments.

The second group of Rangers, numbers 3 through 5, is designed to make close-up observations of lunar characteristics and land a working instrument on the surface of the moon designed for a two-month operation. The design of this group of Rangers evolves in a natural manner from the first two. The basic structure, including the six equipment boxes, the solar panels, and the directional antenna, remains essentially unchanged, but the superstructure is replaced. For the Ranger 3, 4, and 5 design, as shown in Figure 6-4, the superstructure is replaced by a combination of retrorocket and survival sphere to be detached from the basic bus at an appropriate altitude above the moon. At this point the retrorocket is ignited to slow down the surviving sphere to a speed at which the equipment can survive the resulting impact.

The scientific subsystem of this group of Ranger spacecraft (8) involves four types of measurements of lunar characteristics. A gamma-ray spectrometer will measure the intensity of gamma rays in the spectro region characteristic of potassium-40 emissions. This spectrometer involves a blank crystal, a photomultiplier, and a pulse-height analyzer to record the intensity of gamma rays with energies around this line.

This gamma-ray information will give us our first direct measurement of the chemical nature of the surface of the moon. Crustal rocks of the earth contain considerably more radioactive material, such as potassium 40, than the rock of meteorites. It is assumed that this indicates a differentiation of crustal material on the earth which has resulted from the thermomigration of the heat-producing radioactive rocks upward, whereas the average composition of the earth is presumed to be the same as the average composition of meteorites.

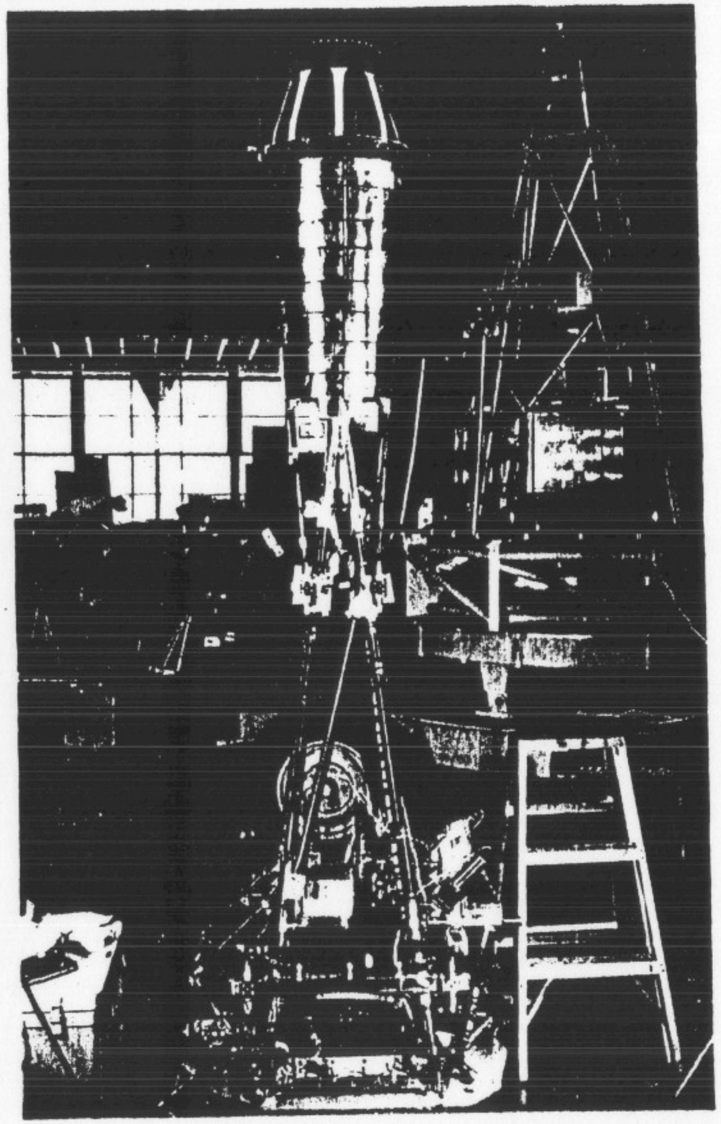

Figure 6-3 Superstructure of the Ranger 1 with the proof-test model of the Ranger 1 spacecraft in the background. Near the bottom of the superstructure is an array of particle counters. The small sphere near the upper end of the truss structure is an ionization chamber. A rubidium vapor magnetometer is housed within the aluminum-covered truncated cone at the top of the superstructure; an omnidirectional transmitting and receiving antenna is at the upper end.

