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SCIENTIFIC EXPERIMENTS FOR A MANNED MARS MISSION

by Hugh J. Dudley, James K. Harrison, James O. Ballance, Milton A. Page, Joseph R. Dabbs, James A. Power, Kermit O. Hudson, and M. Louis Powell

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16. Abstract

This report presents scientific experiments for an assumed first manned mission to Mars. Experiments have been established in the following scientific disciplines: planetary atmospheres, planetary surfaces, planetary dynamics and interiors, particles and fields and planetary interactions with the solar wind, and exobiology. The emphasis throughout the report is on a detailed program of experiments as opposed to a broad and general outline. Instruments needed for the experiments have been described and tabulated. Briefly discussed are requirements for certain operational aspects of the mission, such as crew size, surface rovers, unmanned orbiters, scientific laboratories, and landing sites.

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FOREWORD

This report has been prepared for Dr. William Haberman, NASA Headquarters, who requested in December 1969 that the Planetology Group develop a science program for the Planetary Mission Requirements Study. Dr. Haberman was the director of the in-house study with participation by the Manned Spacecraft Center, Langley Research Center, Goddard Space Flight Center, Kennedy Space Center, and the Marshall Space Flight Center.

This report is the result of efforts by the members of the Planetology Group, Mission and Payload Planning Office, Program Development Directorate (PD-MP-P). The members and their area of contribution are as follows:

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SCIENTIFIC EXPERIMENTS FOR A MANNED MARS MISSION

SUMMARY

This report includes the results of an in-house study to develop a representative science program for a hypothetical manned mission to Mars. This work was accomplished in late 1969 and early 1970. It was an advanced planning effort and was not in support of an approved Agency program.

The report discusses, for an assumed initial manned mission to Mars, possible scientific experiments in the following disciplines: planetary atmospheres, planetary surfaces, planetary dynamics and interiors, particles and fields and planetary interactions with the solar wind, and exobiology. Some experiments have been suggested for Venus, since the spaceship on the assumed mission would fly by that planet.

A brief outline of the mission assumed for this study effort is as follows. Two planetary space vehicles, of essentially the same design, will depart Earth in the spring of 1985 on a heliocentric transfer to Mars. Each space vehicle will have two principal components: a planetary mission module and a Mars excursion module (MEM). After a Venus swingby the space vehicles will arrive at Mars where, after a brief orbital period, one MEM from each space vehicle will descend to the surface. The planetary mission module will remain in orbit. After a 40- to 60-day surface stay-time, the ascent stage of the MEM will rendezvous with the planetary mission module for a direct heliocentric transfer to earth.

Instruments needed for the experiments have been identified and tabulated. The total mass of the instruments is 6950 kg.

Certain operational requirements have been established to accomplish the scientific experiments.

Five scientists will be needed at each landing site to accomplish the experimental program. A different landing site for each of the two spaceships is desirable. Landing sites near the equator (perhaps in the Tithonius Lasus region) and near the south polar cap (at about 50 deg S) are recommended. A manned rover will be needed to investigate the surface with any degree of thoroughness.

SECTION I. INTRODUCTION

In all likelihood the next body in our solar system to be visited by man will be the planet Mars. Unlike early expeditions to the Moon, which were primarily devoted to engineering considerations, the exploration of Mars will be a more balanced program with heavy emphasis on scientific investigations. For the first time man will propel himself beyond the influence of the Earth-Moon system and explore another celestial body for an extended period of time.

Possibly the most intriguing question faced by man today is the prospect of life on other planets, and although recent data from Mariners VI and VII discourage such prospects on Mars, they do not rule them out. Therefore, the search for life has been given the highest priority, followed by the desire to learn more about the origin and evolution of the solar system.

This report presents scientific experiments for the first manned mission to Mars. The emphasis throughout the report has been on a detailed program of experiments as opposed to a broad and general outline. By adopting this approach it is hoped that the report will serve as a baseline for further and more detailed planning.

Experiments have been established in the following scientific disciplines: planetary atmospheres, planetary surfaces, planetary dynamics and interiors, particles and fields and planetary interactions with the solar wind, and exobiology.

In developing these scientific objectives close coordination has been maintained with members of the Systems Analysis Office (PD-SA), who have provided assistance by supplying details on typical mission profiles, launch vehicles, and spacecraft. This has assured considerable (though not complete) compatibility between systems currently being considered and the scientific experiments suggested here. It should be noted, however, that the experiments presented in this study are considered applicable for other mission profiles and spacecraft systems.

A 1986 opposition-class mission has been selected as typical of those being considered, and it has been assumed that the experiments will be done on this mission. Briefly the details of the mission are as follows. Two planetary space vehicles, of essentially the same design, will depart Earth in the spring of 1985 on a heliocentric transfer to Mars. Each space vehicle will have two principal components: a planetary mission module (PMM) and a Mars excursion module (MEM). After a Venus swingby the space vehicles will arrive at Mars where, after a brief orbital period, one MEM from each space vehicle will descend to the surface. The planetary mission module will remain in orbit. After a 40- to 60-day surface stay-time, the ascent stage of the MEM will rendezvous with the planetary mission module for a direct heliocentric transfer to earth. The approximate dates for the 1986 mission are as follows:

Launch from Earth.	March 26, 1985
Arrive Venus.	Sept. 12, 1985; 170 days
Arrive Mars	March 11, 1986; 350 days
(About 60 days at Mars, 40 days on surface)	
Leave Mars.	May 10, 1986; 410 days
Arrive Earth.	Oct. 7, 1986; 560 days

A conjunction-class mission with a 360- to 560-day stay-time at Mars (depending on launch date) has been assumed as a likely follow-on to the 1986 mission. This report does not include the scientific objectives of the conjunction-class mission since this will be covered in a subsequent study; however, many of the experiments proposed here would be appropriate for the longer mission.

Some of the important physical features existing at Mars on arrival are illustrated in Figures 1, 2, and 3. Figure 1 presents the locations of Mars in its orbit, Figure 2, the temperature as a function of latitude, and Figure 3, the extent of the polar caps and wave of darkening.

In accomplishing the experimental objectives the inherent and unique abilities of man will bring a dimension to scientific investigations heretofore absent in the study of any planet other than earth. Man is the only reliable instrument available that can rapidly adjust observations over the many orders of magnitude resolution needed for some scientific investigations. His judgment is unsurpassed in selecting locations for instruments and for gathering samples and examining complex situations. His ability to interpret experimental results and, if necessary, redirect the investigations will be very valuable. He can manipulate and repair the instruments. His faculty

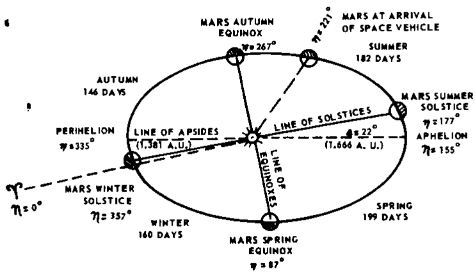

Figure 1. Position of Mars in orbit on arrival.

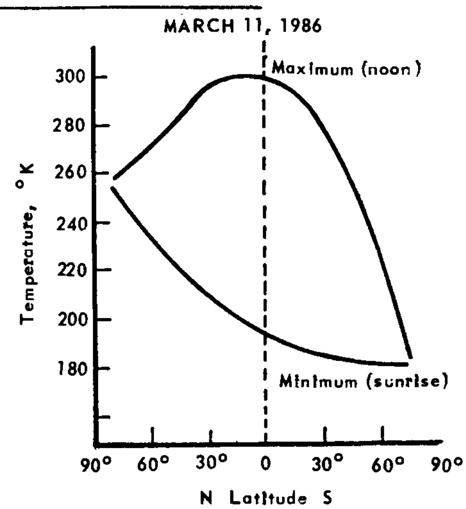

Figure 2. Martian temperature variations with latitude at time of landing.

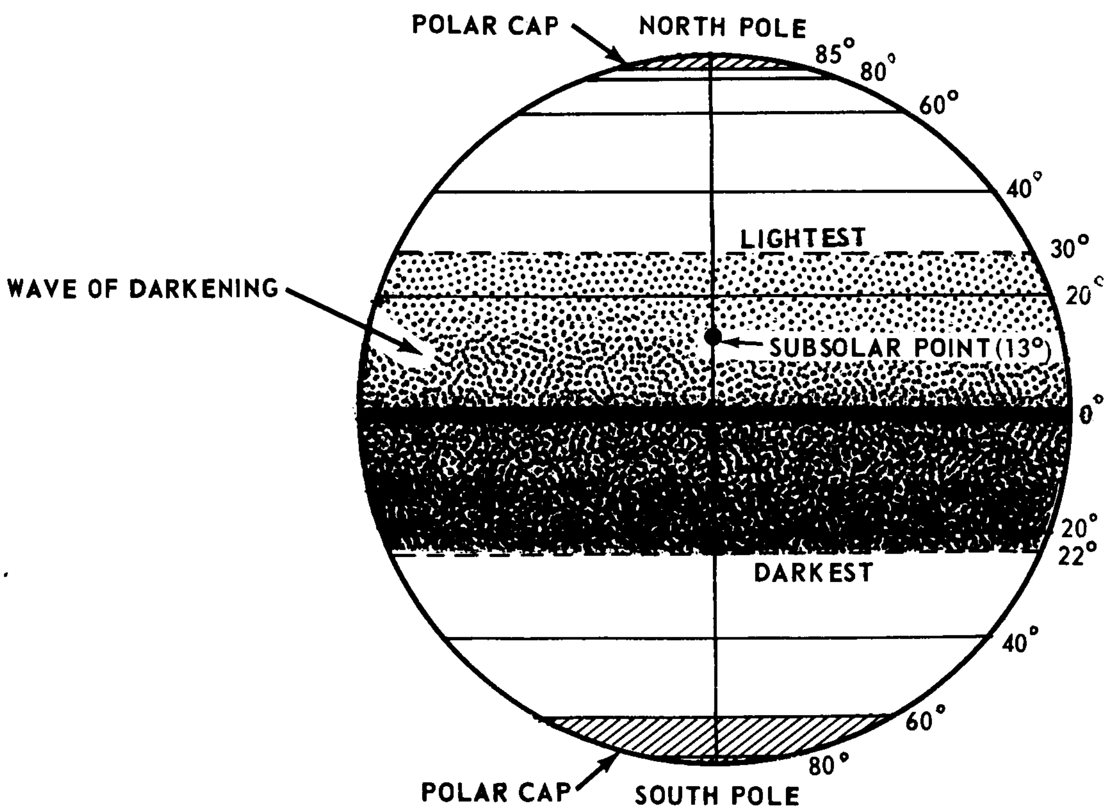

Figure 3. Physical conditions on Mars at time of landing.

for appraising and correlating interdependent measurements (some occurring simultaneously) of many physical properties and for improvising when unexpected situations occur cannot be overemphasized.

Estimates of the instrumentation state-of-the-art in the early 1980's can be made by extrapolating the advances that have occurred during the last 10 to 15 years. Using these estimates as a guide it is envisioned that most of the measurement results will be transmitted in near real-time to earth.

SECTION II. PRECURSORY SCIENCE

In planning scientific experiments one must carefully review and consider the experiments that have or will have been accomplished before the planned flight data. Because it is unlikely that the results from unmanned probes will fully answer all scientific questions about Mars, a manned mission will be a logical extension of these unmanned missions. A review has been made of the completed and projected scientific results from unmannned probes to Mars and Venus. The accomplished experiments pertaining to Mars and Venus are from five Mariner-series spacecraft: Mariner IV (1965) and Mariners VI and VII (1969) for Mars; Mariner II (1962) and Mariner V (1967) for Venus. All five missions were flybys with distances from the planet surface at nearest approach as follows: Mariner II, 34 950 km; Mariner IV, 9850 km; Mariner V, 4101 km; Mariner VI, 3431 km, and Mariner VII, 3430 km.

The past and projected experimental results from missions to Mars are shown in Table 1. The experiments are listed according to scientific disciplines and include the launch date and spacecraft. For some of the spacecraft still in the planning stages, several launches are planned over a period of several years, an example being the Mars Explorer Orbiter with three launches planned from 1975 through 1981.

Venus scientific results and plans have also been reviewed because current plans for the manned mission include a flyby of that planet. This information is shown in Table 2.

Although some of the planned experiments are tentative, they represent the only practical basis for present planning.

