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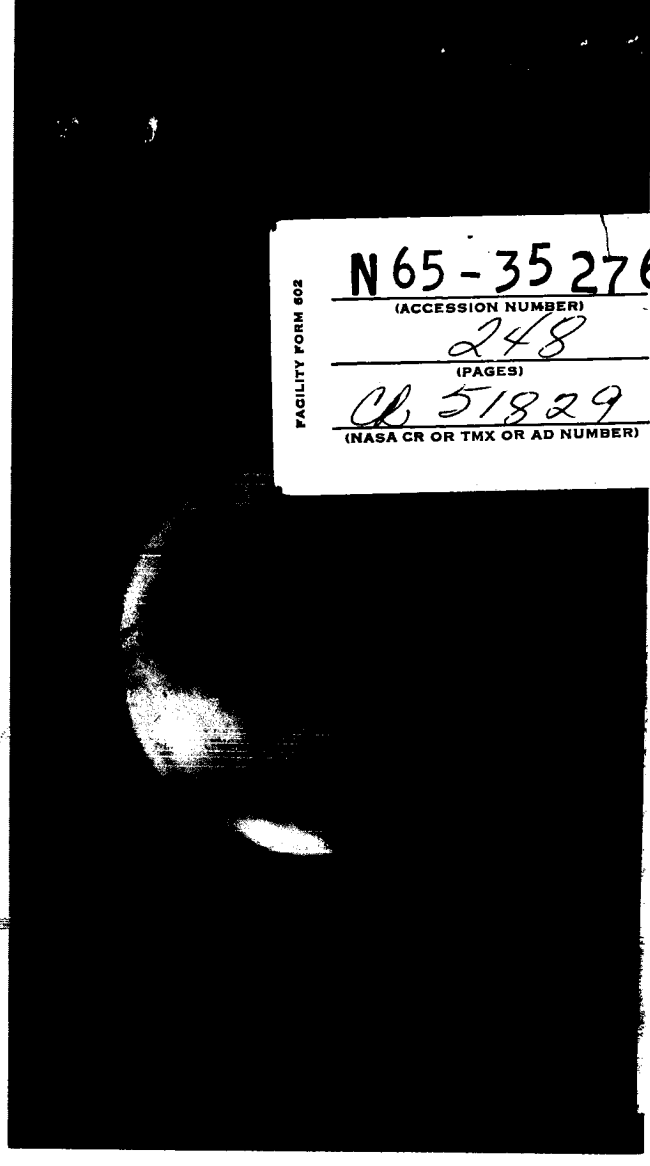

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VOYAGER
DESIGN STUDIES

Volume Two: Scientific Mission Analysis

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Prepared under Contract No. NASw 697 by

RESEARCH AND ADVANCED DEVELOPMENT DIVISION
AVCO CORPORATION
Wilmington, Massachusetts
for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

[redacted]

FOREWORD

The Voyager Design Study final report is divided into six volumes, for convenience in handling. A brief description of the contents of each volume is listed below.

Volume I -- Summary

A completely self-contained synopsis of the entire study.

Volume II -- Scientific Mission Analysis

Mission analysis, evolution of the Voyager program, and science payload.

Volume III -- Systems Analysis

Mission and system tradeoff studies; trajectory analysis; orbit and landing site selection; reliability; sterilization

Volume IV -- Orbiter-Bus System Design

Engineering and design details of the orbiter-bus

Volume V -- Lander System Design

Engineering and design details of the lander.

Volume VI -- Development Plan

Proposed development plan, schedules, costs, problem areas.

TABLE OF CONTENTS

Summary 1

1. Introduction 2

2. Outline of Mission Analysis 4

3. Review of Observations and Measurements 6

4. Multidisciplinary Study 16

   4.1 Exogenetic and Endogenetic Energy 16
   4.2 Atmospheric Statics 22
   4.3 Atmospheric Dynamics 54
   4.4 Magnetism and Electrodynamics 69
   4.5 Cosmic Rays 81
   4.6 Communications and Electromagnetics 90
   4.7 Planetary Morphology and Geology 101
   4.8 Geochemistry 118
   4.9 Seismology 129
   4.10 Exobiology 136
   4.11 Physiology 142

5. Scientific Measurements 147

6. Scientific Instrumentation 150

   6.1 Instrumentation Lists 150
   6.2 Payload Designs 157
   6.3 Instrumentation Evaluation 167

7. Planetary Exploration Program 193

   7.1 Martian Lander Experiments 193
   7.2 Mission Evaluation 210
   7.3 Landing Sites -- Mars 219
   7.4 Landing Sites -- Venus 227

References 232

LIST OF TABLES

1. Review of Observations and Measurements - Mars 7

2. Review of Observations and Measurements - Venus 13

3. Ionization Parameters 53

4. Atmospheric Statics and Dynamics..... 78

5. Magnetism and Electrodynamics (Mars and Venus)..... 80

6. Cosmic Rays (Venus and Mars) 89

6a. Communications and Electromagnetics (Mars and Venus).....100

7. Planetary Morphology and Geology (Mars).....116

8. Planetary Morphology and Geology (Venus) 117

9. Geochemistry 128

10. Seismology (Mars and Venus) 135

11. Exobiology.....140

12. Physiology and Man-Machine - Environment Relationships (Mars) 146

13. Scientific Measurements Value Matrix, 1969 Mars Opportunity.....149

14. JPL Instrumentation List 151

15. Minimum 24-Hour-Mission Payload 158

16. Optional Minimum 24-Hour-Mission Payload 159

17. Supplement to Optional 24-Hour-Mission Payload.....162

18. Schedule of Instrument Use 163

19. Orbiter - Bus Payload 165

20. Radiation Belts 171

21. Cloud Structure.....171

LIST OF TABLES (Concl'd)

22. Atmospheric Composition 172

23. Physical Properties of the Atmosphere 173

24. Biological Structure of Cells 174

25. Cell Growth Process 175

26. Inorganic Soil and Dust Analysis 176

27. Organic or Biological Compounds 177

28. Surface Topography 179

29. Seismology 180

30. Soil Mechanics 180

31. Instrument Merit Rating Index Tabulation Model 190

32. Instrumentation Selection Model 191

33. Mars Options 213

34. Recommended Launch Configuration 214

35. Definition of Partial Mission Success 215

36. Expected Fractional Mission Success 216

37. Probabilities of Fulfilling Mars/Venus Program Objectives 217

LIST OF FIGURES

Figure 1 Intensity of Continuous Solar Spectrum 18

2 Meteoroid Distributions 23

3 Vertical Distribution of Neutral Gas Concentrations 32

4 Photochemical Equilibrium in Atmosphere of Mars 37

5 Photochemical Equilibrium in Atmosphere of Venus - Model I 38

6 Recombination and Diffusion Times for Atmosphere of Mars 39

7 Recombination and Diffusion Times for Atmosphere of Venus--Model I 40

8 Vertical Distribution of Atmosphere Constituents--Venus Model II 44

9 Vertical Distribution of Atmosphere Constituents--Venus Model I 45

10 Transmission Curves for Solar Radiation in Martian Atmosphere 47

11 Photoionization Rate by Solar Radiation 48

12 Vertical Distributions of Positive Ions 49

13 Positive Ion Composition of Martian Atmosphere 50

14 Terrestrail Atmospheric Regimes 58

15 Symmetrical Laminar Vortex Regime 60

16 Wave Regime 62

17 Planetary Magnetic Phenomena 70

18 Solar and Galactic Cosmic-Ray Flux 82

19 Solar Magnetic and Cosmic-Ray Phenomena 83

LIST OF FIGURES (Cont'd)

Figure 20 Propagation of Horizontally Polarized Electromagnetic Waves 92

21 Model Planetary Ionospheres 94

21A Atmosphere Sferic Activity 98

22 Polar Stone Rings 103

23 Interior Structure of Earth and Mars 119

24 Planetary Differentiation 120

25 Geochemical Optimization of Soil and Atmosphere for Plant Growth 124

26 Planetary Seismic Activity 130

27 Transfer Oribt Parameters - 1969 195

28 Transfer Orbit Parameters - 1971 196

29 Transfer Orbit Parameters - 1973 197

30 Transfer Orbit Parameters - 1975 198

31 Central Angle of Impact on Mars 200

32 Geometry at Planetary Intercept -- 1969 201

33 Geometry at Planetary Intercept -- 1971 202

34 Geometry at Planetary Intercept -- 1973 203

35 Geometry at Planetary Intercept -- 1975 204

36 Derivation of Mars Landing Footprint 206

37 Mars Landing Footprint 207

38 Latitude Limits on Mars Landers -- 1969 and 1971 208

39 Latitude Limits on Mars Landers -- 1973 and 1975 209

LIST OF FIGURES (Concl'd)

Figure 40 Martian Seasons and Lander Footprints 221

41 Voyager Landing Sites--Mars 223

42 Voyager Landing Sites--Venus 228

SUMMARY

This report presents the results of a 6-month conceptual design study conducted by Avco Research and Advanced Development Division for the National Aeronautics and Space Administration. The objectives of the study were the synthesis of a conceptual design of an unmanned spacecraft to perform scientific orbiter-lander missions to Mars and Venus during planetary opportunities from 1969 to 1975, and the formulation of a plan delineating the development program leading to first launch during the Mars 1969 opportunity.