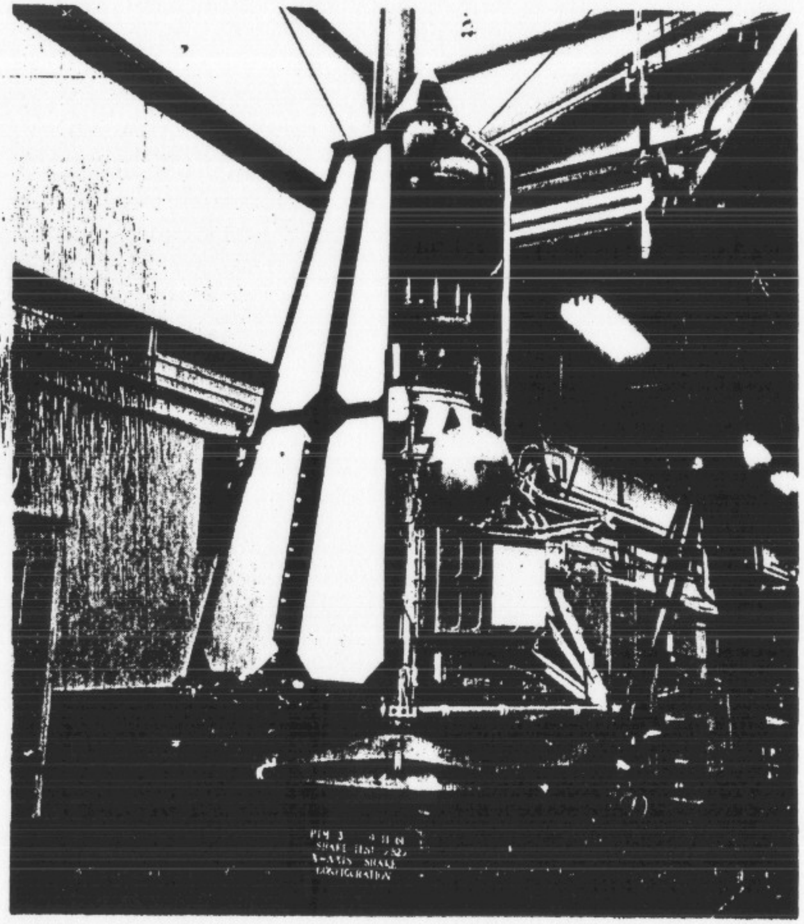

Figure 6-4 Proof-test model of the Ranger 3 spacecraft mounted on a support fixture for a vibration test. A conical omnidirectional antenna is at the upper end. The large ball below it is a balsa impact-absorbing shell containing in the center a single-axis seismometer, together with its power supply, amplifier, transmitter, temperature control, righting mechanism, and antenna assembly. Below that is a solid-propellant retrorocket motor in a fiberglass case. The sphere to the right and below that contains the detector of the gamma-ray spectrometer.

In order, then, to estimate whether the moon has had a thermodynamic history similar to that of the earth, it is of great importance to know whether the surface of the moon also contains a higher abundance of potassium 40 than the meteorites.

The gamma-ray spectrometer is located on a boom that will be extended out away from the spacecraft after the completion of the midcourse rocket maneuver—a course-corrective action designed to direct the Ranger toward the moon on a preselected impact trajectory.

As the spacecraft approaches the moon, its orientation will be changed. Instead of having its head end pointed toward the sun (as is required for adequate illumination of the solar panels), the spacecraft will be reoriented so that its base will be aimed directly at the moon. In this position, using a special Cassegrain telescope (Figure 6-5), it will take a series of vidicon photographs of the surface and relay them back over the communication link once every

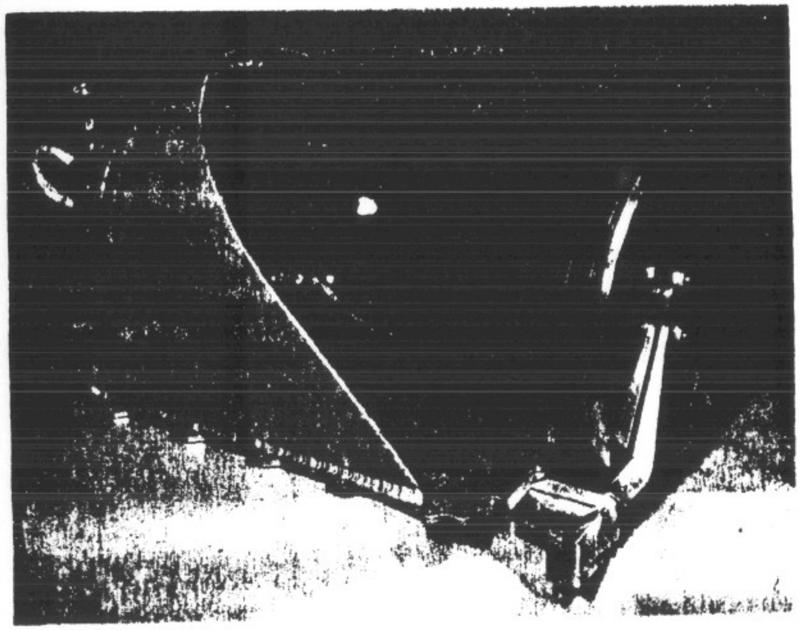

Figure 6-5 The Cassegrain telescope of Ranger 3 used in conjunction with the vidicon television tube to photograph the surface of the moon. The main structural component of the telescope is a fused quartz tube 8 in. in diameter which maintains the proper spacing between the primary and secondary mirrors.

13 sec. This will result in a series of pictures of increasing resolution and decreasing surface area coverage.

The target material of the vidicon is designed to hold the image for well over the 10 sec necessary for the readout—a readout time required by the limited bandwidth of the communication system. During the remaining 3 sec of the vidicon cycle, the image will be erased to prepare for the next photograph.

The first of the series of more than 100 photographs will show lunar-surface features at a resolution similar to that now available in earth-based photographs. However, the last photograph, taken at an altitude of 50 to 100 km above the surface and read out during the remaining stable portion of the spacecraft flight should show a picture approximately two orders of magnitude better in resolution than any now available. The spacecraft impact trajectory is designed so that each succeeding picture will overlap that preceding.

During this approach trajectory a radar altimeter will be in operation. The fundamental purpose of this altimeter is to trigger the retrorocket for the survival sphere at the appropriate altitude. However, the strength of the return signal to the radar will be telemetered to give some indication of the reflectivity characteristics of the area of the moon directly under the spacecraft. This information will help us to interpret radar measurements on the moon made from the surface of the earth.