TABLE 1. MARS PRECURSORY SCIENCE

Science	Date	Spacecraft
Planetary Atmospheres:		
Atmosphere is predominantly CO_2. Some CO, H, O, and C. Solid CO_2 at high altitudes. Polar cap is either solid CO_2 or covered by cloud of solid CO_2. Solid H_2O (as fog or surface hydrates) detected at all latitudes. Scale height above 130 km is 23 km. No cloudiness found except traces near polar cap. A haze stratified into layers about 10 km thick, thought to contain solid CO_2 particles, was discovered 16 to 50 km above the surface. No blue haze detected. Pressure at surface is 600 to 700 N/m^2 except in Hellespontus region, where it is 380 N/m^2, suggesting an elevated plateau 4 to 5 km high. Temperatures in early spring at 58 deg S latitude varied from about 220°K at surface to 150°K at altitude of 38 km.	1964 1969	Mariner IV Mariners VI and VII
Upper atmospheric properties will be measured during entry by mass spectrometers, accelerometers, pressure, and temperature sensors. Reflection of sunlight by atmospheric particles will be measured with a UV photometer. Atmospheric temperature, pressure, and humidity at surface and wind velocity as a function of time and location will be measured. Chemical analysis of atmosphere.	1975- 1979	Viking
Visual imaging.	1971	Mariner Mars Orbiter
Visual imaging with resolution to 10 m.	1979 1984	Mars High-Data Orbiter

TABLE 1. (Continued)

Science	Date	Spacecraft
Planetary Surface:		
Mars has a heavily cratered surface resembling that of the Moon. Three types of terrain exist: (1) cratered terrain, which is prevalent, (2) featureless terrain, which is flat and smooth like dry lakebeds on earth, and (3) chaotic terrain, which is an irregular and jumbled topography like a landslide area on earth.	1964	Mariner IV
Surface features lose contrast in blue light. This is attributed to surface effects, namely, albedo variations, and not to blue haze in atmosphere. No seasonal darkening was observed. Only in a few cases were surface structures identified with "canals." These cases involve linear alignments of craters and dark patches. Polar cap is predominantly CO_2, with lowest temperature of south cap about 150°K. At noon equatorial temperature is about 290°K and about 230°K at polar cap edge. At night equatorial temperature is about 200°K.	1969	Mariners VI and VII
Imaging to make topographic and thermal maps of Mars.	1971	Mariner Mars
Facsimile camera for taking pictures of specific objects. Soil will be heated to produce gas by evaporation and burning of material for analysis in gas chromatograph and mass spectrometer. Determination of amount of water in soil and whether water is bound in minerals or free.	1975-1979	Viking

TABLE 1. (Continued)

Science	Date	Spacecraft
Planetary Surfaces: (Cont'd)		
Visual imaging to 10-m resolution and thermal mapping.	1979 1984	Mars High-Data Orbiter
Planetary Dynamics and Interiors:		
Earth-Moon mass ratio is 81.3 ± 0.0015. Earth-Mars mass ratio is 9.3069227 ± 0.0003031. Equatorial radius is 3394 km. Dynamical flattening measurements are more accurate than optical flattening measurements.	1969	Mariners VI and VII
Lightweight seismometer.	1975	Viking
Geophysical measurements on planet surface.	1984	Mars Soft-Lander/ Rover
Particles and Fields and Planetary Interactions with the Solar Wind:		
Negative results on cosmic ray telescope and ionization chamber experiments. Mars magnetic dipole moment is about 3×10^{-4} that of Earth value.	1964	Mariner IV
CO_2^+ is dominant ion in the ionosphere. On day side electron density at 130 km altitude in the afternoon is 1.5×10^5 e/cm^3. Plasma temperature is about 450°K. No ionization detected on dark side.	1969	Mariners VI and VII
Measure magnetosphere, magnetosheath, detached "bow shock" wave.	1975-1981	Mars Explorer Orbiter

TABLE 1. (Concluded)

Science	Date	Spacecraft
Exobiology:		
Hard UV penetration and scarcity of H_2O offer only discouraging evidence for the prospects of life, yet the results do not totally exclude the possibility.	1969	Mariners VI and VII
Photosynthetic fixation of carbon dioxide. Carbon dioxide released from previously fixed carbon dioxide and from added labeled organic compounds. Clouding of a medium by growing organisms.	1975-1979	Viking
Biological measurements.	1984	Mars Soft-Lander/ Rover

TABLE 2. VENUS PRECURSORY SCIENCE

Science	Date	Spacecraft
Planetary Atmospheres:		
The probable composition is as follows: $CO_2 > 90\%$, $N_2 < 2.5\%$, $O_2 \sim 1\%$, and H_2O from 1 to 8 mg/cm^3. Temperature varies from 760° K at surface to 300° K at 53-km altitude. Pressure varies from 7 500 000 N/m^2 at surface to 73 500 N/m^2 at 53-km altitude. Density varies from 66 kg/cm^3 at surface to 3.5 kg/cm^3 at 40 km. Number density varies from 1×10^{20} cm^{-3} at 37 km to 2×10^{17} at 77 km. The foregoing temperature, pressure, and density values assume a Venus radius of 6053 km.	1962 1967 1967	Mariner II Mariner V Venera IV

TABLE 2. (Continued)

Science	Date	Spacecraft
Planetary Atmospheres: (Cont'd)		
Nature and composition of clouds, composition and structure of atmosphere, and atmospheric circulation.	1973-1983	Venus Explorer Orbiter
Profile and composition measurements in different zones of Venus' atmosphere.	1975	Venus Mariner Flyby/Multiple Probes
Measurement of atmospheric properties during descent.	1983 1986	Venus Mariner Orbiter/Rough Lander
Measure cloud characteristics and atmospheric circulation, temperature-pressure-density profiles to surface.	1980	Venus Mariner Orbiter/Buoyant Station
Planetary Surfaces:		
Microwave temperatures are about 460°K (sunlit side), 480°K (dark side), and 590°K (terminator).	1962	Mariner II
Microwave map of surface.	1978	Venus Mariner Orbiter
Analysis of surface properties and surface mapping by orbiters.	1983-1986	Venus Mariner Orbiter/Rough Lander
Planetary Dynamics and Interiors:		
Mass is 0.81585 times that of earth.	1967	Mariner V

TABLE 2. (Concluded)

Science	Date	Spacecraft
Particles and Fields and Planetary Interactions with the Solar Wind:		
The magnetic dipole moment is roughly a thousand times smaller than that of earth. The solar plasma is deflected by a dense ionosphere. The ionosphere has a sharp upper boundary and is pushed down close to the planet (about 500 km) by the solar plasma.	1962 1967	Mariner II Mariner V
Measure magnetosphere, magnetosheath, and detached "bow shock" wave.	1973-1983	Venus Explorer Orbiter
Exobiology: None		

The Viking spacecraft will test for the presence of life, and if these tests are positive, scientists will attempt to measure and characterize this life. If any indications of life are found, the question of compatibility or possible pathogenesis and back contamination must be resolved.

Therefore, an additional precursory experiment that may be beneficial, and even necessary, to the manned mission is a lander system which contains numerous earth-type life samples, even possibly including human tissue cultures, that could be exposed to the Martian bio-environment and the results monitored. Because of the highly specific nature of pathogens, a positive result may be a necessary but not sufficient guarantee that man (or any earth organisms) will be safe, but at least such an experiment would be a partial answer.

Some biologists believe that it is necessary to firmly establish before a manned mission whether life exists on Mars and if so, whether it is pathogenic to Earth life. If this is to be done, the number and type of unmanned probes needed, e.g., Viking, and Soft Landers with remote-controlled roving vehicles and with soil sample return capability, may be greater than is currently planned.

SECTION III. IN TRANSIT

The scientific experiments deal mainly with the orbital and landed period of the mission; however, the extended time available in the environment of heliocentric space (500 days) will permit the accomplishment of some important measurements and observations.

The Venus swingby will occur during the Earth-to-Mars phase of the mission (Fig. 4). The Venusian science objectives are the subject of Section VI.

During the return trip of the space vehicle from Mars, measurements made will probably be substantially the same as those made while going to Mars. In addition, the crew will be occupied with the examination of Martian samples and the interpretation of data.

A. Planetary Atmospheres

No experiments are planned in this discipline during the in-transit phase of the mission.

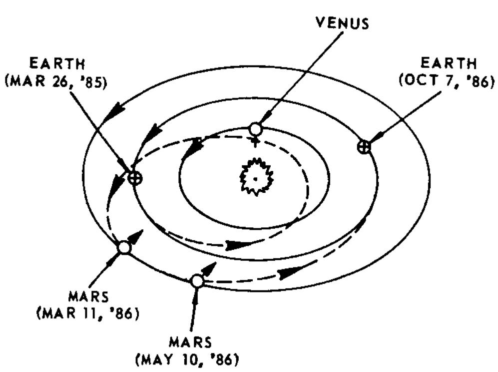

Figure 4. Mission profile with accompanying dates for 1986 opposition-class mission.

B. Planetary Surfaces

1. Introduction. During the transit period the collection of dust particles will be made. The results of analysis of these interplanetary dust particles will be useful in explaining the origin of Mars and other solar system bodies. The carbonaceous content will be of interest to the biologist.

2. Space Dust Collection and Analysis. Although some space dust (micrometeorites) measurements have been made, this experiment permits a complete laboratory analysis

of particles collected during the transfer from Earth to Mars and return. This dust will be analyzed for particle size and count, chemical and mineral composition, electrostatic charge, and age. A comparison of the chemical composition and ages of the collected micrometeorites with those of Martian and lunar dust will provide additional data on the origin and evolution of Mars and the Moon.

The experiment can be done on the Martian inbound and outbound transits by one or two men, who could deploy the collectors in a few hours at the beginning of the trip and retrieve them before reaching the planet. A short training period will be required for deployment and retrieval of the collector and operation of the instrument. A highly skilled chemist, physicist, and microbiologist will be required to analyze the collected particles. Analysis can be accomplished during the flight, or the samples can be returned to earth for analysis. Chemical analysis will be useful in determining the carbonaceous content of the micrometeorites. This will be important in the exobiology area.

C. Planetary Dynamics and Interiors

No experiments directly relating to dynamics and interiors are planned during the in-transit phase.

D. Particles and Fields and Planetary Interactions with the Solar Wind

1. Introduction. During the transit phase of the mission, solar observations including H-alpha emission will be made, not only to provide valuable information on the sun and the interplanetary fields but also as a system to provide solar-flare warnings to the spaceship crew.

2. Solar H-Alpha Monitor. The H-alpha solar emission will be monitored to allow observations of that part of the sun's surface not visible from earth. Regularly timed photographs will be scanned for interesting events, with unwanted data discarded. A solar-flare monitoring system

will alert the crew, enabling them to make rapid observations of the short-lived flares. A 25- to 40-cm telescope will be used for these investigations.

3. Solar Radio and X-Ray Flux Monitor. This experiment is designed to monitor the solar radio flux at 10.7-cm wavelength and in the X-ray region of the spectrum. These measurements will aid in the determination of long-term and slowly varying solar activity, solar flare observation, and sunspot monitoring. They will also aid in the investigation of the interaction of the solar plasma with the Earth and Martian atmospheres. The sun will be tracked, and the 10.7-cm radio signal will be recorded automatically and used as an alert to begin other experiments, especially the H-alpha monitor. The X-ray bursts should correlate with the 10.7-cm radio signals.

4. Observatory. Although an observatory is not in the nature of an experiment per se, the inclusion of a 25- to 40-cm telescope with supporting equipment such as special filters will make possible many interesting observations. The position of several of the solar system bodies may be tracked with exceptional accuracy, especially some of the asteroids. Planets can be observed to determine their albedo in the UV and visible ranges. Other features such as equatorial and polar radii, period of rotation, inclination of the rotational axis, and satellites of the planets may be determined, but in all cases the emphasis should be placed on the investigation of peculiarities and anomalies discovered in predecessor programs such as the Venusian dichotomy anomaly. Opportunities may occur for the observation of stellar occultation by the outer planets, and ephemerides should be developed for these observations. The crew interest should be of such nature that the observatory would be in constant use, both as a recreational item and as a scientific tool.

5. Interplanetary Magnetic Field. This experiment will be conducted throughout the mission and will assist in the determination of the structure of the interplanetary magnetic field, its dynamic nature and turbulence and its effect on charged particles, and the extended structure of planetary magnetospheres. The sources of the field and the interactions with planets and their satellites will be studied. The principal method of measurement will be a helium vapor magnetometer with a triaxial response. Additional measurements of the field should be made by observation of ion clouds produced by the release of solar ionized particles (e.g., barium). The observatory telescope could be equipped for this operation.

E. Exobiology

Determination of the chemical composition, especially the carbonaceous content of extraterrestrial dust, has already been mentioned under the subsection on Planetary Surfaces.

SECTION IV. ORBITAL

Soon after arrival at Mars the MEM will separate from the space vehicle and descend to the surface, leaving in orbit the part designated as the planetary mission module. The true anomaly (position of mission module measured from periapsis), time, and distance from the surface of Mars of the mission module in an elliptical path for one of the orbits being considered are given in Table 3. This orbit has a period of about 14 hours. Figure 5 is an illustration of the orbital path.

TABLE 3. ORBITAL DATA FOR PLANETARY MISSION MODULE

True Anomaly (Deg)	Time from Periapsis (Hr)	Distance from Surface (km)
0	0	500
20	0.0873	600
40	0.1842	925
60	0.3040	1 540
80	0.4710	2 580
90	0.5860	3 340
100	0.7330	4 320
120	1.202	7 230
140	2.148	11 940
160	4.100	18 200
180	7.360	21 790

To optimize the scientific data and mission profile, the orbital science part of the manned Mars mission will consist of two distinct modes: (1) experiments done on the planetary mission module (mode 1) and (2) experiments done on an unmanned spacecraft (mode 2). The unmanned spacecraft mode is needed because of the orbital characteristics required for in-situ atmospheric measurements in the transition zone. This zone, which is located at about 80 to 120 km in the Earth's atmosphere and probably below 100 km in the Martian atmosphere, divides the uniformly chemically mixed region and the diffusely separated region. A 100-km altitude would be unacceptable for periapsis of the planetary mission module because of orbital lifetime, aerodynamic heating, and other engineering considerations. One unmanned spacecraft will be launched from each space vehicle (before MEM descent) and placed into an elliptical orbit around Mars with a periapsis and apoapsis of approximately 100 km and 1000 km, respectively. Each orbiter (perhaps electrically propelled) will have a weight of about 1961 N and require approximately 100 W of power. The first orbiter will be deployed soon after the space vehicle orbit is determined. After several days of experimental investigations and observation of orbital parameters, the scientist will select and optimize the orbital parameters for the second orbiter.