The basic approach makes use of a 6000- to 7000-pound orbiter-lander; tradeoff studies were conducted to determine the payload and mission capabilities with smaller and larger spacecraft. The orbiter-lander was selected as yielding the maximum in scientific value short of manned exploration. The lander separates from the orbiter-bus and descends to the planet surface by parachute, where it makes atmospheric and surface measurements and conducts a variety of scientific experiments. The information obtained is relayed to Earth via the orbiter-bus which meanwhile is placed in a planetocentric orbit. The orbiter-bus collects scientific data in transit and maps the planet while in orbit. The lifetime of both orbiter-bus and lander is 6 months for the Mars missions. For Venus, the orbiter life is also 6 months, but the lander life is only 10 to 20 hours because of the hostile environment. A small capsule was designed for Venus, in addition to the lander, to conduct atmospheric measurements after entering from orbit; the capsule does not survive landing. Landers and capsules would be sterilized to avoid contamination of the planets, but the orbiter-bus would be placed on a trajectory which would ensure that it would remain above the sensible atmosphere for at least 50 years; thus, no sterilization would be required. The development plan shows that to obtain the scientific value desired, two spacecraft should be scheduled for each launch opportunity and hardware development should begin in 1964 to meet the 1969 launch date for Mars.

1. INTRODUCTION

The justification of the Voyager project rests ultimately on the scientific knowledge to be gained from the spacecraft flights. Not only the central question as to the desirability of Voyager, but the magnitude and timing of the effort can be properly determined only when the scientific objectives are considered along with the many other important questions. An integrated, multidisciplinary study of each of the planets as objects of scientific investigation, when carried out in combination with a conceptual design of the spacecraft, can provide the most effective measure of the capabilities of the project. Simultaneously, consideration of the interactions among scientific measurements, spacecraft and physical environment will lead to a more effective spacecraft conceptual design.

The analysis of the Voyager scientific program has been guided by three broad objectives established by NASA. In order of priority, these are as follows:

1. Exobiological Investigations,

2. Geophysical/Geological Measurements, and

3. Manned Landing Information.

The most exciting possibility of planetary exploration is that of discovering evidence for the existence of life of nonterrestrial origin. The first objective of the Voyager program, exobiological investigations, is to obtain a definitive answer to the question of the existence of life-forms on Mars and, of lower priority, in the cloud layers of Venus. The second objective of the Voyager mission is to gather geophysical and geological information concerning both Mars and Venus. This mission analysis treats each planet as an aggregate of matter acted on by exogenetic forces (solar, cosmic) and by endogenetic forces (radioactive, seismic), and attempts to determine the essential questions of interest and the relationships of the various measurements intended to answer those questions. The third priority objective of the program is to gather information necessary to make possible future manned landings on Mars. This includes physical information such as temperatures, pressures, and winds; data concerning human physiology, such as cosmic ray intensity at the surface; and information which may permit a degree of coupling of the man-machine spacecraft to the Mars environment, such as availability of potable water.

Finally, the evolution of the Voyager program must be made to contribute to its own success. To the broad NASA objectives we add the requirement that flights to each planet must gather the data necessary to enhance the

probability of success of later flights. In addition, the scientific data obtained on each mission must be effectively assimilated into the body of knowledge of the planets to guide the design of subsequent scientific measurements, and an effective procedure for this is presented.

Each of these objectives contains a broader application than merely the intellectual satisfaction of answering the specific questions concerning each target planet. This broader value is of course the application of the knowledge so gained towards understanding ourselves, our own planet, and the potential capabilities we have for exploring our universe. The discovery of a life mechanism in any way different from those available for study on Earth will provide a powerful stimulus to the understanding of the reasons for various evolutionary paths and the origin of life. Similarly, new bodies of descriptive geophysical/geological data from other planets will be very helpful in understanding the vast body of data which has been gathered concerning earth. For example, studies of the atmospheres of Venus and Mars may enable the complex circulatory patterns of our atmosphere to be more easily interpreted. Consequently, the Earth's weather may be more easily understood, predicted, and eventually controlled.

Finally, the knowledge we gain to enable a future manned expedition to travel to Mars will also help us define the accessible limits of even more extended space travel. Mars represents a much better opportunity than does the moon for coupling a man/machine ecological loop to an alien environment, and should provide us with a firmer understanding of our potential capabilities in this respect.

The objectives of this study of the scientific mission of Voyager were considered to be fourfold:

1. To provide a complete analysis of the scientific capabilities of the Voyager project,

2. To determine and specify scientific requirements and to predict the physical environment to be encountered in order to ensure the most effective spacecraft design,

3. To examine the scientific objectives and mission constraints in sufficient detail so as to make possible a precise exploration schedule,

4. To organize the study in such a way that a capability would be provided for future continuing modification and updating of the analysis as new information becomes available and as program objectives evolve.

2. OUTLINE OF MISSION ANALYSIS

In order to achieve the objectives of this study, the following areas of work were undertaken:

1. A multidisciplinary study of Mars and Venus,

2. An analysis of desired scientific measurements,

3. A selection of optimum scientific instrumentation, and

4. Establishment of a planetary exploration program.

The first of these areas consisted of a study of each of the planets as objects of scientific interest and investigation. In order to quickly carry out a review of the present state of knowledge concerning the planets, aid was sought from Geophysics Corporation of America, and their group contributed a valuable tabulation of the available measurements of Venus and Mars.

Within each specialty represented in this multidisciplinary analysis, a study has been carried out to determine areas of primary interest, to note special questions arising from the individual natures of each of the planets, to interpret where possible the available observations and measurements, and to suggest the most profitable measurements to be made on the Voyager project. In several instances, models have been proposed and original analyses performed in order to predict the conditions on the planets. Each of the studies has been summarized in a table which lists the expected conditions and measurements desired, and assigns to each measurement a value index as to the importance of that measurement to furthering the understanding of the planets within specialty.

The second stage of the mission study has been termed an optimization analysis of the scientific measurements to be made on the Voyager program for each planet and for each of the orbiter and lander. First, a master list of measurements was compiled by combining those suggested by each discipline. Each of the broad objectives specified by NASA was assigned a weighting factor to reflect the relative emphasis given each objective. In addition to the three stated NASA objectives, a fourth has been added concerned with planetary measurements needed to improve the probability of the success of succeeding Voyager flights. For each of these objectives, a value rating was assigned to each measurement on a scale of 1 to 10. The net value was finally obtained as the sum of the individual values each weighted according to the emphasis placed on each objective.

It should be pointed out that this scheme of attempting to optimize the scientific gain by means of a systematic analysis should be of continuing

value. As more information becomes available from early flights, the value ratings for each measurement will change, and the relative emphasis of the broad objectives will also change. At the very least this matrix of priorities, updated as desired, should be able to provide a guide and a check for project management, even if other criteria and judgements are subsequently applied to the results.

Once the most important measurements had been selected, the next task was to determine the optimum instrumentation. At the start of the present study contract, Avco was provided with an instrument list, from which instruments were to be selected for integration into the spacecraft design. The initial approach to this problem was to design separate packages, or groups of instruments, of increasing weight to accomplish the broad objectives of the Voyager program. These packages were treated as inputs to tradeoff studies which also included power supplies, communication requirements, and payload capabilities. It soon became evident that the conceptual design of the spacecraft as it evolved was going to exceed substantially in total payload capability the smaller of the lander instrumentation packages. Therefore, attention was concentrated primarily on the largest of these packages, which finally totaled approximately 200 pounds of instrument weight.