The flight time to the moon will be approximately 66 hr. At the conclusion of this period, at an altitude of approximately 20 km, the radar altimeter will signal the initiation of the retrorocket sequence. The retrorocket and survival capsule will detach from the bus section of the spacecraft, spin up around its longitudinal axis in order to maintain its aiming direction, and fire. At the conclusion of burning of the solid propellant retromotor, the survival capsule should be at an altitude of approximately 1100 ft above the surface, traveling with zero velocity in relation to the surface of the moon. At this point it will be detached from the retrorocket and fall freely the rest of the way. The instrumentation in the sphere is surrounded by a thick shell of balsa wood (Figure 6-6) designed to withstand the estimated impact which will occur at a speed of approximately 125 mph. If the retrorocket does not perform exactly according to specifications, the burn-out altitude could be either above or below the designed 1100 ft, and the burn-out speed could differ from zero. In this case the impact speed could vary significantly from the design value of 125 mph. The survival sphere is designed to withstand im-

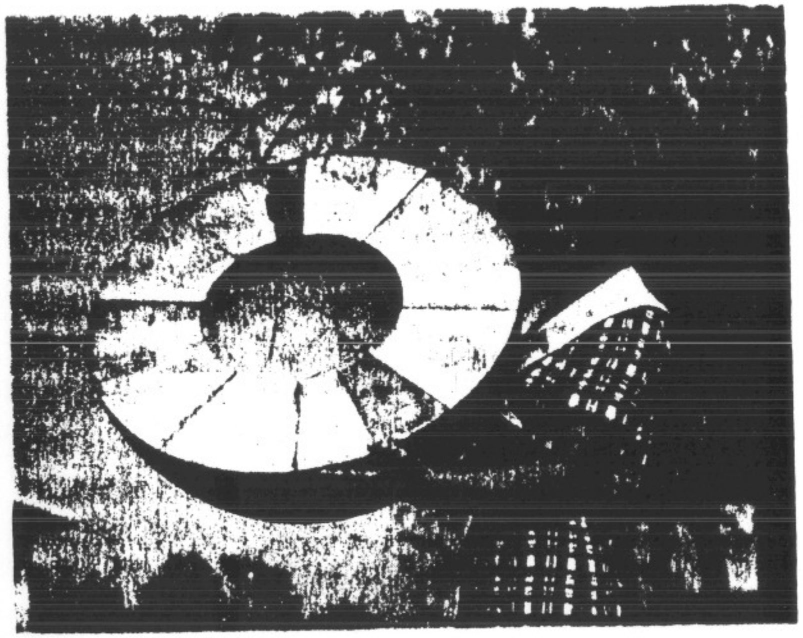

Figure 6-6 A portion of the shock-absorbing structure designed to protect the seismometer and its associated equipment at impact with the lunar surface.

pacts of several thousand g's which might result from an impact speed some 300 mph on reinforced concrete. The instrument system designed to withstand this impact contains a single-axis seismometer. It contains also power supply, amplifier, transmitter, temperature-control system, and righting mechanism. The complete package is designed to detect and transmit lunar seismic data for a period of 1 to 2 months.

The natural seismicity of the moon, if any, will tell us a great deal about the moon's structure and current thermoactivity. Even without internal seismic disturbances, the seismometer may still obtain detectable signals from the impact of meteorites in its vicinity. Considering the average flux of meteorites in the vicinity of the earth-moon system, it is estimated that during the 1-to-2-month operating time of the seismometer, the chances are 9 out of 10 that a meteorite of sufficient size will land close enough to give a detectable signal. The detailed nature of the resulting vibrations from any seismic source, meteoritic or internal, will give information on the thickness of any surface layer in the vicinity of the seismometer.

The Ranger series will continue with four more flights, numbers 6 through 9, devoted to the acquisition of detailed photographic information on the lunar surface. For these spacecraft, the superstructure will be replaced by a structure containing a battery of television cameras and a pair of transmitters. These cameras will operate sequentially during the last portion of a lunar impact trajectory and are designed to give information on small segments of the lunar surface to a resolution of at least a fraction of a meter. No attempt at survival will be made for any instrumentation in this series of flights, and the experiment will terminate when the spacecraft impacts the moon.

The Surveyor spacecraft

The Surveyor spacecraft (Figure 6-7) is designed to land softly a package of instruments for a detailed inspection of the lunar surface. The spacecraft, complete with its loaded retrorocket, will weigh more

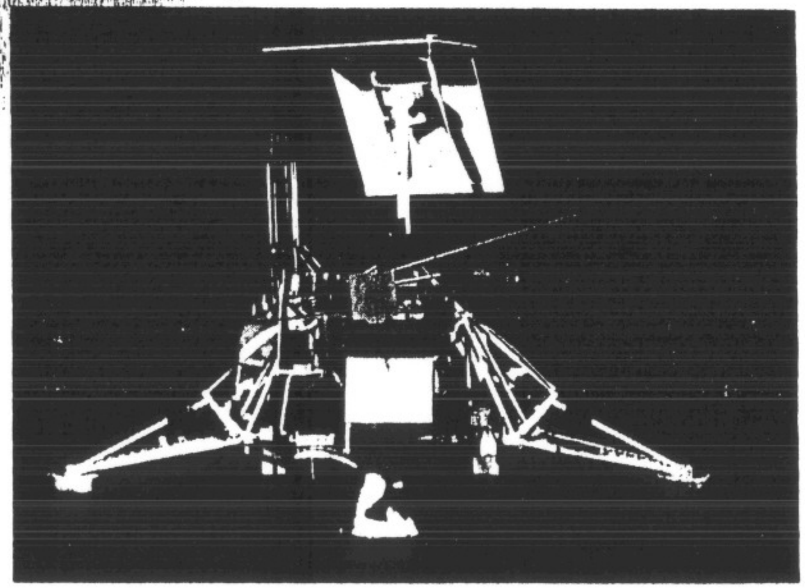

Figure 6-7 A model of the Surveyor spacecraft with landing legs extended and a main retrorocket motor (the large gold sphere in the center with the gold nozzle) still attached. In this photograph two omnidirectional antenna booms are shown extended and the solar panel and antenna array at the top of the spacecraft are shown partially unfolded, although in actual operation the deployment of these components would await landing on the surface of the moon.

than a ton—approximately three times the size of the Ranger spacecraft. Its instrument system contains a range of geophysical and geochemical devices intended to make a very detailed analysis of the portion of the lunar surface under and immediately around the Surveyor landing site.