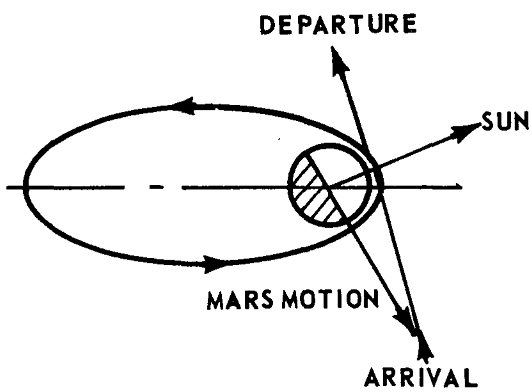

Figure 5. Illustration of orbital path of planetary mission module around Mars.

Although the principal activities on the planetary mission module during the initial orbital phase will be related to preparations for the manned descent, several experiments, in addition to those on the unmanned orbiter, will be accomplished to support the final site selection. Among these will be the topographic and thermal mapping experiments. The scientists will study the most interesting areas determined from precursor data, compare and evaluate the most recent information (in particular noting significant changes from the precursor data), and choose the site with the greatest potential for manned exploration and scientific return.

A very significant experiment to be done from Mars orbit will be the observation of the two Martian moons (Phobos and Deimos). These moons will appear to observers on Mars as smaller objects in the sky than the Earth's moon appears to observers on Earth. Only if the spacecraft approaches within about 1800 km of Phobos (or about 900 km of Deimos) will they appear as large as the earth's moon. However, high-resolution observations can be made with the reflecting telescope if the proper orbit can be achieved. In any case, the observation of the Martian moons by scientists in the planetary mission module will be a major activity.

A. Planetary Atmospheres

1. Introduction. The properties of the Martian upper atmosphere will provide information about the nature of the interaction of the Sun's energy (and variations in energy) with the planet's atmosphere. A measurement of the variability of the upper atmosphere during the mission will add greatly to the library of data being gathered and to a further understanding of the dynamic processes involved. Except for the cloud observation, the atmospheric measurements, together with the experiments concerned with particles and fields, will be most easily accomplished on the unmanned orbiter.

2. Atmospheric Density and Composition. This experiment will measure the atmospheric density and neutral and ionic composition as part of the complete meteorological survey. The Martian exosphere is strongly influenced by the Sun, and both should affect the circulation of the lower atmosphere. Knowledge of the density and compositional variations are necessary for the interpretation of other experiments involving atmospheric temperature, diffusion rates, reaction rates, and phase changes. These measurements will be made continuously by automatic instruments. The features to be measured will be the number density, mass density, density and pressure scale heights, temperature, and particulate density for each constituent in the atmosphere. The minor constituents will be measured to within one part in 10^6. A quadrupole mass spectrometer onboard the unmanned orbiters will be used in this experiment.

3. Atmospheric Temperature. In addition to the temperature derived from the mass spectrometer, a metastable detector probe onboard the unmanned orbiters will be used to determine the velocity distribution of the atmospheric molecules from which the molecular temperature profile

can be derived. A metastable temperature detector is in the laboratory development phase and should be available for this experiment.

4. Cloud Photography. Photographic records of the clouds on Mars will be used to study their shape, motion, altitude, and location, thereby enabling one to understand the general atmospheric circulation patterns and cloud origin. By observing the clouds with filters of various wavelengths and polarization, the shape and motion may be correlated with particulate matter due to phase changes of atmospheric gases or with various terrain features on the Martian surface. This experiment will be done from the orbiting space vehicle and from the surface. From orbit, a surface resolution of about 1 km should be a minimum requirement with continuous automatic operation at fixed-time intervals and provisions for manual operation when required.

B. Planetary Surfaces

1. Introduction. During the orbital phase of the mission, the surface experiments will be done principally by remote sensing. The intent of the investigations will be to enable final decisions as to the landing site.

2. Topographic Mapping. The result of this experiment will be a map of the candidate landing sites that will assist the geologist in his surface traverses and investigations. The features photographed and visually observed (using multispectral television) will be relayed to earth for interpretation and correlation. Reconnaissance of the landing area should be accomplished during the initial orbital phase. Instruments for mapping will consist of a camera, television, and radar.

3. Thermal Determinations. An IR spectrometer and radiometer for thermal mapping will be available to give continuous measurements during the orbit. These measurements will be useful in selecting a landing area possibly having moisture, geothermal activity, and unusually interesting physical properties. Anomalous variations in surface temperatures could indicate the presence of these latter conditions.

4. Observation of the Martian Moons. Observations of the surface features, spin and orbital rates, and inclination of axis of the Martian moons, Phobos and Deimos, can be made while the spaceship is in Martian orbit. The observer can note unusual features, and describe color and light

variations, and obtain photographs of interesting features from various phase angles for further study. The observations can be made onboard the mission module using the 25- to 40-cm reflecting telescope already mentioned.

C. Planetary Dynamics and Interiors

1. Introduction. Orbital experiments to study the gravitational and magnetic fields are recommended. For the gravitational determinations a completely passive experiment is envisioned, using the orbital parameters of the unmanned probes.

2. Gravity Determination. Changes in the orbital parameters of the unmanned orbiters can be used to determine the gravitational fields. The information will be useful in studies related to planet dynamics. Gravity measurements can be used to locate mass anomalies and to estimate the extent of an anomaly. Location of anomalies will aid in determining those sites on which to drill and execute traverses.

3. Magnetic Field Determination. A magnetometer will be used to map the magnetic fields and determine more accurately the location of the magnetic poles and the magnetic field strength. Anomalies, if discovered, could indicate the concentration of magnetic mineralization. Should igneous-bearing magnetic materials occur, one could well have a planetary magnetic history. Indications of subsurface anomalies will allow the geologist to select drilling sites or areas where more extensive study is warranted.

A major part of the magnetic field information may be obtained during the precursor missions. However, additional data will probably be required on any local anomalies discovered to aid in surface investigation. Therefore, further magnetic field measurements should be made. Magnetic effects (if any) of the Martian moons may be observed as the planetary mission module passes near them.

The magnetometer, mentioned earlier for the interplanetary magnetic field measurement, will be used for this experiment.

D. Particles and Fields and Planetary Interactions with the Solar Wind

1. Introduction. An unmanned orbiter (possibly electrically propelled) will be used to provide a platform for a series of experiments to examine the interaction of the planet with the solar wind. The experiments will be concerned with obtaining additional information on phenomena which will have been adequately described from previous investigations in terms of magnitude, spatial, and temporal variations so that equipment limits can be established. However, to provide the necessary interrelationship among the many experimental parameters being obtained, these measurements must be repeated during the mission. Several experiments, such as the H-alpha monitor, will be an integral part of the experimental program throughout the flight and thus will not be duplicated on the unmanned orbiter.

2. Magnetosphere Magnetic Field Measurements. The magnetic field around Mars will be measured to determine the extent of the penetration of the solar wind into the Martian exosphere and the magnetic field strength and direction. Although it is known that Mars has a magnetic dipole moment no larger than 3×10^{-4} that of Earth, the presence of ions in the upper atmosphere does allow an interaction between the solar wind and the planet's ionosphere so that a "bow shock" may be formed which might even lie behind the planet with respect to the flow direction of the solar wind. Even with previous measurements of this feature, a continuous measurement of the magnetic field is required to interrelate the many resulting phenomena with the other observations. A helium vapor magnetometer with triaxial response, similar to the one used for the in-transit measurements of the interplanetary magnetic field, will be used for this measurement.

3. Energetic Charged Particle Flux. The electron and proton energies and fluxes near Mars will be measured to determine the energetic particle environment and its interactions with the Martian exosphere. Whereas previous missions will have made extensive measurements of this nature, new measurements will be required for correlation of any periodic changes with other measurements of the properties of the exosphere and lower atmosphere. The unmanned orbiting spacecraft will include a series of Geiger tube arrays in telescopes of varying shielding and window thicknesses, scintillation crystals, and solid-state detectors to be used for the particular energy range of interest.

4. Topside Ionosonde Electron Density Measurements. This standard radiophysics measurement will be used to investigate the electron density of the ionospheric layers as a function of height above the altitude at which the peak value of electron density occurs. It will be used in conjunction with a surface-based ionosonde discussed later in this report. The pulse of energy in the frequency range of 0.1 to 10 MHz traveling normal to the ionosphere will be reflected back to the orbiting spacecraft, allowing the structure of the ion density about the peak density near periapsis (100 km) to be studied. The orbiter will also provide a longitude and latitude survey of the upper ionosphere at slowly varying local time, giving diurnal and seasonal effects. The instrument will be operated at uniform intervals with almost continuous operation during increased solar activity.

5. In-Situ Electron Density Measurement. The electron density and temperature will be measured in situ by the unmanned orbiter using a Langmuir probe. In addition to being supplemental measurements to the ionosonde measurements, the small-scale structure and irregularities can be observed along with local minima in the electron density which cannot be observed by the radio techniques. The vertical profile and the diurnal variations of the electron temperature will aid in the complete formulation of the ionospheric layers.

E. Exobiology

1. Introduction. Most measurements made while in orbit about Mars that pertain to environmental factors relevant to the biosciences will be returned to Earth for analysis. Microwave and IR measurements of planetary humidity and thermal conditions will be used to locate areas of most probable biological interest.

The metric photography and telescope-aided visual observations will assist in noting seasonal color variations and similar possible indications of life. These instruments will be primarily intended for planetary studies, but peripherally they will aid the biological disciplines.

2. Ultraviolet Reflection Spectroscopy of the Martian Surface. The Martian surface will be observed from the mission module using a narrow

field-of-view UV spectrometer. Special attention will be paid to absorption bands indicative of oxygen, ozone, nitrogen, acetaldehyde, and similar bands of biological interest. Indications of the presence or concentration of these molecules would indicate possible local ecological conditions favorable to life. Special concentration on regions affected by the wave of darkening should prove very interesting.

Once the instrument is set up, tracking and data-recording are automatic. The subspacecraft point is scanned and spectra are produced at a given spatial resolution. A desirable feature would be to have each spectrum automatically identified by time, longitude, and latitude. The mission module computer can process and reduce this data.

3. Infrared Spectroscopy of the Martian Surface. There are numerous absorption bands in the IR spectrum of interest to the exobiologist. The Sinton bands which some scientists have accepted as indicative of C-H bonds have been observed on Mars and, although controversial, should be of great interest from near-Mars orbit. Various other organic bands such as methane and ammonia, as well as water and nitrous compounds, should be observed.

An interferometer spectrometer may be used to automatically scan as the spacecraft orbits, with the ability for detailed scans at higher spatial resolutions should promising areas appear. The instrument results should be linked with the space vehicle computer for time and spatial reference and for inversion of the Fourier spectra. Normal operation will be automatic, and the spectra will be processed and available for display on demand.

SECTION V. SURFACE OPERATIONS

A thorough exploration of Mars requires that man be landed there to perform surface experiments to determine the planet's composition, environment, physical characteristics, and life forms.

Selection of landing sites will be accomplished before Earth departure, using information from earlier missions. Precise locations will undoubtably be verified during final reconnaissance in orbit about Mars. The number of landing sites will depend on the duration of the landing mission. For short stay-time missions, two landing sites (one per spaceship) will probably be the maximum that can be investigated with any thoroughness. One of the sites will be located in the polar region and the other near the equator, preferably near a region which has strong seasonal darkening. Selection of these sites should be determined by the emphasis placed upon each experiment. In addition to the experiments normally done at a site near the equator, a landing site near the polar cap will permit experiments related to the polar cap composition and movement.

Remote scientific stations will be located on the periphery of the exploration area. The location of these stations will be selected for unique surface features and to set up a network of data stations. Instruments at the stations can be operated by scientists there and by remote control from the MEM laboratory or from earth. It is important that these experiments be operative after completion of the mission, sending data back to earth over an extended time period (perhaps a decade). This will permit measurements during seasonal changes, which may be very important.

A systematic plan for conducting the experiments will undoubtedly be established. The following plan is offered as typical: (1) observe and photograph the immediate vicinity, (2) collect samples of soil, rocks, life specimens, air, and liquids; (3) set up a communication network, (4) put into operation the automatic scientific stations which gather atmospheric and geological data, and (5) deploy the remote scientific stations on the periphery of the exploration areas. Investigations requiring considerable time and attention can be done after the base has been established, e.g., atmospheric pressure, active seismic, observation expeditions, drilling operations, and in-situ observations for life. Some laboratory work may be done during periods after sunset and during times of adverse weather conditions.

The usefulness of man in scientific investigations will be demonstrated in the following ways: his judgment in selecting sites for instruments, his ability to place instruments in locations that would be inaccessible to automated devices, and his rapid response to unexpected occurrences of scientific importance will enable measurements of targets of opportunity that would otherwise not be possible. Observations made by man will aid in the reduction and interpretation of data, especially anomalous geological and biological measurements. Finally, his ability to calibrate, adjust, and repair the instruments will be of great value.