The selection of the scientific instruments for lander package considered first the utility of each of the possible instruments for the desired measurements. Where instruments were not available on the supplied list, additions were made in order to achieve a complete capability in the package. Considerations taken into account in selecting among possible instruments for each desired measurement included weight, power, volume and bits requried, deployment and sample acquisition complexity especially as it affected the spacecraft design, and utility for several different desired measurements.

The last task included in this study was to establish a detailed exploration schedule for each planet. The first step was to determine the capability of the Voyager design to place a lander at desired sites on the planet. This capability was limited by several constraints which were analyzed to determine the net footprint available on the planet to the lander. Next, consideration was given to the influence of predicted reliability on the exploration schedules, and the program effort determined which would be required to meet the goals of the program. Finally, specific landing sites were selected with detailed reasons as to the importance of each in the light of both available knowledge and the results of the multidisciplinary studies. These landing sites are listed specifically for each launch attempt in each launch opportunity for both Mars and Venus.

3. REVIEW OF OBSERVATIONS AND MEASUREMENTS

In order to quickly review the present state of knowledge of Mars and Venus, Geophysical Corporation of America was asked to support the Avco RAD study by preparing notes on the observations and measurements which have been performed. These have been provide by G. C. A. in the form shown in tables 1 and 2. For each parameter listed, these tables list the measurements desired, present indications of the occurrence of the phenomena, the significance of the parameter to the study of the planet, and suggest instruments for each recommended measurement.

These tables have been utilized in the present study as source material, but no attempt has been made to reorganize the tables themselves to match the outline used in this report.

TABLE 1

REVIEW OF OBSERVATIONS AND MEASUREMENTS -- MARS

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Temperatures	Surface and atmospheric values; seasonal, latitudinal, longitudinal, diurnal, and secular variations.	At surface -- $\bar{T} \sim 230°K$; large diurnal variation at equator, 50 to 100 K°; latitudinal gradient may reverse at night and in winter. In atmosphere -- decrease with height at adiabatic rate, 3.7 K°/km, or less to tropopause; above tropopause at lower rate.	Environmental constraint for life on Mars (especially night time and winter temperatures). Environmental parameter for manned space flights to Mars. Meteorology of Mars and Earth. Surface T is boundary condition for Martian atmosphere and interior models; determines reaction rates and directions for surface geochemistry.	Orbiter -- IR bolometry in 8 to 13 μ window for surface temperatures. -- Microwave radiometry for temperatures of the near subsurface. -- High resolution IR spectrometry in the 15μ CO_2 band or equivalent microwave spectrometry for atmospheric temperature profile. Descent Capsule -- Thermistor temperature sensor and altimeter for atmospheric temperature profile. Lander -- Temperature sensors in subsurface and in atmosphere immediately above surface -- perhaps part of automatic meteorological station.
Winds	Surface and atmospheric; seasonal latitudinal, longitudinal, diurnal, and secular variations in direction and speed.	Occasional cloud drift observations; theoretical estimate of geostrophic wind from temperature gradient at surface and Lettau's model; alternation of wave and symmetrical regimes; possible "tidal" or diurnal variability due to large diurnal temperature changes; transport of water vapor from pole to pole. Very little reliable information available.	Meteorology of Mars and Earth; check on suggestion of meridional circulation regime. Environmental parameter for manned space flight to Mars. Environmental parameter for life on Mars; spore distribution mechanism.	Orbiter -- Low resolution TV for cloud drift and sand storms observations. Descent Capsule -- Constant level superpressure balloons released on descent; balloons tracked by orbiter for winds. -- Pitot-static tube. Lander -- Anemometry for speed and direction. (Absolute direction calibration from surface may be difficult).
Pressure	Surface and atmospheric values; seasonal, latitudinal, longitudinal, diurnal, and secular variations.	85 mb (within factor of 2) at surface from polarimetry and photometry; but recent spectroscopic observations suggest ~ 15 to 20 mb at surface. Pressure decreases slowly with height because gravitational acceleration on Mars is small; vertical pressure gradients have been computed. No information on horizontal variability.	Martian atmospheric physics. Environmental parameter for design of unmanned and manned spacecraft (descent through atmosphere). Meteorology of Mars.	Orbiter -- High resolution IR spectroscopy of rotational contours of rotation-vibration spectra; by properly choosing lines at different degrees of saturation, atmospheric pressure profile can be determined. -- Visual light polarimetry. Descent Capsule -- Pressure gauge for atmospheric pressure (hypsometer or aneroid). Lander -- Aneroid barometer.
Density	Surface and atmospheric values; seasonal, latitudinal, longitudinal, diurnal, and secular variations.	From pressure, temperature, and mean molecular weight values and the ideal gas law.	Upper atmosphere densities important for predicting lifetime of Martian orbiters.	Orbiter -- Orbital accelerations give upper atmospheric densities if altitudes are well known. Descent Capsule -- Accelerometer. -- From pressure and temperature (composition must be known). -- Velocity of sound measurements. Lander -- From pressure, temperature and mean molecular weight.
Oxygen	Atmospheric concentration as a function of altitude and time; regions of photoproduction and photodissociation.	Not detected; instrumental detectivity places upper limit at 2.5 m NTP. If all O_2 arises from CO_2 photodissociation, calculation puts the O_2 abundance at 0.2 cm NTP with a maximum abundance at the 110 to 160 km level.	Life on Mars -- Potential requirement for higher life. Manned flight to Mars. Evolution of planetary atmospheres; rates of interior outgassing. Oxidation of surface material.	Orbiter -- Microwave, 7500 A, or UV oxygen absorption line radiometry, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass and light spectrometry. Lander -- Mass and light spectrometry. -- Analytic chemistry.

TABLE 1 (Cont'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Carbon Dioxide	Atmospheric concentration as a function of altitude, topography and time; level of photodissociation.	3100 cm NTP or 2 percent by volume; but some recent spectroscopic evidence suggests downwards revision of absolute abundance and upwards revision of relative abundance necessary. Until recently, only gas identified in Martian atmosphere.	Meteorology of Mars and Earth. Greenhouse effect. Carbon geochemistry; test of validity of Urey equilibrium. Possible utilization by Martian organisms. CO_2 photodissociation intimately involved with problem of Martian exosphere temperatures.	Orbiter -- IR Spectroscopy of CO_2 absorption bands at 2.7, 4.3, 9.4, 10.4, and 15μ, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass spectrometry, infrared spectroscopy or filter radiometry at pre-chosen frequencies. Lander -- Mass and light spectrometry. -- Analytic chemistry.
Water Vapor	Atmospheric concentrations; vertical, seasonal, latitudinal, longitudinal, and secular variations, especially near surface.	Little water vapor -- 10^{-2} to 10^{-3} gm cm^{-2}, from IR spectroscopic and theoretical arguments. Polar caps which vaporize and reform seasonally are known by polarimetry and IR spectroscopy to be water hoar frost; most white clouds show polarimetric character of ice crystal composition.	Probable single most critical requirement for contemporary life on Mars. Biologically significant question of existence of Martian seas in primitive times. Meteorology of Mars and Earth. Clouds and polar cap composition and variations. Greenhouse effect. Precipitation. Geochemistry and geomorphology. Photochemistry of upper atmosphere.	Orbiter -- IR Spectrometry at 1.1, 1.4, 1.9, 2.7, and 6.2μ, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Frost point hygrometer. Lander -- Frost point hygrometer. -- Analytic chemistry.
Nitrogen and Argon	Atmospheric concentration; level of dissociation.	No direct observations, but thought by terrestrial analogy and cosmic abundance arguments to be the major constituents of the Martian atmosphere.	Composition of atmosphere. Understanding of ionospheric, auroral, and airglow phenomena on Mars.	Orbiter -- UV absorption lines of the molecule and the ion (e.g., N_2^+ First Negative system at 3914A), as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass and light spectrometry. Lander -- Mass and light spectrometry. -- Analytic chemistry.
Ozone	Atmospheric concentration; vertical distribution.	Not detected. Threshold of detectivity and lack of oxygen places upper limit ~0.1 cm NTP.	Ozone absorption moderates UV radiation constraint for life on Mars. Meteorology -- Vertical temperature distribution in stratosphere. Exosphere temperatures and atmospheric escape. Oxidation of surface material.	Orbiter -- 9.6μ, UV, visible or microwave radiometry in ozone absorption bands, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Regener Ozonesonde. Lander -- Regener ozone meter.
Cloud and Haze Abundance and Location	Seasonal, latitudinal, longitudinal, diurnal, and secular variations of cloud opacity.	White, yellow, and blue clouds are occasionally observed, blue haze is frequently present; white haze at dawn limb of Mars.	Meteorology. Greenhouse effect. Intensity and spectral distribution of sunlight available for Martian organisms.	Orbiter -- TV camera with filter wheel; yellow, blue, red filters or color TV.
Ultraviolet Radiation	UV albedo; UV penetration as function of height in atmosphere; UV intensity and wavelength distribution at surface; variations of surface UV spectrum and possible correlation with blue haze variability seen at longer wavelengths.	UV albedo is ~0.05, <0.5 the visible albedo; lack of ozone in atmosphere suggests high UV intensities reach surface.	Environmental constraint for life on Mars. Manned landings on Mars. Composition of upper atmosphere. Application to blue clearing.	Orbiter -- UV photometry, spectrometry as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- UV photometry, spectrometry. Lander -- UV photometry, spectrometry.