It will also contain a number of television cameras designed for panoramic, stereoscopic observation of the surrounding lunar terrain and for close-up mineralogical investigation of the material immediately below the Surveyor.

The physical nature of the lunar surface will be investigated by an array of separate devices. These devices will measure the shear strength and bearing strength of the lunar surface material as well as its density, thermoconductivity, magnetic susceptibility, and acoustical propagation speed.

The Surveyor spacecraft will be able to extend its analysis to material below the surface of the moon. It carries a drill designed to penetrate 18 to 60 in. below the surface, depending on the hardness of the surface material. As the drill penetrates into the crust, the fragments of crustal material from the drill hole are carried upward and distributed to several instruments for chemical and mineralogical analysis.

The investigation of lunar seismicity, which is begun with the Ranger spacecraft, will be continued with the Surveyor. A larger, and therefore inherently more sensitive, seismometer can be carried by the Surveyor. The additional weight-carrying capacity of the Surveyor makes possible the inclusion of a three-axis seismometer in contrast to the single-axis instrument carried in the Ranger capsule.

Both the steady-state and variable components of the moon's magnetic field will be measured by a magnetometer carried by this spacecraft. In addition, the radiation level near the moon's surface and the density of the rare lunar atmosphere will be measured by Surveyor equipment.

The availability of a soft-landing spacecraft such as the Surveyor permits the inclusion of a wide variety of instrumentation too delicate for the rough-landing techniques of the Ranger. To take advantage of this soft-landing feasibility, a number of different instruments are being designed and developed. For example, a gas chromatograph is now under development which might be able to detect the existence of complex molecules in lunar surface material. This would, of course, be of great importance if organic molecules were to be found on the moon. Although actual living organisms are not likely there, it is possible that organic molecules could have developed on the surface or have been deposited there by the fall of carbonaceous chondrites or could result from spores drifting through space after having escaped from some planet with an active life form (perhaps the earth?). This last possibility is, of course, the panspermia hypothesis suggested more than half a century ago by Arrhenius to account for the origin of life on earth.

The discovery of organic substances on the surface of the moon will not in itself resolve the conflict between various theories on the origin of life on earth. Instead, it will point the way toward more detailed chemical analyses of whatever molecules are so discovered. This subsequent detailed analysis of any such material might indeed be a major step in man's search for the secret of life's beginning.

To analyze the chemical and mineral nature of lunar material, X-ray fluorescence spectrographs and X-ray diffractometers are being developed. These instruments must operate remotely and automatically on a power supply considerably more limited than that which is customarily employed with earth-based X-ray equipment. Furthermore, they must be able to accept samples that can be prepared by reliable, remote, automatic equipment from the material removed by the lunar drill. In spite of these considerable problems, the developers of these instruments are confident that they will operate satisfactorily and give us an accurate picture of the elemental nature of the lunar material over a wide range of important constituents.

An effort is under way to develop a remote-operating petrographic microscope with a television readout. The availability of such an instrument would considerably enhance our ability to identify lunar material and to relate it to similar material—if any—found here on earth.

The physical nature of the lunar surface is also of primary importance, not only for an understanding of the nature of the moon, its origin, and its history, but also for the adequate design of subsequent vehicles designed to roam over the lunar surface—vehicles that will eventually carry a man. In order to conduct such experiments, the techniques of soil measurement are being applied to the development of remote equipment to measure the shear strength, bearing strength, and hardness of the lunar surface.

The lunar orbiter

The first Surveyor soft-landed vehicles will be stationary and will make a careful analysis of the lunar material in their immediate vicinity. Their range of exploration will be limited by the mechanical reach of the various arms and booms that deploy the instruments. Of course, the television cameras on the Ranger will be able to survey the lunar surface as far as visual range from the stationary Surveyor permits.

A series of several Surveyors will be flown, so that a number of separate sites will receive thorough investigation. Then, in order to relate the results of these stationary measurements to conditions over the rest of the moon, it is expected that the Surveyor soft-lander will be complemented by the operation of a lunar orbiter. A series of such orbiters are now in the planning stage.

It is intended that these lunar orbiters be placed in a fairly well-controlled circular orbit a few hundred kilometers above the surface. In order to complete a survey of the moon, the orbiter would have to operate for one lunar period—about a month. During this time, if it were launched into a polar orbit, it would have made one pass over all portions of the lunar surface twice—once in sunlight and once in shadow. During the sunlight passage it could photograph the lunar surface and take the spectral measurements that depend on reflected sunlight. The gamma-ray analysis of the surface material could be carried out over the complete orbit, regardless of sunlight conditions.

The lunar orbiter is an extremely powerful tool for completing a thorough survey of the lunar surface. It is to be compared to the airplane (rather than a satellite) in the survey of the surface of the earth. Since no clouds or other atmospheric disturbances will impede the observation of the surface from the orbiter, the surface resolution that could be obtained from photographs taken with an orbiter depends primarily on the design of the photographic system.

Preliminary design studies have been carried out in an effort to determine the most efficient way to obtain and transmit to earth accurate photographs of the lunar surface.