Three major tools will be required for detailed exploration: (1) a manned roving vehicle to transport personnel and equipment to remote sites and on traverses (this vehicle is especially needed for extended stay-time missions), (2) a hand-operated drill, similar to that used in the Apollo program to obtain cores and samples from a depth of 3 m (the drilled holes will be receptacles for temperature probes and gas and moisture detectors), and (3) an automatically operated drill with a depth capability of 15 m or more to obtain deep-seated samples for chemical, biological, and structural analysis.

Probably the single most important piece of equipment is a reliable vehicle for transportation. Manned traverse distances will be limited by the amount of time a man can work without excessive fatigue and the duration of his life-support supplies. Therefore, without a mobile vehicle, the exploration will be limited to a few kilometers about the MEM and the transportation of equipment to that which can be carried by a man. A rover will permit traverses of approximately 30 km to obtain data from remote sites and investigation of outstanding geological and biological features. The vehicle can also serve as a truck to transport samples back to the MEM laboratory, move heavy experimental equipment, and collect data along the traverse. Weight of the rover would be approximately 13 827 N. It would carry two persons (approximately 3579 N) and 2206 N of experimental equipment. Design of the rover would use the experience gained from the Lunar Roving Vehicle.

Laboratories with equipment for experiments, preparation of samples for return to earth, and sample storage will be required, especially in the geological and exobiology areas where specimens must be stored in a simulated planetary environment. It is anticipated that a MEM of greater size and payload capacity than those currently planned will be required at each landing site.

A. Planetary Atmosphere

1. Introduction. Atmospheric experiments will be used to measure thermodynamic properties, motion, and changes in composition. They will also serve as parallel information sources needed to confirm the normal operation of most experimental and engineering equipment. Although much knowledge of the Martian atmosphere will exist because of data obtained before man's arrival, probably the most important and still not fully understood feature, in terms of transporting particulate matter and life forms, will be the atmospheric circulation patterns. In this area the challenge to the metorologist will be to formulate the optimum experiment

with his limited resources. By launching about one-fourth of the available constant-density weather balloons, which will be tracked and interrogated by a high bit-rate orbiter, data will be obtained with which to develop an elementary circulation pattern model (or the data, by comparison with model results, can be used to determine the most accurate of several proposed models stored in the data center information files). From the model the meteorologist will then determine the optimum experimental procedure for releasing subsequent balloon stations.

2. Atmospheric Pressure. This experiment will map the pressure and its variations on the Martian surface as a function of location and time. Data will be used to further determine the physics of the atmosphere, including diffusion rates, reaction rates, phase changes, and pressure gradients. Measurements will be required at many locations, using automatic stations with vertical probes and balloons. Sampling will be continuous but will be recorded only at fixed intervals or on demand from experiments requiring pressure information. The principal experimental method for vertical soundings of the pressure will be with numerous (approximately two per day for 20 days) constant-density balloon flights which will carry pressure and temperature gages. The balloons will be designed to operate at altitudes of 10 km (pressure about 2.4×10^2 N/m^2) and 20 km (pressure about 1×10^2 N/m^2). The balloon-borne sensors will be linked to a high bit-rate orbiter (discussed in the Instrumentation Section of this report under Communication, p. 43), where the tracking and recording will be done. A meteorologist will be required about one-half time to monitor the automatic stations, launch the balloons, and repair the equipment.

3. Atmospheric Temperature. In conjunction with the atmospheric pressure measurement, the temperature of the Martian atmosphere will be mapped in much more detail as a function of location and time. The temperature will be monitored by automatic instruments which, along with atmospheric pressure devices, will make up the weather stations. The vertical variations in temperature will be measured at the same time by balloon flights. The meteorologist can supplement these measurements with simultaneous pressure measurements.

4. Wind Velocity. The local motion of the atmosphere will be measured (average speed and direction of the wind) by several methods. Cloud photography will allow estimates of the motion. Wind velocities at the landing sites will be measured using aeronomic instruments such as moving wind vanes. The satellite-balloon meteorological network will be

the principal means to deduce the wind speeds and direction. Automatic tracking and ranging of each balloon will be accomplished by the orbiting mission module and by the MEM, with the onboard computer continuously updating the data as new balloons are launched.

5. Cloud Photography. Cloud photography from the landing sites will not only be used to determine the structure, patterns, altitude, and composition at particular locations but also to correlate with the photography from the orbiting mission module. The resolution of the surface instrument should be about the same resolution as the human eye. Images will be made automatically at predetermined intervals and upon demand. A wide-angle TV with several color filters and with about 1 minute of arc resolution will be used.

6. Atmospheric Transmission Properties. This experiment will measure the optical properties of the atmosphere as a function of time and path length. Several spectrometer subsystems will obtain the solar spectra, scattered spectra, and nocturnal luminescence spectra. These results will be highly dependent on the composition of the atmosphere. The systems will be programmed to make measurements at selected times in the 0.1- to 15-μm spectral range with moderate resolution.

7. Atmospheric Electricity. The wind, cloud, and duststorm conditions may result in the generation of static electricity. The electric field of the planet will be measured using an instrument deployed by an astronaut in an uncluttered area of about 3 m on a side. Little astronaut time is needed after deployment except for occasional monitoring of its operation.

8. Atmospheric Particles. The particles filtered for physical and chemical analysis will yield information on the erosion of the surface and the particulate effects on exposed equipment. This experiment will collect and characterize the particles present in the Martian atmosphere. The type of particles may correlate directly with the cloud phenomena on Mars. Although the equipment would operate automatically, a meteorologist should monitor the experiment and inspect the equipment one hour per day. Filtrate from air samples will be used for biological experiments.

9. Atmospheric Composition. This experiment will be used as a general survey of the atmospheric composition and its variations to confirm previous measurements and provide information on the bulk constituents of the atmosphere for the other experiments. An automatically operated mass

spectrometer will scan the range of 1 to 250 amu, providing information at uniform time intervals and on demand.

B. Planetary Surfaces

1. Introduction. The experiments and observations made on the planet's surface should not be too different from those performed in remote areas on earth or on the moon. Of interest are the density, texture, composition, and surface features. Many of these measurements and determinations can be made through the use of automated instruments; however, for thorough investigations of detailed rock structure, geophysical data, mineral and chemical composition, and engineering properties, an experienced geologist is required. Some important samples may be located in places inaccessible to automated devices.

Landing site selection will be strongly influenced by data obtained from earlier missions and the emphasis placed on the different experiments. Also affecting the site selection will be unique surface and subsurface features such as mountain ranges, outcrops, volcanoes, glaciers, moisture, craters, seasonal darkening, and subsurface anomalies. The selection of local regions for sample retrieval and core drilling will depend on the judgment of an experienced field geologist.

As previously mentioned and repeated here for emphasis, three major tools will be required for detailed exploration: (1) a manned roving vehicle to transport the scientists and equipment, (2) a hand-operated drill, similar to that used in the Apollo program to obtain cores and samples from a depth of 3 m, and (3) an automatically operated drill with a depth capability of 15 m or more to obtain deep-seated samples for chemical, biological, and structural analysis. The drilled holes will be used for experiments and for seismic charges.

A small laboratory equipped with standard chemical and geological equipment will be required.

2. Surface Physical Properties. Field experiments will be conducted to extend knowledge previously obtained in determining the physical, chemical, and mineral properties of the rocks, soils, and liquids. Samples will be obtained from the soil, rock outcrops, and drilled cores (preferably oriented), especially where differentiation is observed. Properties such as hardness, color, texture, weathering, grain size,

compactness, moisture content, gas content, mineral composition, and density will be determined on selected samples. A geologist will be required to select the samples and to note the in-situ condition of the specimen. Other properties of the samples, such as chemical composition and radioactivity, will be determined. Samples will be collected during the entire time on the surface. Preliminary analysis may prompt a return to the site for further observation. The tools required are a hammer, labeling material, sample bags, photographic equipment, magnifying glass, and laboratory equipment for chemical analyses.

3. Elemental and Mineral Analysis. This experiment will determine the elements in the samples collected and the minerals they form. Samples representative of the surface and of various strata reached by the core drill (this activity can be combined with field exploration) should be obtained. A large amount of samples can be returned to earth for analysis; however, preliminary analysis on the planet will aid in the search for specific and unique samples. The examination of the samples on Mars will improve reliability should there be any changes in the samples during the return and will insure against a complete loss of information should the samples be lost on the return trip. Samples taken but not selected for return to earth should nevertheless be precisely catalogued, along with all analytical results, for future use in the event they assume unexpected importance.

Experiments to be done are microscopic examination, X-ray diffraction, IR spectrophotometry, and mass spectrometry. Microscopic examinations include petrographic examination and refractive indices determination. Identification of the crystal systems of grains to discover pleochroism and elongations will be made. The measurement of refractive indices of crushed specimens will determine the isotropic, uniaxial, or biaxial characteristics of the specimens.

X-ray diffraction patterns may provide "fingerprints" of pure crystalline materials, which on comparison with fingerprints of known minerals, will allow identification which can be done automatically by the data processing computer. The automatic X-ray diffractometer can be used for samples not having significant patterns when examined by the microscope and infrared spectrophotometry.

Infrared spectrophotometry will provide data for the classification of noncrystalline inorganic samples which do not have informative X-ray diffraction patterns. The instrument can also provide information on the types of anions and other covalently bonded substructures and determine the presence of organic compounds.

A mass spectrometer can be used to identify elements. Other techniques, such as emission spectroscopy, X-ray fluorescence, neutron activation and wet chemical analysis, can also be used as complementary mineral analysis experiments.

4. Polar Cap and Permafrost Characteristics. The selection of a landing site in the polar region will provide an opportunity to examine the polar cap for chemical composition, temperature, melting and/or sublimation rate, thickness, and peripheral processes. Permafrost depth and composition may also be investigated in the polar cap.

Movement of the polar cap and thermal cycling of the soil and rocks may be the predominant mode of erosion. A study of these activities will give some clues as to the extent of surface modifications near the cap as compared with the more temperate regions.

Many of the instruments can be set up for remote operations and operated after completion of the mission. Data taken over a long period of time will allow investigation of the movement, melting, and buildup of the polar cap during the seasonal cycles.

A mass spectrometer will be used to determine the chemical composition. Some instruments used will be very similar to those employed in the earth's polar regions. These studies will be greatly enhanced by using a drill with coring capability.

5. Temperature Determination. Temperature measurements at the surface and subsurface will greatly aid the study of the planet's environment and heat budget. The thermal conduction and radiation from the surface may be an important energy source to the Martian atmosphere. These data will aid in the interpretation of atmospheric thermodynamic and circulational phenomena. Diurnal temperature variations could be a factor in surface erosion.

6. Gas Determination. Gas trapped in the rocks and subsurface can be analyzed with a gas chromatograph. The selected samples are placed in a pyrolizing oven that drives out the volatile components. This operation will take several hours; therefore, samples must be selected with utmost care. Samples can be returned to Earth for analysis; however, analysis at

Mars will guide follow-on surface examinations. It will probably be desirable to analyze the cores upon removal from the hole since any entrapped gases may escape or, if this is not practical, to place the samples in a sealed container for later laboratory analysis.

7. Erosion Processes. The surface of Mars has been exposed to erosion processes which tend to eradicate surface features. Field observations can identify these processes. If, as some investigators report, the Martian surface is subject to extensive duststorms, these would be a severe erosion agent. Freezing and thawing and advance and retreat of glaciers (polar caps) are other erosive agencies which also contribute to the modification of the surface.

The extent of meteoroid impact and the condition of the craters will be observed and photographs made for comparison with the craters on the moon.

These observations will be relayed back to earth. Determination of the weathering (e.g., wind patterns and dust transport phenomena) and erosion processes will permit a better understanding of the surface features and perhaps those on earth and the moon as well. Photographs will be used to record these features.

8. Geological Observations. The observations and records made of the outstanding surface features by an experienced geologist will be important. Probably one-third or more of his time will be spent exploring and photographing the surface and selecting sites for sample retrieval, detailed measurements, and investigation. His instruments will be a hammer, magnifying lens, notebook, pencil, sample bags, charts and maps, and camera.

A roving vehicle, which is considered mandatory, will enable the geologist to traverse much more territory and to reach the more distant features of interest.

C. Planetary Dynamics and Interiors

1. Introduction. Further measurements of gravity, magnetic, and seismic effects beyond those made on the precursor missions will be beneficial to persons investigating the Martian core, crust, seismic events, and tidal forces. Results of the experiments will be correlated with surface

observations and measurements to identify and locate deep interior activity, discontinuities, and stratigraphy.

2. Gravity Determination. Gravity measurements will aid in understanding the forces on the atmosphere, the crust, and the interior. Measurements of variations in the magnitude of the planet's gravity as a function of time at fixed locations will determine the magnitude of tides and seismic events. Measurements taken during traverses will be assigned values relative to gravity measurements at a central station leading to the location of subsurface masses of abnormal density. Gravity forces exerted by other celestial bodies may be determined.

Gravimetric measurements will be taken continuously along the traverses, and the results are expected to outline the larger geological features. Location of these features will assist in the selection of sites for drilling and sample collecting.