TABLE 1 (Cont'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Planetary Albedo	Reflected solar radiation -- topographical and temporal variations; wavelength dependence.	Visual albedo of dark areas ~0.08; of bright areas ~0.14. Bolometric albedo is substantially greater.	Heat budget of planet. Meteorology. Surface composition.	Orbiter -- Suomi radiometer; filters for wavelength dependence.
Topography	Contours of surface topography.	Lowell suggests 2500 ft as altitude discrimination limit at planetary limb. Tombaugh disputes this and claims that smallest vertical height that could be detected from Earth is 27,500 ft. Some suggestion that dark areas are lower lying than bright areas from limb and cloud observations. Some mountainous regions inferred from frost or cloud deposits (e.g., Mountains of Mitchell; Nix Olympica).	Design of landers -- Manned and unmanned. Meteorology. Geomorphology and orogenesis. Biologically critical question of existence of Martian seas in primitive times.	Orbiter -- Stereoscopic TV with concentration on limb observations. Descent Capsule -- TV. Lander -- Rotating TV Camera.
Ionosphere	Vertical variation of electron, positive ion and negative ion densities.	The theoretical model of Chamberlain gives a noontime electron density at the mesopause of $< 10^5$ cm^{-3}; an E_2 region at 200 km with electron density of $< 5 \times 10^4$ cm^{-3}; and an F region at about 320 km with a noontime electron density $\sim 10^5$ cm^{-3}.	Radio communication -- Manned and unmanned exploration. Structure of Martian atmosphere. Solar Martian relations.	Orbiter -- Radio soundings. -- Spectrometry of Martian airglow and aurora. Descent Capsule -- Langmuir probe. -- Ion spectrometer. Lander -- Critical frequency measurements. -- Spectrometry of Martian airglow and aurora.
Magnetic Field	Magnetic field strength, temporal variability, location of magnetic poles, magnetic storms.	Moment of inertia of Mars as determined by motions of Phobos and Deimos suggests that there is not an extensive liquid core, and therefore, that the magnetic field at and above the Martian surface may be small.	Test of dynamo models of the origin of planetary magnetic fields; existence of Wiechert discontinuity in Martian interior; possible existence and structure of Martian Van Allen belts; deflection of solar and galactic cosmic ray flux (of possible significance for the mutation rate of Martian organisms).	Orbiter -- Magnetometer.
Surface Composition	Chemical analysis and physical properties of dark and bright areas, polar caps.	Polar caps -- Thin layer of hoar frost. Bright areas -- Fine opaque powder similar to limonite, a Fe_2O_3 hydrate. Dark areas -- Composition similar to that of bright areas, but with a darker covering, possibly biological.	Substrate for life. Geochemistry, geomorphology, mineralogy, orogenesis. Origin and evolution of Mars. Manned and unmanned exploration.	Orbiter -- Polarimetry, permitting extension of polarization measurements beyond phase angle 47°, to which Earth-based observations must be restricted. -- Infrared spectrometry. -- High-resolution television. Lander -- Analytic chemistry. -- Mineralogical microscopy. -- Gas chromatography. -- Infrared spectroscopy. -- High-resolution television.
Cloud Composition and Particles in the Atmosphere	Concentration; size distribution, 1.4 shape, composition -- dielectric or metallic; density of grains; distribution with altitude and latitude.	Evidence of particulate matter suspended in atmosphere -- Clouds, blue haze; difference between optical and dynamical oblateness. White clouds -- ice?; Yellow clouds -- dust?; blue haze --?	Understanding of cloud phenomena; oblateness difference; long term rate of meteorite infall; erosion processes. Test of Öpik's "retro-directive" hypothesis of blue clearing.	Orbiter -- Polarimetry; intensity and polarization of scattered sunlight -- correlated with TV pictures. Descent Capsule -- Particle counter; -- UV and visible photometers. Lander -- Particle counter; -- Microphone; -- Visible spectrometry when clouds overhead (or command from orbiter).

TABLE 1 (Cont'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Visibility at Surface	Horizontal visibility at surface; diurnal and temporal variations, latitudinal and longitudinal distributions.	Presence of dust and dust storms suggests times of low visibility; morning haze.	Environmental parameter for manned exploration. Design parameter for placement of TV cameras on surface.	TV camera will indicate variations in visibility, but not absolute value. Indirectly from measurements of particle concentrations.
Cloud Heights and Thickness	Cloud-top and base heights.	Morning haze and mist over polar cap, presumably at low elevations; if clouds below tropopause, maximum altitude some tens of kms; dust palls at lower altitudes.	Meteorology.	Orbiter -- Radar. -- Indirectly from cloud-top temperature determination in window region. Descent Capsule -- From correlation of photometry, particle counter, and pressure, temperature measurements.
Exosphere Temperature	Exosphere temperature variation with height; diurnal and secular variations.	Theoretical computations; Chamberlain - 110°K; Öpik - 1800 - 200°K.	Rates of escape of atmospheric gases; history of Martian atmosphere.	Orbiter -- Direct temperature sensor; -- Indirectly from density determinations from accelerations of orbiter? Descent Capsule - Temperature sensor.
Aurora and Airglow	Intensity and spectral distribution of auroral and airglow lines and bands.	No observational evidence. Some lines expected for theoretical reasons in the visible and the near ultraviolet.	Atmospheric structure. Solar-Martian relations.	Orbiter -- Spectrophotometry as a function of θ, the angle from the instantaneous planetary normal. Lander -- Spectrophotometry as a function of θ, the angle from the instantaneous planetary normal.
Electrical Discharges in Atmosphere	Time frequency, altitude and magnitude of discharge current.	No direct evidence, although presence of dust in Martian atmosphere suggests existence of electrical discharges.	Atmospheric composition. Nature of the clouds and surface.	Orbiter -- Sferics. Lander -- Electrometer. -- Ionization gauge. -- Microphone.
Polarization of Sky; Neutral Points	Percent polarization of the Martian sky seen from the surface, as a function of zenith distance, angle from the sun, and local weather.	No observations yet performed.	Provides characterization of the nature and size distribution of dust particles in the Martian atmosphere.	Lander -- Upward-looking visual wavelength polarimeter.
Gravity Variations	Gravitational acceleration; horizontal distribution over planet.	$\sim$377 cm sec^{-2} from planetary mass and radius.	Geodesy. Departures from isostasy.	Orbiter -- Gravimeter. Lander -- Gravimeter.
N_2O, CH_4, C_2H_4, C_2H_6, and Other Gaseous Hydrocarbons	Atmospheric concentration, seasonal abundance variations, and topographic localization.	None; all searches have been unsuccessful.	On the Earth today, all these gases are the products of biological activity. Their existance on Mars, particularly if topographically localized or time-variable, would provide some presumptive evidence for a Martian biology.	Orbiter -- Infrared spectroscopy. Descent Capsule -- Mass spectroscopy. Lander -- Gas chromatography. -- Analytic chemistry. -- Mass spectroscopy.
CH_3 CHC and other Aldehydes	Atmospheric concentration, seasonal abundance variations, and topographic localization.	The 3.69μ feature in the Martian infrared spectrum has been attributed to the existence of acetaldehyde in the Martian dark areas.	A gaseous, photolabile organic molecule restricted to the dark areas is almost certainly indicative of life on Mars.	Orbiter -- Ultraviolet and infrared spectroscopy, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass spectroscopy. Lander -- Gas chromatography. -- Analytic chemistry. -- Mass spectroscopy.