In the case of airplane surveys of the surface of the earth, one of the major efforts concerns the processing of the resulting photographs for the creation of maps, etc. For the lunar orbiter, the same problem arises. A major portion of the lunar-orbiter photographic system will be the ground-data-processing facility. This may well involve the creation of a brand new skill—the lunar photo interpreter. It is very likely that lunar features, resolved on the scale of a few meters, will be so unlike any features occurring on earth, either natural or man made, that completely new approaches to photo interpretation will be required.

The Prospector

The title "Prospector" is used to apply to a class of spacecraft differing in two ways from the Surveyor and lunar orbiter. The Prospector is thought of as being larger than the Surveyor and thus would be launched with a larger booster; second, the Prospector is considered to involve primarily a surface-roving vehicle.

Within the presently defined plans, the Prospector class of lunar spacecraft should be operating at about the same time as the preliminary flights in the manned lunar program. For this reason it is natural to suspect that there will be close correlation between the Prospector spacecraft utilization and the lunar exploration required for landing-site survey and selection. It is also reasonable to suppose that the Prospector spacecraft design will be carried out in conjunction with the design of the manned lunar landing craft, since these two craft will share many design objectives and design problems.

No detailed plans have been made for the scientific experiments to be carried out with the Prospector vehicle. It is reasonable to assume that the experiments conducted with the Surveyor will be extended during the Prospector series; that is, with the roving Prospector vehicle, experiments similar to those in the stationary Surveyor can be conducted over a wide variety of lunar terrain. Of course, it is quite likely that the results of the Surveyor experiments will reveal unimagined problems that will dictate a different course for the scientific program of the Prospector mission.

6-2 THE PLANETARY PROGRAM

Introduction

If the several objectives of the lunar exploration program were to be grouped together into one subject of natural philosophy, then its title would be, "The Question of the Origin of the Solar System," for we expect to find written on the surface of the moon the early history of the formation of the planets. Such a history was undoubtedly written on the surface of the earth, but in the subsequent 5 billion years the earth's crust has been so overturned, so worn away, and so modified that this record is now forever lost. On the moon, where we expect geological forces to have been much less active, this record very likely still remains, awaiting our detailed examination.

In this same sense, the objectives of our first step in exploring the planets can also be grouped into a single fundamental subject of natural philosophy, and that is, "The Search for the Origin of Life."

It is not likely that we will find the origin itself, or even the history of the origin, on any other planet in the same sense that the history of the solar system's formation can now be seen on the surface of the moon. Rather, we hope to find in the life form of another planet one more example of the way in which life can grow.

In spite of the many forms that life appears to take on the surface of the earth, the difference between a sea slug and a sequoia tree is really no more than a variation in the structure of the fundamental genetic molecule desoxyribonucleic acid (DNA). This molecule carries from generation to generation the genetic information that enables the species to reproduce itself continually, and its variations account for the variations between the species and between the cells in an individual.

How this is accomplished, of course, we do not yet understand, but we have at least identified this basic chemical constituent of all life on earth. So, in the most basic terms, there is only one form of life on earth, and thus we know of only one way in which nature can create living matter. On Mars we might be able to find another form of life, and it is possible that we will find a second way in which nature can make life. If this is true, we will immediately double the number of examples we have of life forms.

Mars is chosen as an example because observations of this planet over many years are certainly indicative of some form, at least, of vegetable life on its surface. There is the well-known seasonal change in the dark markings; that is, a color change progressing from the poles toward the equator during the seasonal warming up of the particular hemisphere and the associated evaporation of the polar frost cap. There are the observations of large, new areas, thousands of square miles in extent, of sections of Mars that were light in color for many years and then within a few Martian years changed to dark—a modification possible for growing plants but extremely difficult for a geologic process. There is the ability of the dark areas to survive and "show through" after a planet-wide dust storm (at least "dust storm" seems the most likely explanation of the yellowish clouds that grow up and cover the planet from time to time). Finally there is the work of Sinton (9, 10), who observed the infrared spectrum of Mars in the region between 3 and 4 μ and found there clear evidence of absorption at wavelengths corresponding to the absorption of the hydrogen-carbon bond in a large organic molecule.

Of course, there are alternate explanations for these individual observations. But still there are no adequate explanations (at least in the writer's opinion) other than a life form, which can account for

all of the observations. Certainly, the existence of life on Mars has not been proven, but its likelihood has been so well established that it is accepted as a reasonable basis for the fundamental mission objectives of our early Martian exploration program. Simply the unambiguous proof of the existence of life will be enough for the first step. After that, the chemical analysis of this life will follow.

Planning for the activities in the planetary program has one unique aspect that separates it from all other missile flight programs so far undertaken; the flight schedule is determined not simply by the booster development program or the availability of launching pads but primarily by the intractable orbits of the planets themselves. This implies that a slipped schedule would have truly shattering consequences.

Although, in principle, one could undertake a flight to a planet at any time, since trajectories can be computed with the known equations of motion for any geometry at all, the flight itself under almost all circumstances is hopelessly impractical. Except for a very short interval, the order of 1 or 2 months in as many years, the energy that a rocket would require in getting from here to there is just not available. However, during the practical launch interval (commonly called the "launch window") presently available booster rocket systems have the capability to launch a few hundred pounds toward either Mars or Venus.

The Mariner R

The first attempt to take advantage of this launch-vehicle capability will make use of a spacecraft called the Mariner R. It is planned to launch this spacecraft on an orbit that will take it past the planet Venus after a flight time of approximately 100 days. During its flight, the Mariner R will take measurements of the particle radiation in the space between the orbit of earth and the orbit of Venus and will also measure the magnetic field in this region. As it passes the target planet, microwave and infrared radiometers will scan back and forth over the surface.