Gravitational measurements taken with a gravimeter will not require excessive amounts of power, weight, or time. Data may be relayed to earth for interpretation.

3. Magnetic Measurements. A magnetometer will be used to measure the magnetic field. The instrument should be capable of readout on command signal from the MEM and from earth.

The magnetic field may provide data about the composition and internal structure of Mars. The absolute magnitude of the field will not be as important as the variations and the correlation with other measurements, such as gravity, seismic, and temperature.

The magnetic field strength is affected by subsurface magnetic materials; hence, subsurface magnetic deposits can be located. For this reason the experiment is a valuable geological tool in helping to select areas for examination and adding to information obtained from outcrops and drill cores.

A central location must be established on the surface so that data obtained from other locations can be normalized with respect to the field strength at the central location.

4. Passive Seismic Measurements. Seismometry is an effective means of probing the interior of the planet and will aid in determining whether

the absence of an appreciable magnetic dipole moment implies the absence of a liquid core. Information about deep subsurface structures and the possible source of shock waves may be obtained. Passive seismometers will be located at the landing site and at automatic stations along the traverses. To obtain a geometric distribution of the elastic properties of the rock structure, several measurements of the same wave-packet must be made. This can be accomplished by correlating the readings from stations uniformly spaced on a circle of approximately 10-km radius centered at the landing site. The output from the stations will be transmitted to earth for interpretation. Once the instruments are emplaced they need not be attended.

5. Active Seismic Measurements. Active seismic surveying in conjunction with surface maps and core drilling will form the basis for geological mapping of the subsurface. It may be used to check anomalies and discontinuities indicated by the gravimeter and magnetometer results and to determine the thickness of the surface layers. This experiment will also give the acoustic velocity of the material.

Initial testing will determine acoustic velocities in the surface layer and the best arrangement for the geophones and shotpoints. The holes drilled to obtain core samples can be used for the shotpoints, or new holes can be drilled at precise locations. The seismic shock is produced by a subsurface explosion which is more effective than a surface explosion. The rebounding shock waves, reflected from subsurface discontinuities and objects, will give a map of the subsurface structure. Considerable time will be required to locate the sites, drill and charge the hole, layout the geophones and "blow the hole." The data can be transmitted to earth for interpretation.

D. Particles and Fields and Planetary Interactions with the Solar Wind

1. Introduction. Surface operations dealing principally with the particles and fields of the atmosphere will basically consist of electromagnetic probing of the ionosphere. Because of the excessive power requirements of the lander ionosonde, operating time of this experiment may be limited, making the need for selective observations by a specialist more important than usual.

2. Ionosonde. This experiment will measure the electron density as a function of height below the altitude at which the peak value of electron density occurs in the upper atmosphere of Mars. It will yield information on the electron density and its height, latitude, longitude, and seasonal variations. These data are generally required for communications and other radio-frequency problems. Only one station will be used because of the large power requirements. Frequencies between 0.1 and 10 MHz will be swept, but the meteorologist may select discrete frequencies for the more interesting features. Initially, several hours per day will be devoted to this experiment by the meteorologist, but later more automatic operations can be programmed.

E. Exobiology

1. Introduction. The search for and study of extraterrestrial life will be one of the most important and interesting experiments on the surface of Mars. Three outstanding areas of interest for exobiology experiments have been proposed in a study prepared by the National Academy of Sciences [1]. These areas are (1) detection of life and its characterization, (2) characterization of any existing organic matter detected, with particular reference to terrestrial biology, and (3) characterization of the organic and physical environment.

The most valuable instrument in the search for life will be the biologist, who can make observations of the environment and search for evidence of life. The successful collection of specimens of biological interest will depend upon his training and intuition. Experiments will consist of four primary phases: (1) observation, (2) collection, (3) separation and preparation, and (4) test and analysis. A laboratory will be required for some of the experiments and for storage facilities.

Samples for investigation in the laboratory could include atmospheric gas, atmospheric particles, soil and rocks (surface and subsurface), solid and liquid condensates, and life forms. The most exciting occurrence would be to find distinct and identifiable living organisms. It is possible that life forms exist which would not be immediately obvious as such, except to an experienced field biologist. Earth-like organisms such as coral and lichens are some of the life forms that are not readily recognized except by a specialist.

2. <u>Life Detection and Characterization Experiments.</u> The following types of experiments will be accomplished in this area.

a. Detection Experiments. By direct observation the biologist and/or ecologist will examine the surface during periods of outside activity. Emphasis will be placed upon areas which, in his opinion, provide local environs or microecologies favorable to life such as fissures, caves, under stones, and in protected areas in general. If life or evidence of life is detected, it will be documented by photography and the specimens collected, if possible. Remote collecting may be required to prevent contamination by organisms leaking from the suit. It may be sufficient to approach from down wind and employ a long-handled collection scoop with a hermetically sealed sample container.

Samples taken in various locations will be examined by the following techniques for evidence of biological activity:

(1) Metabolic activity monitored by isotope tracers such as ^{14}C, ^{18}O, and ^{15}N.

(2) Microscopic examination for actual cell structure, non-Brownian movement, or even microfossils.

(3) Calorimetric measurements will provide information on the metabolic energy cycle and rate of reproduction. The basic difficulty in this type of approach is finding a nutrient medium which supports Martian life.

(4) Changes in the physical and chemical characteristics of a nutrient medium. Basic measurement parameters include, but are not limited to, fluorimetry, turbidimetry, nephylometry, pH, and Eh, or changes in redox potential. Again, a very likely nutrient solution based upon Earth experience might be highly toxic to Martian life forms, so development of media might have to be done on the Martian surface.

(5) Response to stimuli (irritability) movement or chemical responses to external stimuli may be strongly suggestive of biological activity. Incubators and environmental simulation chambers will be used to evaluate possible biont reaction to heat, cold, moisture, light, and other external stimuli.

(6) Various chemical tests will be used as indicative of possible life sources. These will be partially covered in the next general area.

b. Characterization of Martian Life Forms. If life forms are detected and specimens are returned to the MEM laboratory for study, the biologist will address himself to specific questions of characterization and classification. Some of these questions may be answered in the field. Smaller specimens and samples from larger forms will be dissected and studied under microscopes. An environmental box with manipulators or gloves allowing handling of samples under simulated surface conditions will be a necessity. Samples might be toxic to the crew, and the pressure, humidity, and temperature in the laboratory might be disastrous to the sample. Generally the following areas will be observed:

(1) Characteristics of observed life forms.

(2) Identification of the ecological system and the relationship of the biont with respect to the Martian environment and other life forms. It may be that the harsher environment has promoted complex symbiotic relationships which would be very difficult to understand based on earth biology. Extended field observations, coupled with samples and their laboratory analysis, will also be necessary. A remote TV camera with a self-contained power source and transmitter would be very helpful in monitoring biological activity beyond the endurance of an extra-vehicular activity (or the mission).

(3) Compatibility of Martian life forms with Earth life chemistry. The derivation of suitable culture media and nutrients will require assumptions followed by much trial and error. Basic chemical stores will include various sugars, amino acids, and proteins. During the short stay it is doubtful that a really compatible cultivation medium can be found, but if a partially successful one is derived, organisms may be transported much more efficiently than if large quantities of natural soil had to be transported.

(4) Pathogenic effects of Martian organisms upon Earth life. Some earthly organisms in the form of tissue, eggs, and seeds can be carried and exposed to Martian life and materials. Nonreaction will be no guarantee that man is safe since most pathogens are highly specific, but at least more potentially dangerous forms could be identified.

3. Detection, Analysis, and Classification of Any Existing Organic Matter. Samples will be subjected to laboratory tests intended to detect and characterize organic constituents.

a. Detection of Organic Compounds. A simple experiment utilizing pyrolysis of a sample and detection of carbon ions will be an excellent screening test to determine the suitability for further testing. A portable version of this device can be used on extra-vehicular activity to measure the amount of organic material in samples before collecting. In the laboratory a mass spectrometer may be used to indicate to what extent macromolecules are present and their relative abundance.

b. Classification of Organic Matter. If organic material is found to be present, the complex problem of classifying it will exist. Many earth-based organic molecules are still little understood. Specific questions may be answered even with minimal laboratory facilities and limited time:

(1) Determine if it is prebiotic in nature or is part of a life cycle. This may be very difficult because no real knowledge of prebiotic evolution on earth is available. All earth experience with organic matter indicates that asymmetric optical rotation is a function of life. No presumptive test will resolve this unequivocally, but by performing many tests and cross-correlating the results, informative estimates may be made.

(2) Classification of organic materials into groups analogous to earth-based biochemistry. Tests for molecules essential to earth life should be made. The discovery of DNA, RNA, ATP, or proteins similar to ones known on earth would have tremendously exciting implications. Even if the chemistry of Martian life is completely different from the terrestrial forms, it would still be worthwhile to have reagents and specific catalysts such as phosphatase, luciferin, and luciferase included in the laboratory.

Many organic compounds are difficult to identify, and yields of reactions are small; therefore, it is desirable to investigate the biochemistry of Martian life in as much detail as possible while on the surface. An electron microscope will allow the examination of macromolecules and identification of reaction mechanisms. If a cellular structure similar to known life is found, the electron microscope will allow examination of cell mechanics such as cell membranes, mitochondria, and similar structures. The exact sequencing of experiments and priority will be determined by availability of specimens and preliminary indications of initial experiments. Bringing to earth living organisms would be of inestimable scientific value, but should this prove impossible, emphasis would be placed upon gaining as much knowledge as possible of Martian life processes in-situ.

c. Evaluation of Toxicity of Martian Organic Matter with Respect to Earth Life. This will necessitate inclusion of some samples of earth life and cultivation chambers. The crew may be used in carefully programmed experiments with blood samples and even exposure to minute samples by skin patches or similar techniques.

4. Evaluation of Martian Environment with Respect to Bioactivities. The measurements of planetary surface parameters will be of great interest to the exobiologists. Subjects of concern will be:

a. Existence of life and how it has affected the surface of Mars. An ecologist will be able to identify, primarily by field observations, dynamic processes that contribute to erosion, dust deposition, and concentration and conservation of gases and moisture.

b. If life does not exist, why not? Evaluation of data from the other disciplines will help answer this question.

c. What orders of organic evolution exist upon a lifeless planet? Life is such a highly competitive process that all traces of protobiological activity have been obliterated upon earth.

d. What were the conditions when and if life originated on Mars? If life originated but lost its foothold and died out, or if it has never proliferated to the extent it has upon earth, the earlier phases of evolution may be much more readily available for study in the fossil and minerological records of Mars' past.

e. If life existed in the past can we deduce how it ended and is earth destined for the same fate?

SECTION VI. VENUSIAN SCIENCE

A. Introduction

The manned Mars mission, in utilizing a Venus flyby, will present a unique opportunity to exploit the capabilities of man to observe another planet in our solar system. On this outbound part of the mission, man will for the first time be near a celestial body other than the earth or the moon. For a period of about 24 hours, the space vehicle will be closer to Venus than the Moon is to the Earth. At closest approach the space vehicle will pass within 4550 km of the surface of Venus. Table 4 gives trajectory data for the space vehicle during the Venusian encounter. Figure 6 illustrates the spaceship flyby of Venus.

TABLE 4. TRAJECTORY DATA FOR SPACE VEHICLE AT VENUS ENCOUNTER

True Anomaly (Deg)	Time from Periapsis (Hr)	Distance from Surface (km)	Velocity Relative to Venus (km/sec)
0	0	4 550	11.92
20	0.089	5 080	11.80
40	0.199	6 950	11.43
60	0.372	11 420	10.89
80	0.773	24 200	10.10
90	1.35	43 500	9.7
95	2.04	66 600	9.48
100	3.92	129 600	9.25
104	12.83	421 500	9.06
105	27.85	911 000	9.05

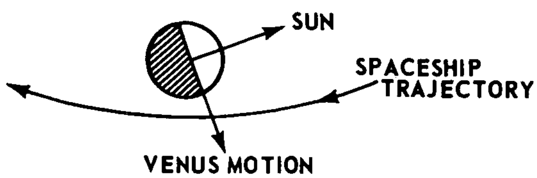

Figure 6. Illustration of Venus encounter during 1986 outbound Venus swingby Mars mission.

The scientific program to be accomplished during flyby will consist of three major elements. The first will be concerned with remote observations made from the space vehicle; the second, with experiments on unmanned orbiters, and the third, with measurements on an unmanned entry-probe system. Although the experiments of these elements are interrelated, for convenience they will be discussed with the element in which they are principally involved.

B. Remote Observations

During the Venusian flyby, extensive observations of the planet's features will be made from the manned space vehicle. The experiments will be identical to those in Martian orbit except that the intent of the information will not be partly for landing site optimization. A discussion of the experiment techniques to be used for this activity would be a repetition of remarks already made about Mars and therefore will not be repeated; however, pertinent comments as to the unique aspects will be noted.

Certainly one of the most useful experiments will be observations of the cloud formations on Venus by a skillful meteorologist. Any unusual and puzzling features discovered by the precursor programs can be examined in detail during the flyby. Topographic mapping and thermal scans of selected surface areas will be accomplished; however, the wavelength in which the observations are made will have to be carefully selected to penetrate the cloud layer. Similarly, the UV and IR spectroscopic observations of Venus will be concentrated on those regions in the Venusian atmosphere where previous measurements have shown the need for more intense inspection.