TABLE 1 (Cont'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
NO, NO_2, N_2O_4	Atmospheric concentration, seasonal abundance variations, and topographic localization.	Continuous absorption in the photographic ultraviolet has been attributed to nitrogen oxides. The required abundances seem inconsistent with the low upper limits set on the NO_2 and N_2O_4 abundance by infrared spectroscopy.	Proponents of the view that the nitrogen oxides are abundant on Mars hold that many of the visual surface features and time variations on surface features can be attributed to chemical reactions and phase changes of these substances.	Orbiter -- Ultraviolet and infrared spectroscopy, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass spectroscopy. Lander -- Gas chromatography. -- Analytic chemistry. -- Mass spectroscopy.
NH_3, H_2S, etc.	Atmospheric concentration, seasonal abundance variations, and topographic localization.	None; all searches unsuccessful.	Would provide a better understanding of the photochemistry of the Martian atmosphere and the geochemistry of the Martian crust.	Orbiter -- Ultraviolet and infrared spectroscopy, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass spectroscopy. Lander -- Gas chromatography. -- Analytic chemistry. -- Mass spectroscopy.
CO	Atmospheric concentration and vertical distribution especially at photo-production level.	No observations. If all CO arises from CO_2 photodissociation, calculations put the CO abundance at 0.03 cm NTP (Marmo and Warneck) with the volume abundance above the mesopause between 0.02 and 0.06 (Chamberlain and Öpik).	Photochemistry of the Martian atmosphere. The CO abundance is a principal determinant of the Martian exospheric temperature, and therefore dominates questions of the rate of escape and evolution of the Martian atmosphere.	Orbiter -- Spectrometry, e.g., at 2.35 μ and elsewhere in the visible and infrared, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule -- Mass and light spectrometry. Lander -- Mass spectrometry. -- Analytic chemistry. -- Gas chromatography.
Surface Organic Matter	Surface distribution, time variation, and relative abundance of various organic molecular species.	Features in the infrared spectrum of Mars at 3.45, 3.58, and 3.69μ attributed to absorption by hydrocarbons and aldehydes.	The existence of organic matter which is non-uniformly located and/or which varies seasonally in abundance is presumptive evidence of life. Characterization of the organic matter provides some evidence on the biochemistry of Martian organisms.	Orbiter -- Infrared and (probably much less useful) ultraviolet spectroscopy. Lander -- Infrared, visible and ultraviolet spectroscopy of surface samples. -- Gas chromatography. -- Mass spectrometry. -- Automated analytic chemistry. -- Biological staining.
Stereochemistry of Martian Organic Matter	Optical rotary dispersion profiles of Martian organic matter	None.	Detection of biologically produced organic matter.	Lander -- Optical rotatory dispersion detector, operating in organic absorption bands; e.g., in the 2600 A purine and pyrimidine absorption band region.
Metabolic Activities of Martian Micro-Organisms	Output of metabolites.	None.	Biochemical characterization of the metabolic pathways of Martian organisms.	Lander -- Radio-isotope growth detector. -- Multiple chamber biochemical experiment. -- pH change detector.

TABLE 1 (Concl'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Growth of Martian Micro-organisms	Size change and rate of growth of Martian micro-organisms.	Seasonal wave of darkening; Color changes; Polarimetric evidence for changes in size distribution of granules in the dark areas in spring.	Characterization of physiology and life cycle of Martian organisms.	Lander -- Turbidity detector. -- Microscope. -- Radio-isotope growth detector. -- Multiple chamber biochemical experiment.
Enzymes in Martian Soil	Abundance of specifically prechosen enzyme categories in Martian soil samples.	None.	Enzymes from dead organisms may be present in soil even when organisms are not. Enzymes are so complex and specific that their a biological production in large amounts is unlikely; thus they provide good presumptive evidence for life.	Lander -- Multiple chamber biochemical experiment with photocell detection of enzymes-substrate fluorescence.
Artifacts of Civilization	Nature, function, and distribution of artifacts.	None.	Characterization of possible intelligent life on Mars.	Orbiter -- High-resolution television. -- Radio wavelength receivers. Descent Capsule -- High-resolution television. Lander -- Surface television. -- Microphone.
Seismometry	Seismographic observations during Marsquakes and during explosive detonations in and on surface.	Experiment not yet performed.	Nature of the immediate subsurface; Structure of the Martian deep interior.	Lander -- Seismometers. -- Detonators. -- Explosives.
Size and Morphology of Martian Organisms	High-resolution three-dimensional geometry; characterization of motion.	Polarimetric evidence for opaque granules ~ 0.1 mm diameter which seasonally change size distribution. No evidence in other size ranges.	Characterization of Martian life forms.	Orbiter -- Visual light polarimetry high resolution television. -- Microwave radar. Lander -- Television. -- Visible, ultraviolet, and phase contrast microscopy.

TABLE 2

REVIEW OF OBSERVATIONS AND MEASUREMENTS - VENUS

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Extent of Cloud Cover	Spatial and temporal distribution of breaks in cloud cover; transparency of clouds as a function of wavelength.	Temporary increases in 8-13μ radiation suggest breaks in cloud layers; 7820A and 1.6μ radiation arises from below the clouds; Mariner saw no breaks in clouds.	Meteorology Test of Greenhouse and Aeolosphere models Illumination of lower atmosphere	Orbiter - High and low resolution TV in visual and near IR wavelengths, especially in CO_2 windows.
Surface Topography	Surface topography; height contours.	Cold spot observed in 8-13μ bolometry. Otherwise nothing of any significance is known.	Design of manned and unmanned landers Meteorology Geology Planetary cosmogony	Orbiter - Radar - Near IR television Descent Capsule - Near IR television - Visual wavelength TV
Atmospheric Composition	Number density as a function of altitude for carbon dioxide; nitrogen; oxygen; water vapor; ozone; hydrocarbons; nitrogen oxides; CO, C_3O_2, $(C_3O_2)_n$, Ar^{40}.	CO_2 2 to 10% by volume N_2 presumed most abundant gas, though not detectable from earth O_2 disputed identification by Prokoffief; previous upper limit 100 cm NTP. $H_2O<10^{-5}$ volume mixing ratio down to 5.6 atm. pressure level in unsuccessful search. Disputed detection from high altitudes of 10^{-3} to 10^{-2} gm/cm^2 above clouds. $(C_3O_2)_n$ disputed identification of 11.2μ feature. CO disputed identifications by Sinton and by Moroz NO_2, N_2O_4 ultraviolet continuum identification contradicted by unsuccessful IR searches Unsuccessful searches for N_2O, CH_4, C_2H_4, C_2H_6, NH_3.	Life on planet or in atmosphere Meteorology Manned exploration Planetary cosmogony and evolution	Orbiter - Spectroscopy at appropriate UV, visible, IR and microwave frequencies, as a function of θ Descent Capsule - Ibid looking both up and down. - Mass spectroscopy
Atmospheric Pressure	Surface and cloud top pressures; vertical distribution of pressure, and topographical or temporal variations.	Surface pressure ~10 to 50 atmospheres; visible cloud-top pressure ~90 to 600 mb.	Meteorology Upper atmospheric physics Greenhouse effect Structure of lower atmosphere Surface chemistry Planetary cosmogony	Orbiter - Polarimetric observations at cloudtops - Spectral line contours at IR and microwave frequencies, as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule - Aneroid barometer
Temperatures	Surface and cloud temperature: topographical and temporal variations; thermal structure of atmosphere and its seasonal, secular, diurnal, latitudinal, and longitudinal variations.	Surface: ~ 800°K on bright side, 650°K on dark side from microwave emission and radar reflectivity data. Cloud top - 236 ±8°K at 3.75μ in dark hemisphere; - 234± 5°K at 8-13μ in both dark and bright hemispheres, but more recent data suggests a 20K° downward revision may be necessary. Occultation level T~ 203°K above clouds. Expect value of adiabatic lapse rate is 7 to 9 K°/km. Darkside atmosphere probably subadiabatic.	Environmental constraint for life Manned and unmanned exploration Atmospheric physics and chemistry Surface temperature is boundary condition for Cytherean atmospheric and interior models; determines reaction rates and directions for surface chemistry.	Orbiter - Surface temperature from microwave spectrometry and radiometry and high resolution IR spectrometry. - Cloud top temperatures from IR radiometry. - Atmospheric temperature from high resolution CO_2 band spectrometry, e.g., at 4.3μ. Descent Capsule - Direct temperature sensor. -Downward-looking IR and microwave spectroscopy and radiometry at frequencies ordinarily absorbed by the clouds.
Amount of Solar Radiation Reaching Surface of Planet	Insolation at ground; spectral variation of insolation with local solar zenith angle.	IR probably absorbed by CO_2 and H_2O; short wavelengths depleted by scattering; some visible wavelengths may reach surface.	Life Manned and unmanned exploration Greenhouse effect Meteorology	Descent Capsule - Visible radiation bolometer and visible spectrometer, looking both up and down.
Atmospheric Density	Spatial and temporal variations.	High at surface	Lifetime of orbiters Design of landers	Orbiter - Indirectly from orbital accelerations Descent Capsule - Accelerometer - Indirectly from pressure and temperature (composition must be known).