The Mariner R is similar in many ways to the Ranger spacecraft. It has a hexagonal base structure, two panels of solar batteries, and a 4-ft-diameter parabolic antenna for communication with the earth. Its general appearance (Figure 6-8) is similar to the Ranger 1; however, the Mariner R weighs approximately half as much as the first Rangers and carries considerably fewer instruments.

The microwave radiometer uses a single parabolic reflector and two receivers: one at 13 mm and one at 19 mm. Microwave radiometric

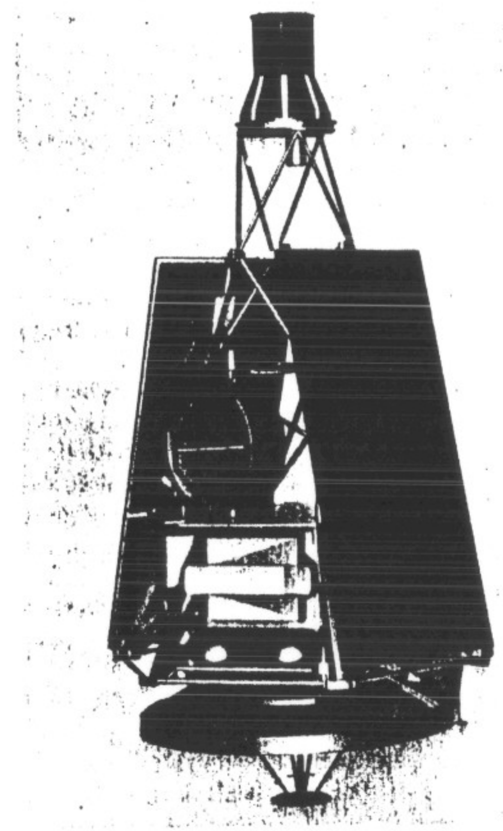

Figure 6-8 A model of the Mariner R spacecraft with the parabolic reflector for the microwave radiometer located in the center of the structure.

measurements carried out from the surface of the earth have shown that Venus has an apparent temperature of several hundred degrees centigrade. At least in the longer wavelength region of several centimeters the radiating strength of Venus is so high that it requires such a temperature if this strength is due to radiations from the planetary surface. At shorter wavelengths, from a few millimeters down to the infrared, the radiative power of Venus corresponds to a considerably cooler temperature. The signal-to-noise ratio of these measurements is very poor because of the low strength of the energy radiated by Venus in this region and the great distance to the planet. Thus

the probable error on these temperature measurements is considerable; that is, the order of 100°K in a total reading of 400 to 600°K. Nevertheless, the general trend of cooler temperatures at short wavelengths and hot temperatures at long wavelengths seems by now substantiated.

It is reasonable to believe that the difference between these two measurements is caused by the presence of the atmosphere of the planet; that is, at longer wavelengths the atmosphere is transparent and the surface itself is being detected. At the shorter wavelengths radiations from the surface are absorbed in the atmosphere, and it is the upper atmosphere, considerably colder than the surface, that is responsible for the detected radiation. The two wavelengths chosen [illegible] R experiment correspond to the transition region be-[illegible] long wavelength regimes of this experiment. Since [illegible] pass within approximately 10,000 to 20,000 km of the surface, the signal-to-noise ratio will be greatly enhanced for these radiometric measurements. Therefore, accurate readings can be obtained of the radiation in this critical wavelength region. Furthermore, the passage near Venus is close enough and the beam width of the antenna narrow enough (2 degrees between half-power points) that the distribution of temperature over the surface of the planet can be resolved. This resolution is beyond the capabilities of earth-based antenna systems. For example, limb brightening, if any, could be detected. One of the alternate theories to account for the high radiometric measurements of Venus is that these radiations come from a highly active ionosphere. If this theory is correct, then this comparatively close inspection of the disk should show limb brightening in these wavelength regions.

Two infrared radiometers with a 1-degree square window will also scan the surface in conjunction with the microwave radiometers. One of the IR detectors will be sensitive in the 8-to-9-μ and the other in the 10-to-10.8-μ region. The first region corresponds to a window in the CO_2 absorption spectra, and the second covers the weak 10.4-μ absorption band of CO_2.

It is possible that the cloud cover of Venus has breaks in it too small to be resolved by telescopes here on earth. Such breaks might be revealed by inspection from the Mariner R. However, an extremely simple lightweight device must be used, since at the range of Venus the operation of photographic or television equipment is quite beyond the capability of the Mariner R system. This is one of the reasons for the inclusion of the IR radiometers. As the instrument scans over the surface of the planet, the output of the two detectors will be compared. If they should follow each other, always in the same ratio, one would conclude that they are both looking at the top of an unbroken cloud layer, since the absorption band of CO_2 in the 10.4 region is too weak to respond to the amount of CO_2 above the clouds. If, on the other hand, points are noted in which the proportionality between the two detectors suddenly changes and then returns, one would conclude that the 8-to-9-μ detector has seen through a break in the clouds to the surface, unimpeded either by CO_2 or clouds, whereas the 10-to-10.8-μ detector, looking into the same cloud break, has seen only a little farther down to a point at which the optical depth of CO_2 in the Venus atmosphere (at least for the 10.4-μ absorption region) became appreciable.

In addition to the information gained from these comparative readings, the absolute value of the readings themselves will give information on the temperature distribution over the cloud layer to compare with the temperature reading obtained from the microwave radiometers.

The particle detectors and magnetometer operating in the vicinity of Venus should reveal any planet-centered magnetic field and any belts of trapped radiation.

The Mariner B

The Mariner B spacecraft will be a considerable advance over the Mariner R. The Mariner B will be launched with a larger vehicle and will more than two times outweigh the Mariner R. This will permit the inclusion of a larger family of instruments.