C. Unmanned Orbiter

Each of the manned space vehicles will deploy, as in the case of the Martian portion of the mission, an unmanned orbiter to study the upper atmosphere and the interaction with the solar wind. The unmanned orbiters will have highly elliptical orbits (periapsis $\approx$ 150 km; apoapsis $\approx$ 5000 km) with inclinations differing by about 90 deg, i.e., 0 deg, and 90 deg. Accurate orbit determination will be made using the tracking equipment aboard the manned space vehicle. Each orbiter will have the following experiments:

1. Atmospheric density and composition measurements.
2. Atmospheric temperature measurements.
3. Magnetic field measurements.
4. Energetic charged particle flux measurements.
5. Topside ionosonde electron density measurements.

6. In-situ electron density measurements.

The descriptions for these experiments were given in Section IV.

D. Entry-Probes

Perhaps the most productive aspect of the Venusian flyby will be the use of entry-probes to enter the Venusian atmosphere and to make vertical soundings of its physical properties. Each space vehicle will launch and track an entry-probe; one will enter the sunlit side of the planet and the other, the dark side. Each probe will have identical instruments except for possible differences in sensitivities for those measurements using available light levels. After entry into the atmosphere each probe will divide into two elements. One, an atmospheric drifter, will descend from 150 km to the surface in 20 to 40 days measuring temperature, pressure, and composition; the other, a soft-lander, will not only make the measurements just mentioned but will also carry a TV camera using selected filters to make a vertical survey of the clouds as well as a scan of the surface. It has been predicted that conditions in the Venusian atmosphere at about 25 km altitude are favorable to life. Certain biological experiments may be included on the drifters to investigate this possibility.

SECTION VII. INSTRUMENTATION

A. Instrumentation System Summary

The early missions will probably provide only a "maybe" to the questions of life on Mars. Whatever the findings, the purpose of the manned mission should be to search for evidence to answer, in a statistical manner, the questions about the origin of life and the origin of our solar system. To do this, extensive measurements over a large surface area and for a long time must be made.

The primary communication system will be on the mission module and will use a laser system for high-bit rate transmission (10^7 bits/sec) of data to earth ($\sim 10^4$ bits/sec on Mariners VI and VII). The mission module could be designed so that the part containing the laser communication system will separate and remain in orbit at Mars to continue the high bit-rate transmission of data to Earth after completion of the mission. A conventional data link will be used between the spaceship and earth during the return flight.

Secondary communication systems will consist of orbiting relay satellites to establish data links between the MEM, mission module and unmanned orbiters, a direct low bit-rate Mars-to-Earth link, and an HF system for Mars surface-to-surface transmission.

The manned space vehicle will contain an advanced computer center involving a number of computers to automate as many of the repetitive station-keeping tasks as possible. A library of programs will be provided for a variety of functions including navigation, data management, communications, power regulation, and environmental control. Computing facilities will permit the manipulation and processing of data such as the conversion of an interferometer spectrometer's output, which is a Fourier transform, to the desired intensity as a function of frequency. Study of the experiment results can then be done by onboard scientists. Availability of a computing facility and use of similar indirect techniques can provide a considerable increase in the quality of the data.

B. System Detail Description

1. Introduction. Advancements in many technological areas will increase our ability to obtain scientific data through experiments. Some of the technologies, with the effect of the experimental results, are discussed in the following pages. These areas are also those where development funds should be directed.

2. Imaging Systems. The successful development of direct visual-to-electronic storage systems such as dielectric tape recordings or perhaps holography (which would also allow three-dimensional viewing) is the key to electro-optical sensors becoming a chief data-gathering device. The devices will be the following types:

a. TV cameras used with telescopes and microscopes.

b. Scanning IR radiometers.

c. Multiwavelength point scanners (UV-IR imagers).

d. Scanning spectrometers (polychromatic spectrograms).

e. Microwave radiometers.

f. Radar imagers.

These facsimile-producing systems will make possible multi-wavelength (from radio to extreme UV and perhaps X-ray) mapping and photogrammetry for any desired science objectives, such as earth resources, planetary investigations, solar studies, or stellar astronomy. Collected data can be stored, reviewed, edited, processed (enhancement, compression, repacking), and then transmitted to the principal investigators.

Development of multiple detector arrays will allow the simultaneous acquisition of facsimiles or pictures in many wavelengths. This will provide rapid time response and accurate registration from one wavelength picture to the next.

Means for cooling detectors to the necessary temperature for optimum sensitivity and development of better detectors will allow the use of narrow entrance slits, hence providing increased resolution.

3. Electronics. Advances in Large Scale Integration (LSI), Micro-Integrated Circuitry (IC's) and hybrid packaging, together with the continuing arrival of new devices, will provide a technological foundation for constructing the experiment hardware that the other areas discussed here will be hard-pressed to match. Reliability requirements can be met for planetary flyby missions of up to 12 years and for exposure on planetary surfaces up to 5 years.

Combining electronics with optical and mechanical components to provide active electro-optical-mechanical systems will permit an order of magnitude improvement over the passive systems in stability, resolution, and sensitivity. The figure for large optical surfaces may be met with electro-optical systems as an example.

4. Mechanical. The availability of exotic materials such as Ultra Low Expansion (ULE) glass, high-temperature plastics, and lightweight alloys will allow the mechanical design to maintain pace with the other disciplines. Perhaps optical benches and telescopes will be made from ULE materials. Plastics that can withstand temperatures as high as 645°K and maintain structural integrity are becoming available. Larger radiation-collecting surfaces and larger focal-length components will increase the volume required, but perhaps the weight of the instruments can be reduced with the use of these materials.

5. Power. Packages will be available to provide long-term power in almost any quantity desired up to a few hundred watts. Maximum utilization of this development will be needed to operate the remote instrumentation stations. The lifetime of these stations will be about 5 years (with 10 years desired).

6. Data Acquisition and Management. It is planned that real-time communication will be maintained between the mission module, MEM, rovers, and the earth principally for monitoring the crew's physiological and psychological status and also for the life-support and system-critical engineering parameters.

Selected data will be "real-time" transmitted to earth; however, the bulk of the data will first be collected and manipulated by a data-management center in the orbiting mission module.

Bulk facsimile data obtained from the electro-optical sensors will be collected, catalogued, and stored by the computer-controlled Data Acquisition System (DAS). These data, along with all other raw data collected in the vicinity of Mars, could be stored by using electron optical demagnification with ratios of demagnification of 1:1000 or 1:50 000. It has been estimated that a 1-million-volume library (500 pages per volume) could be sorted on a tape reel which contains an area the size of this page [2].

Callup of these data could be done by the station data operator or remotely by earth investigators on a noninterference basis for transmission to earth. The data processing would allow the selection of portions of a full frame for electrical expansions and transmissions. The data processing will be able to do optical spatial frequency filtering and image restoration and enhancement, i.e., smoothing or sharpening of the picture. The multispectral data will be processed for pattern recognition and signature detections.

The data operator will be able to call up data in a variety of ways — by measurement number, time of measurement, place of measurement, summary, limits, or variations.

As part of the data center, computing facilities will be provided for doing on-the-job calculations.

7. Communication. The primary data link for the communication requirements at Venus and at Mars will be a laser system providing a high

bit-rate capability of 10^7 bits/sec. This system, initially part of the mission module, will be designed as a module able to separate and become an unmanned orbiter remaining at Mars and continuing to transmit data to Earth after the space vehicle leaves Mars for return to Earth.

Three secondary communication links are required for mission operations at Mars. By placing relay satellites in orbit at Mars and using standard telemetry techniques, noninterrupted, real-time communication can be maintained between the mission module, MEM, rover, remote stations, and unmanned orbiters. A direct, low-bit-rate, Mars-surface-to-Earth link will be provided, and an HF propagation surface-to-surface link will be used for ranges up to several hundred kilometers to avoid congestion of the primary surface-to-orbiter data link.

8. Summary of Instrumentation. A detailed account of the instrumentation weight, volume, and power requirements is given in Tables 5 through 11. Several reports have been used in compiling this information, most notably Reference 3. The weight values are with respect to earth gravity. Table 5 shows the instrumentation requirements for the planetary mission module.

Table 6 shows the instrumentation requirements for the orbiter and entry-probes at Venus and for the unmanned orbiters at Mars. Tables 7 and 8 show the MEM instrumentation used outside and inside, respectively, during the surface operation. Table 9 is an instrument list for the remote stations placed on the surface.

Table 10 gives the instruments proposed for the bioscience and geoscience laboratories. The instrument list in the bioscience area may seem overly ambitious, but one must keep in mind the possible developments in this important area and the present uncertainties of the precursor findings. Table 11 is a summary of the information in the foregoing tables.

Figures 7a and 7b illustrate a typical panel layout for use of the instruments listed in Tables 8 and 10. The layout in Figure 7a is primarily for instruments in Table 8 and the layout in Figure 7b, for instruments in Table 10. The instruments are suitable for use in the bioscience airlock of the planetary mission module.

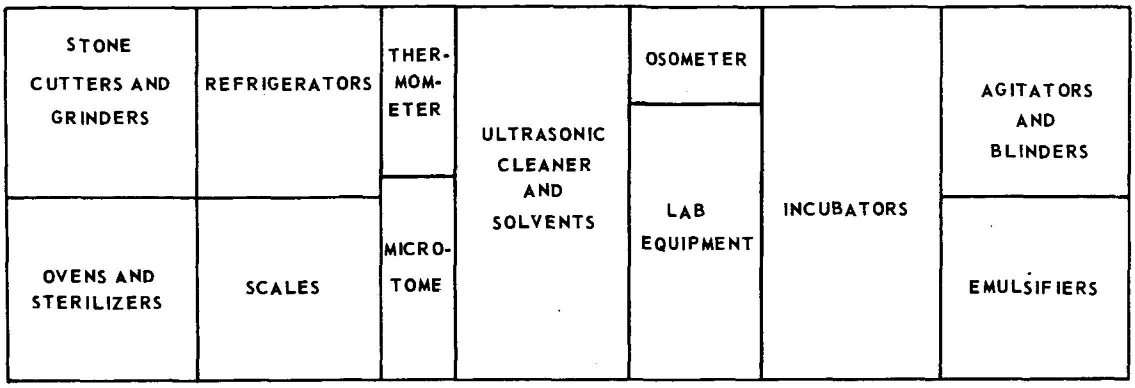

Figure 7a. Typical panel layout for bioscience and geoscience laboratories in MEM: sample preparation and wet chemistry area.

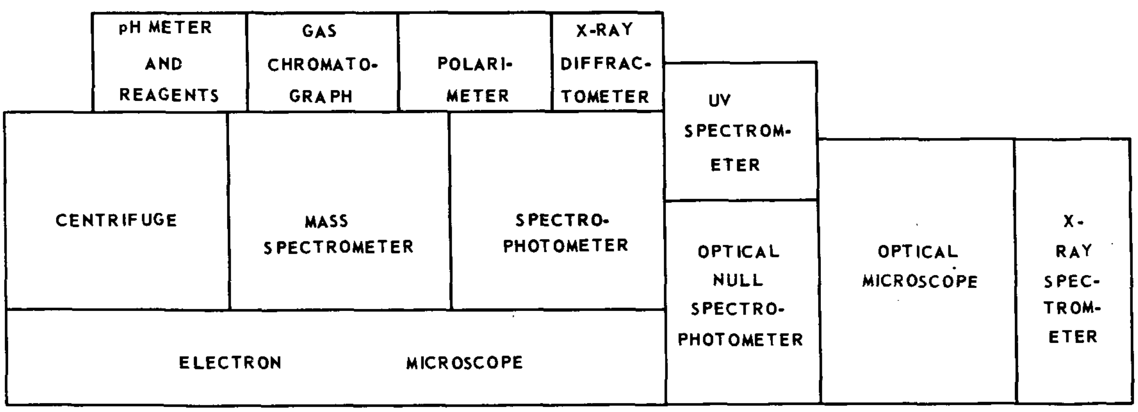

Figure 7b. Typical panel layout for bioscience and geoscience laboratories in MEM: instrument analysis area.