TABLE 2 (Cont'd)

Parameter	Measurements Desired	Present Indications	Significance	Instruments Required
Magnetic Field	Field strength, orientation, temporal variability.	Mariner - Surface magnetic field strength probably $<10^{-2}$ gauss.	Ionosphere formation; aurorae; airglow; radio whistlers; test of dynamo models of the origin of planetary magnetic fields; existence of Wiechert discontinuity in Cytherean interior; possible existence and structure of Cytherean Van Allen Belts; deflection of solar and galactic cosmic ray flux.	Orbiter - Magnetometer Descent Capsule - Magnetometer
Ionosphere	Vertical distribution of electrons, positive and negative ions.	Absence of appreciable dispersion between 12.5 and 68 cm radar returns sets an upper limit to the electron density of the Venus ionosphere $\sim 10^8$ cm^{-3}. Theoretical computations are severely hampered by the absence of reliable information on the composition of the upper atmosphere.	Test of ionospheric model of origin of microwave emission. Limitation on radio communication frequencies for manned and unmanned exploration Upper atmosphere physics	Orbiter - Top-side sounding techniques Descent Capsule - Langmuir probe, ion spectrometer if descent velocities are low -Radiosonde techniques between descent capsule and orbiter.
Albedo	Planetary and spectral distribution of reflected solar radiation.	Ultraviolet - 0.5 Visual - 0.8 Bolometric - 0.73	Greenhouse effect Cloud composition Meteorology and atmospheric heat balance	Orbiter - Filter radiometry in visible and IR
Cloud Top Height and Thickness	Heights and thicknesses of cloud layer (s); spatial variations.	Cloud top height $\sim$90 km in one recent estimate; may be as low as 30 km. Probably thick, up to 20 km. Possibly more than one cloud layer.	Meteorology - Greenhouse effect Affects amount of sunlight reaching surface and thermal structure of atmosphere Manned and unmanned exploration	Orbiter - Radar; - Indirectly from cloud-top temperature observations (yields variation of cloud-top height with topographical location) Descent Capsule - Correlation of pressure, temperature and particle counter measurements with visible and IR solar radiation measurements.
Cloud Texture	Cloud-top texture - flat, billowy?	Interpretation of dark markings on ultraviolet photographs of Venus as due to Rayleigh scattering implies cloudtops are billowy on a scale $\sim$100 km. Nothing is known of cloud texture on smaller resolution scales.	Meteorology of cloud formation Interpretation of ultraviolet photographs of Venus	Orbiter - TV camera for visible and UV Descent Capsule - Visible and UVTV
Spectral Distribution of Outgoing Infrared Radiation	Variation with latitude and season	On the Greenhouse model, some infrared emission must occur to space, especially in breaks in the clouds, from deep atmospheric levels at high temperatures. On the aeolosphere model, no such emission is expected.	Greenhouse effect Heat balance of planet General circulation	Orbiter - Wide band infrared radiometry
Gravitational Variations	Gravitational acceleration; horizontal variations and anomalies; distribution over planet	$g = 842$ cm sec^{-2} from planetary mass and radius	Geodesy Departures from isostasy	Orbiter - Gravimeter Descent Capsule - Gravimeter
Exospheric Temperature	Temperature variation with altitude in exosphere; diurnal and secular variations.	Theoretical computations suggest possibly higher values than for earth.	Rate of escape of atmospheric gases History of Cytherean atmosphere	Orbiter - Indirectly from density determinations Descent Capsule - Temperature sensor?
Aurorae and Airglow	Intensity and spectral distribution of auroral and airglow lines and bands.	No reliable observational evidence. Some disputed identifications by Kozyrev. Some lines expected for theoretical reasons in the visible and the near ultraviolet.	Atmospheric structure Solar-Cytherean relations	Orbiter - Spectrophotometry as a function of θ, the angle from the instantaneous planetary normal. Descent Capsule - Spectrophotometry as a function of θ, the angle from the instantaneous planetary normal.
Electrical Discharges in Atmosphere	Frequency, altitude, and current.	No direct evidence, although possible presence of dust in Cytherean atmosphere suggests existence of electrical discharges.	Atmospheric composition Nature of the clouds and surface	Orbiter - Sferics Descent Capsule - Electrometer - Ionization guage - Microphone

TABLE 2 (Concl'd)

Paremeter	Measurements Desired	Present Indications	Significance	Instruments Required
Polarization of Sky	Percent polarization of the Cytherean sky observed from the surface, as a function of zenith distance, angle from the sun, and local weather.	No observations yet performed.	Provides characterization of the nature and size distribution of possible dust particles in the Cytherean atmosphere.	Descent Capsule - Polarimetry, as a function of θ, the angle from the instantaneous planetary normal.
Cloud Composition	Particle counts; chemical analysis for silicates, carbonates, oxides, ice crystals, water droplets, hydrocarbons.	Polarimetric evidence that clouds composed in part of transparent particles in micron size range, consistent, but not exclusively, with water droplets. Disputed spectroscopic identification of ice crystals, $(C_3O_2)n$, and carbonate dust in clouds. Cloud composition must explain high albedo, yellow color, and relevant temperatures and pressures.	Greenhouse Effect Meteorology Environment below clouds Test of aeolosphere model Atmospheric chemistry	Orbiter - Polarimetry - Infrared spectroscopy Descent Capsule - Since cloud is extensive and probably thick, an opportunity exists to collect enough cloud during descent for chemical analysis.
Rotation Rate	Rotation Rate	JPL radar: ~230 days, retrograde; NRL passive microwave radiometry: retrograde; heat capacity of atmosphere implies > 180 days; 8-13μ radiometry possibly suggests rapid rotation. True value should be known precisely by time of Voyager mission.	Meteorology Surface temperature and chemistry Climatology Generation of magnetic fields in liquid cores Planetary cosmogony	Orbiter - TV tracking of cloud features, and of features below clouds - Doppler radar - High resolution IR video may permit observation of surface features through breaks in the clouds.
Inclination of Axis of Rotation to Plane of Ecliptic	Inclination of axis of rotation to plane of ecliptic.	Measurements of apparent atmospheric cloud weather bands at visual wave-lengths suggest mean inclination of 23°. Infrared observations suggest smaller inclinations, and at least one interpretation of radar observations suggests very large inclinations.	Meteorology Climatology Planetary cosmogony	Orbiter - Doppler radar - TV and high resolution IR vidicon tracking of cloud features and features below the clouds.
Composition of Surface	Phase (liquid vs. solid) Chemical composition	For the radar reflectivities, a di-electric constant $7 \geq \epsilon \geq 3$ for the Cytherean surface has been determined. While this is characteristic of many dry terrestrial soils it is only a crude indication of surface composition. It is likely that the surface is a desert, but the possible presence of high-viscosity, low-volatility hydrocarbons has not been eliminated.	Manned and unmanned exploration Planetary cosmogony Geophysics and Geochemistry Physics of lower Cytherean atmosphere Surface organic matter	Orbiter - High resolution mircowave spectroscopy - Radar Descent Capsule - Visual and IR spectroscopy and TV after capsule emerges from the bottom of the cloud layer, as a function of θ, the angle from the instantaneous planetary normal. High resolution millimeter microwave spectroscopy, as a function of θ, the angle from the instantaneous planetary normal -Radar
Wind Velocity	Absolute values of velocities; velocity direction fields; spatial and temporal variations as function of altitude and distance from sub-solar point.	Upper atmospheric wind velocities in excess of several hundred miles per hour would have been detected through Doppler effect. Theoretical discussions suggest that there is no critical reason to expect upper atmospheric wind velocities in excess of gale force; and one exact solution of an admittedly very simplified model gives wind velocities ~0.3 mph.	Meteorology Manned and unmanned exploration Test of aeolosphere model	Orbiter - TV cinematography of cloud motions Descent Capsule- Release constant level balloons tracked by orbiter - Pitot-static tube

4. MULTIDISCIPLINARY STUDY

The central theme of this scientific mission study asserts that an integrated examination of the goals of the proposed scientific investigations will yield the optimum choice of measurements, and hence a maximum return of scientific information. This implies that (a) each discipline or specialty must be included in any effort to determine possible measurements, and (b) no single discipline determine alone the final choice from among these possibilities. The latter of these two requirements is obviously not easy to attain, requiring either a disinterested scientist thoroughly knowledgeable in each field, or an effectual committee of scientists. The difficulties of each of these methods increase rapidly as the scope of a program increases to that of Voyager, where interrelationships increase almost geometrically with the number of instruments available.