Like the Ranger and Mariner R spacecraft, it will rely on panels of solar batteries for its electric power and will communicate with the earth by a parabolic reflecting antenna. The possibility that future flights might carry a capsule for penetration into the atmosphere of either Venus or Mars is being investigated. Such a capsule could be detached at a considerable distance away from the target planet while both spacecraft and capsule were on an impact course. Thereafter the remaining spacecraft might be redirected onto a fly-by course by a maneuver rocket. The capsule would then enter the atmosphere of the planet and decelerate by aerodynamic drag to a point at which it could safely deploy a parachute for continued descent to the surface. During this final descent phase and after landing on the surface the capsule might communicate either directly with the earth or by relay through the parent spacecraft on its fly-by trajectory.

The increased size and weight of the Mariner B spacecraft makes

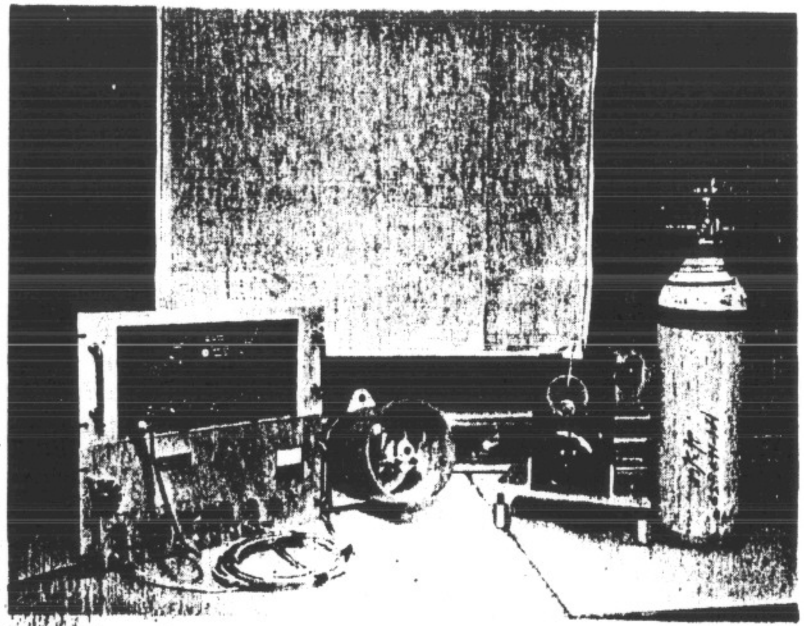

Figure 6-9 Prototypes of an infrared interferometer (*left*) and grating spectrophotometer of the Ebert type designed for possible inclusion in the Mariner B type of planetary spacecraft.

possible a considerable increase in the bandwidth of its communication system; it will also have the ability to store and process data on board for conservation of the bandwidth. Thus it will be possible to take television photographs of the planet from the comparatively close range of the fly-by. For Mars this capability is of primary importance.

Infrared and ultraviolet spectrometers now under development for spacecraft of the Mariner B series (Figures 6-9 and 6-10) can obtain much more detailed and extensive spectroscopic observations than the simple IR radiometers of the Mariner R. In addition, more extensive microwave radiometers have been designed for observation of the Venus surface in several different wavelengths (Figure 6-11). Field experiments can be carried out with Mariner B spacecraft during its flight from earth to the target planet. This will permit an extensive and detailed survey of solar phenomena and their variations with distance from the sun.

Perhaps th[illegible] exciting aspect of the Mariner B is the possibility

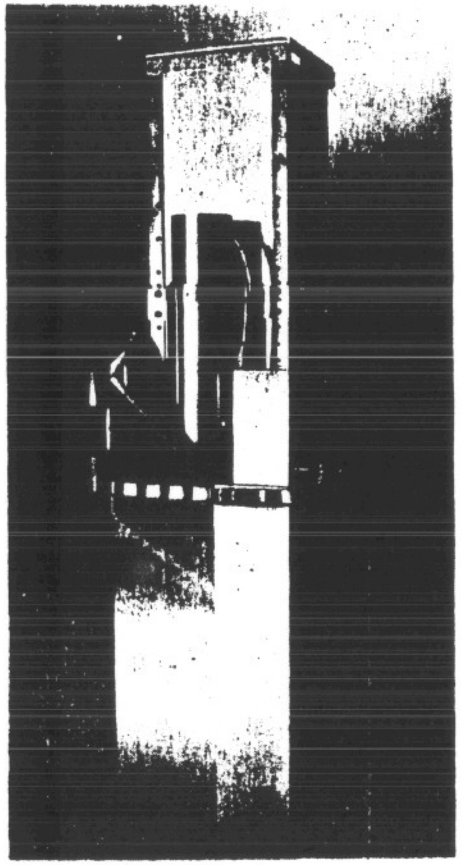

Figure 6-10 An ultraviolet grating spectrophotometer of the Ebert design under development for possible inclusion in the Mariner B spacecraft series.

of including a landing capsule. If the surface of Venus is, indeed, as hot as the radiometric measurements indicate, then a landing capsule would probably not survive for any useful period of time on or near the Venus surface. Thus primary experiments for such a capsule would be designed to measure the characteristics of the Venus atmosphere during the capsule descent phase.

For Mars, however, the possibilities inherent in the capsule are more promising. One of the primary objectives of the national space program is the discovery and analysis of life on another planet. Certainly, Mars is the most likely prospect for such a discovery. It is

this landing capsule that might well make such a discovery. Several ingenious devices are already under development to carry out this search for extraterrestrial life. One such device would collect samples of surface material, distribute them among various nutrient solutions, and then watch for any metabolic changes in the containers of solutions mixed with Mars material. Another device would observe dust particles with a TV-reading microscope. A third device would make use of gas chromatographic techniques to analyze organic molecules found either in the atmosphere or in the surface material.