TABLE 5. INSTRUMENTS LOCATED ON PLANETARY MISSION MODULE

Instrument	Function	Range	Weight		Volume		Dimensions, L × W × H (m)	Average Power (W)
			(N)	(lb)	($cm^3 \times 10^3$)	(ft^3)		
UV Solar Spectrometer	Solar UV Occultation	20 to 300 nm	157	(35)	81	(2.9)	0.6 × 0.3 × 0.45	40
Cold Cathode Ionization Gage	Upper Atmosphere Pressure	1.33×10^{-3} to 1.33×10^{-10} N/m^2	9.8	(2.2)	0.1	(0.035)	0.2 × 0.1 × 0.05	2.0
Metastable Detector Probe	Upper Atmosphere Temp.	1 to 10^3 counts/sec	29	(6.6)	20	(0.071)	0.2 × 0.2 × 0.5	2.0
Quadrupole Mass Spectrometer	Upper Atmosphere Composition & Density	0 to 50 amu	49	(11)	1.0	(0.035)	0.2 × 0.1 × 0.05	10
Multi-Channel IR Scanner	Element Survey, Surface Temp.	0.1 to 1 km Resolution	490	(110)	99	(3.5)	1.1 × 0.3 × 0.3	50
IR Interferometer Spectrometer	High-Resolution Element & Atmosphere Composition	5 to 1 nm Resolution	275	(61)	48	(1.7)	0.6 × 0.2 × 0.4	20
Multi-Frequency Microwave Radiometer	Atmosphere & Surface Temp., Clouds, Ice	200°K to 350°K	775	(173)	2000	(70.6)	1.8 × 1.4 × 0.8	30
	Tracking & Ranging Radar		1 294	(290)	216	(7.6)	0.6 × 0.6 × 0.6	435
	Mapping Radar	0.1 to 8 km Resolution	1 863	(420)	360	(12.7)	1 × 0.6 × 0.6	550
Photo & Multi-Spectral TV	High-Resolution Surface Mapping	1 to 10 m Resolution	1 334	(300)	644	(22.7)	1.5 × 0.8 × 0.5	20
Photo & Multi-Spectral TV	Medium Resolution with Relief Imaging	10 to 100 m Resolution	559	(125)	100	(3.5)	0.33 × 0.38 × 0.56 0.61 × 0.66 × 0.71	20
Photo & Multi-Spectral TV	Wide-Angle Imaging	100 to 2000 m Resolution	559	(125)	100	(3.5)	0.33 × 0.38 × 0.56 0.61 × 0.66 × 0.71	20

TABLE 5. (Concluded)

Instrument	Function	Range	Weight		Volume		Dimensions, L × W × H (m)	Average Power (W)
			(N)	(lb)	($cm^3 \times 10^3$)	(ft^3)		
Ionosonde (0.1-10 MHz)	Ionospheric Structure	10 to 10^5 e/cm^3	539	(120)	25	(0.88)	0.45 × 0.25 × 0.25	6.0
Helium Magnetometer	Magnetic Fields	0.1×10^{-9} to 300×10^{-9} tesla	21.6	(4.8)	80	(2.8)	2 × 0.2 × 0.2	5.0
Langmuir Probe	Electron Density & Temp.	10^3 to 10^6 e/cm^3	12.7	(2.8)	0.5	(0.018)	0.2 × 0.05 × 0.05	3.0
Particle Telescope (Solid-State)	Mars Magnetically Trapped Radiation	10 keV to 100 MeV	32.4	(7.3)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.4
Curved Surface Analyzer	Solar Plasma Measurement	10 eV to 10 keV	13.7	(3.0)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.0
Panels, Collection Trays	Micrometeorite Study		98	(22)	100	(3.5)	1.0 × 0.10 × 0.1	2.0
Magnetogram System	Solar Magnetograms	1×10^{-8} to 100×10^{-8} tesla	490	(110)	60	(2.1)	1.0 × 0.3 × 0.2	50
25-cm Telescope & Equipment	Astronomy Observatory		1 373	(308)	5 670	(200)		100
	Bioscience Laboratory		11 866	(2670)	11 000	(385)		500
	Geophysics Laboratory		2 010	(450)	4 950	(173)		250
	Optics Laboratory		7 159	(1600)	11 350	(397)		300
	Electronics Laboratory		1 118	(250)	11 350	(397)		250
	Data Management Center		8 924	(2000)	14 100	(493)		1000
TOTALS			41 051	(9209)	62 359	(2183)		3667

TABLE 6. INSTRUMENTS USED ON MARTIAN AND VENUSIAN ORBITERS AND PROBES

Instrument	Function	Range	Weight		Volume		Dimensions, L × W × H	Average Power
			(N)	(lb)	($cm^3 \times 10^3$)	(ft^3)	(m)	(W)
Quadrupole Mass Spectrometer[a]	Upper Atmosphere Composition	0 to 50 amu	49	(11.0)	1.0	(0.035)	0.2 × 0.1 × 0.05	10
Metastable Detector Probe[a]	Upper Atmosphere Temperature	1 to 10^3 counts/sec	29	(6.6)	2.0	(0.071)	0.2 × 0.2 × 0.5	20
Helium Vapor Magnetometer	Magnetic Field	0.1×10^{-9} to 300×10^{-9} tesla	21.6	(4.8)	40	(1.41)	1 × 0.2 × 0.2	5.0
Ionosonde (0.1 to 10 MHz)	Ionospheric Structure	10 to 10^5 e/cm^3	539	(121)	25	(0.88)	0.45 × 0.25 × 0.25	6.0
Langmuir Probe	Electron Density	10^3 to 10^6 e/cm^3	12.7	(2.9)	0.5	(0.018)	0.2 × 0.05 × 0.05	3.0
Particle Telescope (Solid-State)	Magnetically Trapped Radiation	10 keV to 100 MeV	32.4	(7.3)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.4
Curved Surface Analyzer	Solar Plasma Measurement	10 eV to 10 keV	13.7	(3.1)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.0
Wide-Angle TV[a]	IR and Visible Cloud Observations		90	(22)	9.0	(0.315)	0.4 × 0.15 × 0.15	6.0
Unmanned Orbiter Totals			971	(219)	94	(3.3)		88
Soft-Lander Probe Totals			177	(40)	12	(0.43)		36
(A total of 4 Unmanned Orbiters is required)			3 883	(876)	376	(13.2)		352

a. Instruments of this type are contained in the soft-lander probe, which breaks away from the main probe and descends to Venus' surface. Two instruments of this type are included in the totals.

TABLE 7. INSTRUMENTS LOCATED OUTSIDE THE MEM

Instrument	Function	Range	Weight (N)	Weight (lb)	Volume ($cm^3 \times 10^3$)	Volume (ft^3)	Dimensions, L × W × H (m)	Average Power (W)
Pressure Transducer	Surface Pressure	100 to 1500 N/m^2	4.9	(1.1)	1.0	(0.035)	0.1 × 0.1 × 0.1	1.0
Quadrupole Mass Spectrometer	Surface Atmosphere Composition	0 - 250 amu	98	(22)	6.0	(0.21)	0.3 × 0.2 × 0.1	12
Load-Bearing Experiment	Soil-Bearing Strength Penetration	0.2 to 50 000 N/m^2	49	(11)	3.0	(0.11)	0.3 × 0.1 × 0.1	2.0
Electrical Conductivity Meter	Electrical Properties of Surface		19.6	(4.4)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.0
Subsurface Probe	Electrical Potential Beneath Surface		49	(11)	10	(0.35)	1.0 × 0.1 × 0.1	2.0
Seismometer	Seismic Activity (Passive)	± 10 cm/0.1 sec	34.5	(7.7)	30	(1.06)	0.5 × 0.3 × 0.2	1.0
Thermal-Diffusivity Meter	Surface Temp. & Thermal Conductivity	200 to 350°K	19.6	(4.4)	1.0	(0.035)	0.1 × 0.1 × 0.1	2.0
Anemometer	Wind Velocity	0 to 250 m/sec	9.8	(2.2)	5.0	(0.18)	0.25 × 0.2 × 0.1	1.0
Helium Magnetometer	Surface Magnetic Field	0.1×10^{-9} to 300×10^{-9} tesla	49	(11.0)	10	(0.35)	1.0 × 0.1 × 0.1	5.0
Scanning TV	Visual Imager		98	(22.0)	7.0	(0.25)	0.3 × 0.15 × 0.15	8.0
Ionosonde (0.1 - 10 MHz)	Ionospheric Structure	10 to 10^5 e/cm^3	539	(120)	25	(0.88)	0.45 × 0.25 × 0.25	6.0
Wide-Angle TV	Wide-Angle Imaging-Clouds		98	(22.0)	9.0	(0.32)	0.4 × 0.15 × 0.15	6.0
Constant-Density Balloons	Atmosphere Pressure & Temp.	0 to 3 N/m^2	5 884 (40 × 147)	(1320)	80 (40 × 2.0)	(2.82)	0.2 × 0.1 × 0.1 each	Battery
Microscope with Vidicon	Soil Sample and Dust Microscope		98	(22.0)	16	(0.56)	0.4 × 0.2 × 0.2	8.0
Pyrolysis Chromatograph & Spectrometer	Sample Preliminary Analysis		147	(33.0)	27	(0.95)	0.3 × 0.3 × 0.3	25
Gravimeter	Acceleration Due to Gravity	0.01×10^{-2} to 200×10^{-2} m/sec^2	147	(33.0)	16	(0.56)	0.25 × 0.25 × 0.25	22
Hand-Operated Portable Drill	Hole for Subsurface Science	0 to 3 m	137	(30.8)	21	(0.74)	0.55 × 0.25 × 0.15	Portable Battery
Automatic Drill	Drill for Core Sample	0 to 30 m	1 118	(250.8)	1 000	(35.3)	1.0 × 1.0 × 1.0	(See next item)
Fuel Cell Power Supply	Automatic Drill Remote Power	4 to 7-kW peak	2 942	(660)	1 000	(35.3)	1.0 × 1.0 × 1.0	
Explosives & Geophones	Seismic Activity (Active)		294	(66)	36	(1.27)	0.4 × 0.3 × 0.3	5.0
UV Spectrometer	Solar Spectra, Nocturnal Luminescence	100 to 300 nm	44.1	(10)	5.0	(0.18)	0.5 × 0.1 × 0.1	5.0
IR Spectrometer	Scattered Spectra	0.3 to 15 μm	44.1	(10)	5.0	(0.18)	0.5 × 0.1 × 0.1	5.0
Mars Surface Rover	Surface Traverses	30 km	13 827	(3100)	28 320	(991)	6.0 × 2.0 × 2.4	Self Contained
TOTAL			25 752	(5777)	30 618	(1072)		117

TABLE 8. INSTRUMENTS USED INSIDE THE MEM

Instrument	Function	Range	Weight (N)	Weight (lb)	Volume ($cm^3 \times 10^3$)	Volume (ft^3)	Dimensions, L × W × H (m)	Average Power (W)
X-Ray Diffractometer	Sample Mineral Identity and Allowance		147	(33.0)	5.0	(0.18)	0.16 × 0.16 × 0.16	15
X-Ray Spectrometer	Abundancy by Element & Isotope		118	(26.4)	4.0	(0.14)	0.4 × 0.1 × 0.1	20
Optical Microscope with Vidicon	Mineral Structure & Composition Life Studies	100 to 500 Magnification	147	(33.0)	36.0	(1.27)	0.4 × 0.3 × 0.3	30
Electron Microscope	Microstudies	10-nm Resolution	147	(33.0)	220	(7.8)	1.0 × 0.15 × 0.15	15
Optical Null Spectrophotom-eter	Detect Shifts in Dye Absorption		29	(6.6)	9.0	(0.32)	0.3 × 0.2 × 0.15	3.0
UV Spectrometer	Peptide Leakage Absorption		29	(6.6)	7.5	(0.26)	0.25 × 0.2 × 0.15	2.0
Centrifuge	Separate Particles of Different Densities		177	(39.6)	14.2	(0.50)	0.3 × 0.3 × 0.16	25
Mass Spectrometer	Gas Composition		49	(11.0)	14.2	(0.50)	0.3 × 0.3 × 0.16	3
Polarimeter	Determine Amount of Light Polarization		59	(13.2)	5.6	(0.20)	0.22 × 0.15 × 0.15	5
Spectrophotometers	Determine Intensities of Light Parts		598	(134.2)	14.2	(0.50)	0.3 × 0.3 × 0.16	60
pH Meter & Reagents	Sample Culture Acidity		186	(41.8)	5.7	(0.20)	0.24 × 0.15 × 0.15	3
Gas Chromatograph	Separate Gases in a Mixture/ Solution		59	(13.2)	5.7	(0.20)	0.24 × 0.15 × 0.15	10
Microtome	Cut (Organic) Sections for Microscopic Examinations		108	(24.2)	8.5	(0.30)	0.38 × 0.15 × 0.15	15
Miscellaneous[a]			2893	(649)	1218	(42.6)		1017
TOTALS			4746	(1065)	1568	(55)		1223

a. These instruments are given in Table 10.