In the following section a semianalytical method of final selection of scientific measurements for Voyager flights, which is suggested, at least, as an aid to the solution of this task, is presented. In this section we undertake the preliminary task of considering the scientific objectives in the light of each discipline. The specialties or topics which have been included in this analysis are:

a. Exogenetic/Endogenetic Energy
b. Atmospheric Statics
c. Atmospheric Dynamics
d. Magnetism and Electrodynamics
e. Cosmic Rays
f. Communications and Electromagnetics
g. Planetary Morphology and Geology
h. Geochemistry
i. Seismology
j. Exobiology
k. Physiology.

For each of these areas the planetary phenomena are reviewed and considered in the light of our present knowledge and theories. In several instances, models are constructed and analyses carried out, and finally measurements are suggested which would be of most value in furthering the state of knowledge within that discipline.

4.1 Exogenetic and Endogenetic Energy

1. External and internal energy of planets. Planetary aggregates and their immediate environments are shaped by endogenetic-energy (from inside), exogenetic-energy (from outside), the manner of energy transmission through the matter, the manner of temporary storage of transmitted energy as potential energy, the percentage of transmitted energy stored as potential energy, the

the manner of conversion of stored potential energies, and the rates of conversion of stored potential energies. Examples of exogenetic energy are electromagnetic (solar and extrasolar), corpuscular (solar wind, solar flares, and galactic), solid particles (indigenous to solar system, possibly extrasolar), tidal forces (solar, satellites, other members of solar system), magnetism (solar and galactic), and light pressure. Endogenetic energy may be divided into a) centripetal -- gravitational, magnetic, and cohesive forces which are largely electrostatic, and, b) centrifugal -- rotational, thermal (probably exclusively from radioactivity), and seismic (this and all tectonic movements are thought to be ultimately linked to thermal radioactive energy). It should be noted that bathymetric heat of compression of planetary bodies is probably only released during destruction of a planet as, for example, when it passes within the Roche's limit of a larger body. Examples of stored potential energy are seen in the continental masses of the Earth's surface where matter is raised above mean base level, and in the barometric highs of the atmosphere, where air masses are raised above "mean base level" for a static atmosphere. Examples of the release of stored potential energy are the movements of sediments from continents to oceanic basins down a gravitational gradient, and in the movement, with spreading of barometric highs.

The main source of electromagnetic energy incident on Venus, Earth, and Mars is the sun (figure 1). The total electromagnetic flux and its spectrum at mean Earth orbit are reasonably well known and tabulated at the end of this section. Values for other planets can easily be obtained by applying the inverse square law. The various parts of the solar spectrum are generated in different parts of the sun. In general, the longer the wavelength of the observed radiation, the higher and more rarified the solar levels that produce it, and the higher the temperature of these layers. Visual disturbances are seen minutes before radio disturbances, and, in general, the longer the radio wavelength, the longer the delay suggesting that corpuscular streams passing through the corona produce these oscillations (200-mc waves may be delayed 3 minutes, 100-mc waves, 5 minutes, and 50-mc waves up to 8 minutes). As the visual disturbances originate from the photosphere and the radio disturbances in the corona, the lag indicates a unity between photosphere, reversing layer, chronosphere, and corona. It furthermore represents the time needed for the corpuscular stream to travel from the photosphere to the corona.

Next to electromagnetic energy, tidal forces are probably most important in shaping 1st- and 2nd-order geomorphic features (see section on geomorphology). Tidal actions on the Earth's hydrosphere have been of great importance in shaping 4th- and 5th-order geomorphic features, while tidal effects on atmospheres would be a function of the density and viscosity of these atmospheres. Models of tidal actions in solids, liquids, and gases have been prepared. It will be interesting to compare geophysical measurements on Venus, Earth, and Mars, and to compare the role of tidal forces in shaping these planets. On Venus, atmospheric tides may dominate; on Earth hydrospheric tides seem to be of most importance; on Mars solar tides in the lithosphere may be most important.

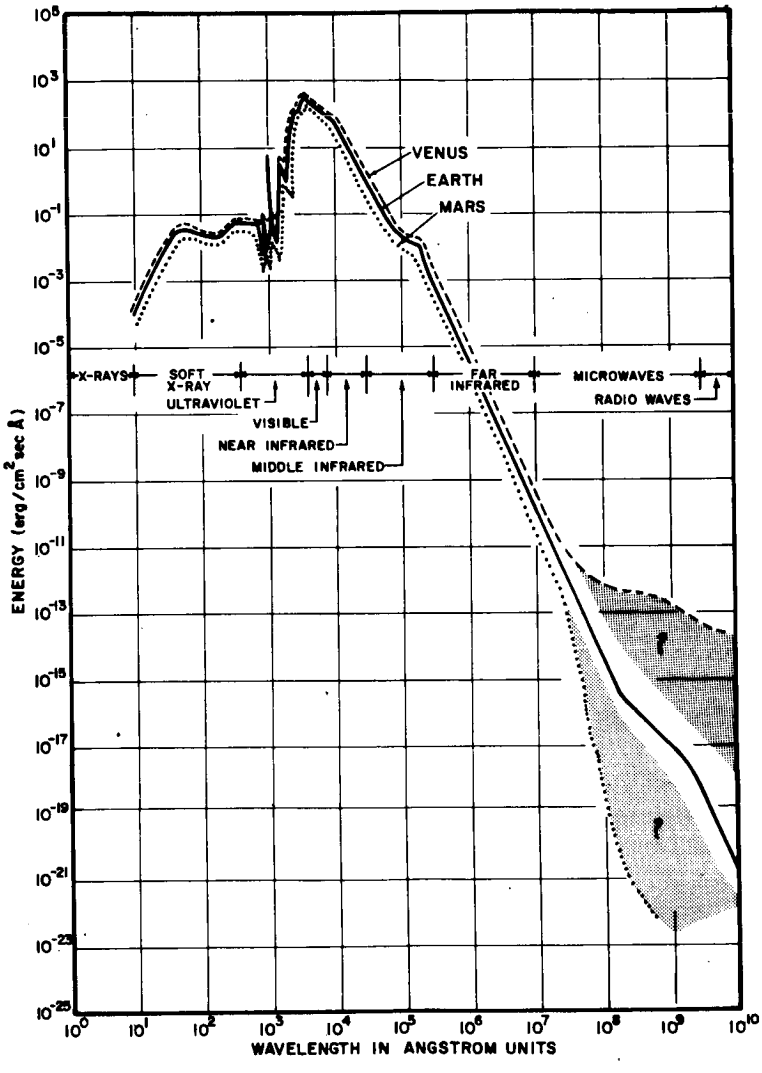

Figure 1 INTENSITY OF CONTINUOUS SOLAR SPECTRUM
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2. Planetary boundaries and zones. A planetary aggregate may somewhat arbitrarily be defined as a body not too much smaller than Mercury and in solar orbit. The boundary of a planet may be taken as the detectable limit at which its exosphere, magnetic field, etc., dominate the configuration, energy state, or composition of the interplanetary environment. If the planet has a strong magnetic field, the magnetosphere is dominant as a boundary. If the planetary field is weak or lacking, the limit at which the characteristics of the exosphere dominate the solar wind constitutes the boundary. The Earth's magnetopause seems to be a relatively sharp boundary toward and tangential to the solar wind. Venus has a weak magnetic field, if any, and the boundary between the planetary and solar environment may be less abrupt.