Of course, one primary problem comes to mind immediately in relation to the search of extraterrestrial life. Regardless of the urgency of the planetary exploration program, we must be quite careful not to contaminate another planet with earthly bacteria or even with earthly viruses. This problem is far from simple. The sterilization of the spacecraft is a difficult and complex operation. It must be carried out in conjunction with all of the other operations concerned with the launching of the nation's largest guided missiles.

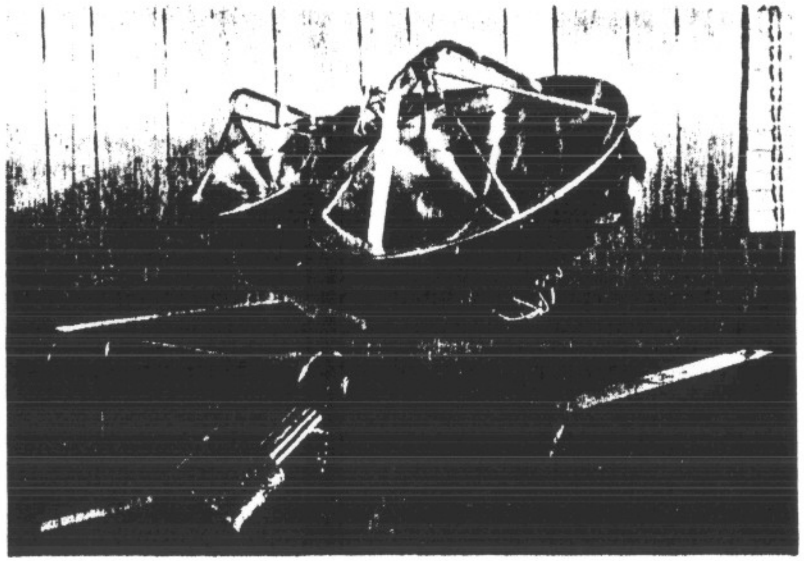

Figure 6-11 The microwave radiometer package under development for possible inclusion in the Mariner B planetary spacecraft series. Four receivers operate from feeds collecting energy from three parabolic reflectors. The 4-, 8-, 13-, and 19-mm regions are examined. Receiver electronics are mounted on the rear of the structural support of the antennas.

The problem is made even severer by the nature of the required sterilization. It is not enough simply to remove the disease bacteria that might be harmful to men; all bacteria must be removed. Furthermore, all complex organic molecules that might become viruses must also be removed. And who is to say what kind of organic molecule might be a virus for an unknown life form on the surface of Mars? Thus the determination of the sterilization requirements is almost as difficult as the sterilization operation itself. The scientists involved with this problem have done their best to combine imagination with practicality and have worked with the engineers to evolve a series of heat treatments and gaseous decontamination operations that will, hopefully, reduce to an acceptably small value the likelihood of accidental contamination of Mars life forms. Certainly, it would be a most tragic blunder if we were accidentally to harm or destroy that very extraterrestrial life form whose discovery is so important to us!

The Voyager

In the planetary program the Voyager occupies an analogous position to the Prospector of the lunar program. It is a title applied to a larger class of vehicles than the Mariners, and it is conceived of as involving a landing device including possibly a roving vehicle, at least in the case of Mars. The design of a Voyager class spacecraft for the surface exploration of Venus must, of course, await further measurements of the condition of the surface, particularly its temperature. As for the experiments that might be carried out for the Voyager spacecraft, there is, of course, no real limit that can be placed on it. Mars is a new world. It has one fourth the surface area of the earth, and, since it is likely that no appreciable fraction of it is covered with oceans, the dry-land area of Mars may be just as great as the dry-land area of the earth. Who can place a limit on the problems and possibilities of its exploration?

6-3 CONCLUSIONS

This completes the summary of the present plans for the exploration of the moon, the planets, and the space between them. It represents a first small step into the vast expanse of the solar system, yet it is an impressive step indeed. The equipment that will carry out the unmanned automatic exploration of Mars, for example, will undoubtedly be the most complex, sophisticated, reliable mechanism ever devised by man. In undertaking the conquest of space, we are not only setting out on an exploration program greater than any human beings have ever attempted in their earth-bound existence but we are doing so with the help of more advanced engineering techniques than have ever been employed in our earthly undertakings. It will be interesting to see which of these two facets results in the greater benefit—the natural phenomena that we will discover or the engineering techniques that we will develop to accomplish these discoveries.

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FOREWORD

In the period since the earth's first artificial satellite, Sputnik I, was launched on October 7, 1957, our knowledge of space science has progressed with tremendous strides. From instrumentation carried aboard satellites and space probes like the Explorer and Pioneer series, new discoveries are being made in areas previously inaccessible to earth-bound man. Examples are the discovery of the Van Allen radiation belts and the large ring currents, which are now known to exist far above the earth's atmosphere but in its magnetic field. Also, much additional scientific information is being obtained about phenomena which a few years ago were little known. Examples are cosmic rays, micrometeorites, solar emissions, and interplanetary magnetic fields.

New discoveries and new scientific information about space have been accumulating so rapidly that it has been difficult for scientists and engineers to keep abreast of this expanding technology. Therefore, a book summarizing the present state of our knowledge of this field should prove both timely and useful. Since no one person is sufficiently knowledgeable in all of the scientific disciplines involved, it is particularly fortunate that it has been possible to obtain contributions from so many nationally recognized experts, each of whom has written a chapter covering his specialty.

In this way an authoritative treatise has been obtained covering not all but many of the scientific areas in space exploration, which will be of great value to the scientists designing space experiments and to the engineers designing spacecraft.

JAMES H. DOOLITTLE

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