TABLE 9. INSTRUMENTS USED WITH REMOTE STATIONS

Instrument	Function	Range	Weight (N)	Weight (lb)	Volume ($cm^3 \times 10^3$)	Volume (ft^3)	Dimensions, L × W × H (m)	Average Power (W)
Pressure Transducer	Surface Pressure	100 to 1500 N/m^2	4.9	(1.1)	1.0	(0.035)	0.1 × 0.1 × 0.1	1.0
Quadrupole Mass Spectrometer	Surface Atmosphere Composition	0 - 250 amu	98	(22.0)	6.0	(0.21)	0.3 × 0.2 × 0.1	12
Measurement on Sample Mechanism	Soil-Bearing Strength and Penetrability	0.2 to 50 000 N/m^2	(Included in Sample Mechanism)					
Soil Sample Mechanism	Soil Sample Retrieval		78	(17.6)	12	(0.42)	0.3 × 0.2 × 0.2	10
Pyrolizer Gas Chromatograph & Mass Spectrometer	Sample Composition & Abundances		147	(33.0)	27	(0.95)	0.3 × 0.3 × 0.3	25
Long-Life Multivator	Multiple Technique Life Detector		147	(33.0)	27	(0.95)	0.3 × 0.3 × 0.3	10
Microscope with Vidicon	Sample Soil & Dust Microscope		98	(22.0)	16	(0.56)	0.4 × 0.2 × 0.2	8.0
Alpha-Scattering Experiment	Crystal Isotope Abundances		39	(8.8)	3.0	(0.11)	0.2 × 0.1 × 0.15	1.0
Neutron-Activation Analyzer	Heavy Crystal Isotope Detection		157	(35.2)	10	(0.35)	0.5 × 0.2 × 0.2	20
Electrical Conductivity Meter	Electrical Properties of Surface		19.6	(4.4)	2.0	(0.071)	0.2 × 0.1 × 0.1	1.0
Helium Magnetometer	Surface Magnetic Field	0.1×10^{-9} to 300×10^{-9} tesla	49	(11.0)	10	(0.35)	1.0 × 0.1 × 0.1	5.0
Gravimeter	Surface Gravity Variations	0.01×10^{-2} to 200×10^{-2} m/sec	147	(33.0)	16	(0.56)	0.25 × 0.25 × 0.25	22
Seismometer	Passive Seismic Measurement	± 10 cm/0.1 sec	34.3	(7.7)	30	(1.1)	0.5 × 0.3 × 0.2	1.0
Thermal-Diffusivity	SurfaceTemp. & Condition	200 to 350°K	19.6	(4.4)	1.0	(0.035)	0.1 × 0.1 × 0.1	2.0
Anemometer	Wind Velocity & Direction	0 to 250 m/sec	9.8	(2.2)	5.0	(0.18)	0.25 × 0.2 × 0.1	1.0
Scanning TV	Visual Imaging		98	(22)	7.0	(0.25)	0.3 × 0.15 × 0.15	8.0
Advanced RTG Source	Remote Power	150 to 200 W	490	(110)	100	(3.5)	0.66 × 0.66 × 0.23	
TOTALS			1638	(367.4)	273	(9.56)		127
(A total of 4 Remote Stations is required)			6551	(1470)	1092	(38)		508

TABLE 10. INSTRUMENTATION FOR BIOSCIENCE AND GEOSCIENCE LABORATORY

Instrument	Function	Range	Weight		Volume		Dimensions, L × W × H (m)	Average Power (W)
			(N)	(lb)	($cm^3 \times 10^3$)	(ft^3)		
Osometer			53.0	(12)	5.7	(0.2)	0.24 × 0.15 × 0.15	
Refractometer			35.6	(8)	5.7	(0.2)	0.24 × 0.15 × 0.15	2
Thermometers			4.4	(1)	2.8	(0.1)	0.28 × 0.1 × 0.1	1
Scales			67.0	(15)	28.3	(1.0)	0.3 × 0.3 × 0.3	1
Refrigerator			44.5	(10)	28.3	(1.0)	0.3 × 0.3 × 0.3	40
Incubators			89.0	(20)	56.6	(2.0)	0.62 × 0.3 × 0.3	100
Ovens and Sterilizers			177	(40)	28.3	(1.0)	0.3 × 0.3 × 0.3	500
Work Bench & Containers			275	(55)	849.0	(30)		
Micromanipulators			98	(22)	(Stored in bench)			5
Ultrasonic Cleaner & Solvents			628	(140)	56.6	(2.0)	0.62 × 0.3 × 0.3	200
Agitators & Blenders			40	(9)	14.2	(0.5)	0.3 × 0.3 × 0.16	10
Emulsifiers			44.5	(10)	14.2	(0.5)	0.3 × 0.3 × 0.16	8
Sample Containers			98	(22)	14.2	(0.5)	0.3 × 0.3 × 0.16	
Hand Tools			98	(22)	20.0	(0.7)	0.5 × 0.2 × 0.2	
Culture Media			49	(11)	3.4	(.12)	0.15 × 0.15 × 0.15	
Specimens (Lichens-Algae)			265	(60)	28.3	(1.0)	0.3 × 0.3 × 0.3	
Ice Samples (Refrigerated)			127	(28)	31.1	(1.1)	0.35 × 0.3 × 0.3	150
Water Samples			39.2	(8)	2.8	(0.1)	0.28 × 0.1 × 0.1	
Surface Soil Samples			667	(150)	28.3	(1.0)	0.3 × 0.3 × 0.3	
TOTAL			2893	(643)	1218	(43.3)		1017

TABLE 11. SUMMARY OF WEIGHT, VOLUME, AND POWER OF INSTRUMENTS

Instrument Location	Weight (N)	Weight (lb)	Volume ($cm^3 \times 10^3$)	Volume (ft^3)	Power (W)
Planetary Mission Module	41 051	(9 207)	62 359	(2183)	3667
Martian and Venusian Orbiters	3 883	(876)	376	(13.2)	352
Outside the MEM	25 752	(5 775)	30 618	(1072)	117[a]
Inside the MEM	4 746	(1 049)	1 568	(55)	1223
Remote Stations	6 551	(1 470)	1 092	(38)	(b)
	81 984	(18 392)	96 013	(3360)	5359

a. Power for the 15-m drill is not included in this value. The 4 kW required for this is to be provided by a fuel cell.

b. Four RTG power sources supply the power to operate the remote stations.

SECTION VIII. CONCLUSIONS

The experiments discussed in the preceding chapters are recommended for the first manned mission to Mars. These experiments were selected after carefully considering the following factors: the recommendations of various individuals and advisory groups such as the Space Science Board of the National Academy of Sciences, the results of numerous NASA-sponsored studies such as the Boeing study of 1968 [4], the past and projected results of precursory missions such as those presented in Section II, the projected technological capabilities in the 1980's, and, finally, the judgment of the members of the Planetology Group.

The experiments have been divided into the following five areas: planetary atmospheres, planetary surfaces, planetary dynamics and interiors, particles and fields and planetary interactions with the solar wind, and exobiology.

Knowledge to be obtained about the planetary atmosphere includes the following: temperature, pressure, density, velocity, and isotopic and chemical composition of the atmosphere. Cloud photography using filters to study the shape, motion, altitude, and location of clouds will be done. Other atmospheric properties to be investigated are the transmission properties in the optical wavelength region, the particles present in the atmosphere, and the buildup of static electricity.

In the area of planetary surfaces the following information will be obtained. Micrometeorites will be collected during the interplanetary flight and subjected to laboratory analysis. Mapping in the visual, thermal, and radar wavelengths will be done for topographic and geothermal analysis. Examinations will be made of the surface material to determine physical properties (e.g., density, color, gas content, grain size, and texture), chemical, and mineral composition. Other soil and rock properties to be investigated are mineral and element analysis using X-ray diffraction patterns, refractive indices, petrographic structure, crystal patterns, and spectral infrared emission. The surface and subsurface temperatures will be measured. Gas trapped in the rocks and subsurface materials will be chemically analyzed. The surface will be observed to study and record erosion processes such as duststorms and geologically important features such as craters. If the landing occurs in the polar region, examinations will be made of the polar cap to determine chemical composition, temperature, melting rate, and thickness. Permafrost depth and composition will also be investigated.

The third area is planetary dynamics and interiors. Experiments to be done in this area are measurements of the gravitational and magnetic fields and active and passive seismic investigations.

Knowledge to be gained in the areas of particles and fields and of planetary interaction with the solar wind are strength and direction of the magnetic field in interplanetary space and in the region around Mars. The electron and proton energies and fluxes near Mars will be measured. The ionospheric layers will be investigated by making measurements of the electron density and its variations due to location, diurnal, and seasonal effects, and the electron density and temperature will be measured in-situ by the unmanned orbiter. Also investigated will be the interaction between the solar wind and the planet's ionosphere. The H-alpha emission, the radio flux at 10.7-cm wavelength, and the X-ray emission from the sun will be monitored. A 25- to 40- cm telescope will make possible many interesting observations; for example, the Martian moons, Phobos and Deimos, will be prime objects of interest.

The fifth area is exobiology. Experiments to be done are UV and IR spectroscopy of the Martian surface from orbit to study absorption bands indicative of those chemical constituents which are of interest to the exobiologist. While on the surface the exobiologist will collect samples to examine for evidence of biological activity. If life forms or organic matter are detected, the exobiologist will concentrate on specific questions of characterization and classification. Specimens of biological interest will be returned to earth in preserved forms and also, hopefully, as living samples or cultures. Extraction and concentration of biotic material will allow more efficient use of the return storage capacity. Preliminary work in comparing Martian organic compounds with Earth types will be initiated on the Martian surface. Presumptive tests for classes of macromolecules essential to earth life, such as amino acids, nucleic acids, and ATP, will be carried out.

Although these experiments have been selected with considerable forethought given to precursor results, knowledge gained from these earlier flights may make some of the experiments recommended here needless by 1986. Nevertheless, we believe that most of the experiments provide a logical extension of the precursor activity. This will be most likely if the measurements are made under different conditions (as will probably be the case), such as with significantly improved instruments, new planetary locations, and greater time periods for investigations.

The convoy mode (spaceships separated) is recommended over the single mode (spaceships coupled) during the voyage to and from Mars. The convoy mode will enable cooperative experiments between the two spaceships, such as investigation of low-frequency RF transmission through the solar plasma. Also, it may be possible to compute the solar wind velocity by recording the time needed for particles to travel the distance separating the spaceships. Tracking of orbiters about Venus can be done from two points rather than one if the two spaceships are separated. In Martian orbit the separated spaceships can reduce the problem of continuous communication by serving as relay links.

At the Venusian encounter each spaceship will launch an orbiter with six experiments which will provide information about the following physical properties: density, temperature, composition, magnetic fields, charged particles, and electron density. The orbiters will be placed into elliptical orbits with a periapsis of approximately 150 km and an apoapsis of approximately 5000 km. The orbiters will have inclinations differing by about 90 deg. From each orbiter an entry-probe will be launched. Each entry-probe will divide into two probes — an atmospheric drifter and a soft-lander. These will make vertical soundings to measure the atmospheric temperature, pressure, and composition; additionally, the soft-lander will carry a TV camera. The drifter may search for biological activity at an altitude of approximately 25 km.

Each space vehicle will have accommodations for an astronomical observatory, which will house a 25- to 40-cm-size telescope. During the transit part of the mission, opportunities for viewing celestial bodies, including the earth, will exist. In transit and while at Mars opportunities, unavailable from Earth, may occur for the observation of stellar occultations by the outer planets. Ephemerides should be completed for these observations.

On arrival at Mars each space vehicle will launch one unmanned orbiter and several relay satellites. The orbiters will pass through the upper Martian atmosphere and make measurements of the physical properties. This is not possible from the planetary mission module because of its orbit. Each orbiter will weigh about 1961 N and require on the order of 100 W of power. The orbiters will be placed in equatorial and polar orbits and will have a periapsis and apoapsis of about 100 km and 1000 km, respectively.

The relay satellites will provide real-time communication links between the MEM, mission module, remote stations, and other components. A module using a laser system to obtain high data-rate transmission will be separated from each mission module (just before return to Earth) and will serve as a continuous communication link between Mars and Earth. This orbiter will continue to relay data from automated surface measurements to earth after completion of the mission.

The total weight of the scientific instruments is approximately 81 984 N, the total volume, were the instruments reduced to a single package, is 96.013 m^3, and the power requirement is 5.359 kW. Summary information about the instrumentation is given in Table 11.

The landings should be made at different sites, permitting the investigation of different locations. For this mission two sites have been selected. One is located at about 50 deg south latitude so as to be on the edge of the polar cap, permitting investigations of this interesting feature. The other site should be at or near the equator, perhaps in the Tithonius Lasus area which is located at 5 deg south latitude. This area becomes darker earlier than other areas in the region. The equatorial region probably has a greater chance of harboring life because of the higher temperatures (298° K maximum at the equator). As an alternative to one of these locations, a landing near a Viking site would be of interest in that abandoned instrumentation and spacecraft components and surfaces would show the effects of prolonged exposure to the Martian environment.

To investigate the wave of darkening when it first forms, the landing should occur in the spring. On the planned landing date the southern hemisphere is in midwinter and the wave of darkening is just before forming; therefore, delaying the earth launch date by about 60 to 90 days would be necessary to achieve a spring landing.

To accomplish the experimental objectives outlined for the landed part of the mission, five scientists will be needed at each site (in determining these requirements a work day of 8 to 10 hours has been assumed). They will consist of one meteorologist (for experiments related to the atmosphere and to particles and magnetic field), two geologists (for experiments related to surface science and the Martian interior), and two biologists (for experiments related to exobiology).

Drills to penetrate the surface will be needed to conduct a number of geologically related experiments. A hand-operated drill, capable of drilling 3 m, will be needed for remote locations in areas not accessible to heavier equipment. An automatically operated drill, capable of drilling 15 m or more, will be required to obtain deep-seated samples for chemical, biological, and subsurface structural analysis.

A manned Martian rover similar in design to the lunar rover will be necessary to fully explore the immediate surface area. The weight would be about 13 827 N (plus 2206 N for experiments), and it should be able to carry two scientists (~ 3579 N) over a traverse distance of approximately 30 km. The vehicle should also be designed to carry heavy equipment to the remote stations and possibly to pull the automated drill to the drilling sites.

The MEM should be designed to provide adequate transportation to the Martian surface for the scientific instruments and associated laboratory equipment, the drill, and the rover. The five scientists will use the MEM for transportation to the surface, as crew quarters, and as a base of operation.

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Marshall Space Flight Center, Alabama 35812, May 7, 1970
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