The nonequilibrium configurations of aggregated matter are a dynamic function of time. From a human point of view, the movements of the atmosphere are rapid, while crustal movements are exceedingly slow. The hypothesized convective movements in the Earth's mantle are thought to be even slower, and it may be expected that they would be still slower in Venus, and slowest on Mars.

Three planetary zones are proposed. These again are somewhat arbitrary but useful for this study. The first may be called the exosphere-atmosphere and extends from the outermost boundary of the planet (defined above) to its solid or liquid surface. The second may be called the lithosphere/hydrosphere, and on terrestrial type planets (Mercury, Venus, Earth, Mars) this includes all matter from the base of the gaseous envelope, if present, to the base of the lithosphere. The base of the lithosphere is known from seismic observations, and is thought to be a phase change where solids become plastic or liquid. The third zone is the body of the planet including all matter from the base of the lithosphere to the center of gravity. The solid body of the Earth can be subdivided into regions as indicated by seismic evidences, and illustrated in the section on seismology. Gaseous matter between a planet's boundary and surface may be divided into layers on the basis of kinetic, thermal, compositional, photochemical, electrodynamic, and other properties. In many cases, the properties can be related to primary causes; in some cases this has not yet been done. It is expected that there will be some parallel between the atmospheres of Venus, Earth, and Mars; however, it is suggested that both missing, and a multitude of additional, subdivisions will be found in the colossal atmosphere of Venus, and that some elements may be missing from the thin atmosphere of Mars.

3. Energy transfer and dominant forces. The transfer of energy through a planetary aggregate is a complex phenomena involving radiation, reflection, scattering, absorption, conduction, convection, chemical changes, and physical movements; in short, every known reaction between electromagnetic energy, various potential energies, and matter in all its states. Different processes dominate in different parts of a planet, and they do so over different time spans according to (a) different energy flux rates and (b) the composition and masses

of the zones. All processes move toward an ultimate equilibrium, but in so doing, create temporary configurations which are very different from what might be considered as "equilibrium." The energy, frequency, and depth of electromagnetic energy penetrating planetary atmospheres and functions of compositions, densities, partial pressures, and relative distributions of atmospheric components. Little visible light could reach the surface of Venus, and little ultraviolet reaches the surface of the Earth. A greater proportion of many parts of the spectrum must reach the surface of Mars through its tenuous atmosphere, and the entire spectrum must be incident on airless bodies like Mercury and the Moon.

On planets with atmospheres, the atmosphere is the overwhelmingly dominant method by which solar electromagnetic energy is coupled to the surface and consequently the lithosphere of that planet. The percentage of electromagnetic energy coupled to planetary surfaces by atmospheric actions and the net mass movements resulting are of great geological interest. Endogenetic energy passes through the lithospheres of planets as heat and, to a degree, is supposed to be coupled by friction to the bases of their lithospheres. The percentage of internal energy escaping as compared with the percentage coupled and stored in gravitational gradients, or used to rework the lithosphere, is of great geological interest. Comparative data from several planets would lead to a better understanding of Earth processes. The lithosphere of the Earth tends to move toward equilibrium over time intervals of geological magnitude. The surface features are current expressions of the movement toward equilibrium.

The Earth's atmosphere tends to filter incident electromagnetic energy as a function of frequency. A magnetosphere will reflect longer waves, while very short waves such as the ultraviolet band will be absorbed by the atmosphere. The net effect is a series of windows which appear and broaden upward from the surface.

The topography of a planet may be dominated by internally or externally generated forces. Furthermore, the type of internal or external force shaping the surface of a planet may differ. The Earth's airless moon is an example of what may be domination by impact of meteors, planetoids, and particles. The surface of Mars may be dominated by a combination of exogenetic impact structures smoothed by solar energies coupled to them through its thin atmosphere. The Earth is dominated by endogenetically formed continental and oceanic domains. The dominant features of Venus are not known. It is conceivable that a body could have its dominant surface features formed by tidal forces. Lunar tides do shape 4th- and 5th-order geomorphic feature, but these are not dominant features.

Distribution of matter from the base of lithospheres to the centers of planets is thought to be dominated by vertical differentiation resulting from gravitational forces. The only complication would be convective movements in the mantle.

Below planetary lithospheres, exogenetic energies are thought to have little effect with the possible exception of kneading by tidal forces. Tides slow down relative rates of rotations of parent and satellite unless the bodies are perfectly rigid. Tides are thought to be of importance in the triggering of seismic shocks. It has been suggested that convection may store tensional energies in the "stress fluid" below the lithosphere, and that strong tidal forces may periodically cause release of this tension as real movement.

The heat balance of the Earth's atmosphere is treated by what are essentially empirical methods. Most of the work has been done by meteorologists, and because of the vastly greater influence of exogenetic heating, only solar heating is accounted for. An equation is given which is applicable to planetary atmospheres, lithospheres, and mantles. It incorporates terms accounting for exogenetic energy flux, endogenetic energy flux, and temporary storage of potential energy in these zones. It is quite generally applicable. A comparative study of energy flux through, and energy storage in, the lithospheres, as well as the atmospheres, of Venus, Earth, and Mars would be of great value to the formulation of geomorphological theories. This generalized heat balance equation is:

$$\alpha A_p (S + M)(a + b .. + n) - \epsilon A_p (E_r + E_s)(a + b + n) - Q - V = \epsilon T^4 A_s + WC \frac{\partial T}{p \partial t} + K A_s \frac{\partial T}{\partial x}$$

α	=	absorption factor
ϵ	=	emission factor
A_p	=	projected area to exo and endo energy
S	=	exogenetic electromagnetic energy incident on A_p
M	=	endogenetic electromagnetic energy incident on A_p
E_r	=	energy radiated outward through A_p
E_s	=	energy transmitted downward through A_p
(a+b+n)	=	frequencies a to n
T	=	absolute temperature
A_s	=	area of radiator
W	=	weight of heat sink
Q	=	power dissipated internally

V = power stored as kinetic energy

C_p = specific heat of increment

The solid particle flux in the solar system has played an important role in the shaping of the lithospheres of terrestrial type planets (see figure 2). There is a suggestion that the asteroid belts between Mars and Jupiter represent fragments of a planet which broke up early in the history of the solar system. It is further suggested that all planets closer to the sun were bombarded by fragments. The topography of the moon suggests this. The circular features of the surface of Mars suggest similar impacts which have been smoothed by weak erosional forces expressed through at least 3,000,000,000 years. The known features of the surface of Mercury hint at similar craters. Exploration of the surfaces of the moon and Mars -- unmanned or manned -- will perhaps throw further evidence on the question of whether such a cataclysm may have resulted in unifying scars on the features of the inner planets. It might be mentioned here that expressions of ice ages, which seem to recur at intervals of approximately 250,000,000 years, may be found on several planets, and Mars seems to be the best ground for such researches.

Micrometeorites are possible hazards to both unmanned and manned spacecraft. The known concentrations of the inner solar system are (1) concentration immediately about the Earth, (2) Trojan clouds of the Earth/moon system and possible Earth/Mars, Earth/sun, and Mars/sun Trojan concentrations, (3) meteor swarms, (4) bands of the asteroid belt, (5) concentrations with asteroids, and (6) concentrations associated with comets. Micrometeorites can be expected to show a Gaussian distribution down to sizes that are moved by solar winds. At this point, distributions will show skewed curves. These distributions should grade down to sizes which are so small that the particles will have been swept out of the solar system by photon and corpuscular pressures over geological eras.

4.2 Atmospheric Statics

Static characteristics of atmospheres include mean surface pressure, total atmospheric mass, colligative points of atmospheric components, viscosity, composition, albedo, photochemistry, reflectivity, B-field and orientation, E-field and orientation, absorption, transmissivity, and atmospheric and surface temperature (many of these as functions of altitude, latitude, and longitude). This list is imposing but still incomplete. The static character (a condition never seen) of the Earth's atmosphere has not been completely defined.

Measurements of the static characteristics of the Martian and Cytherian atmospheres are of vast importance to every discipline and are prime objectives of the space programs directed toward these planets. Cloud-particle sizes may or may not be a hazard to reentry heat shields. Mean surface pressure on Mars will dictate whether a glide path or retrorocket, manned landing

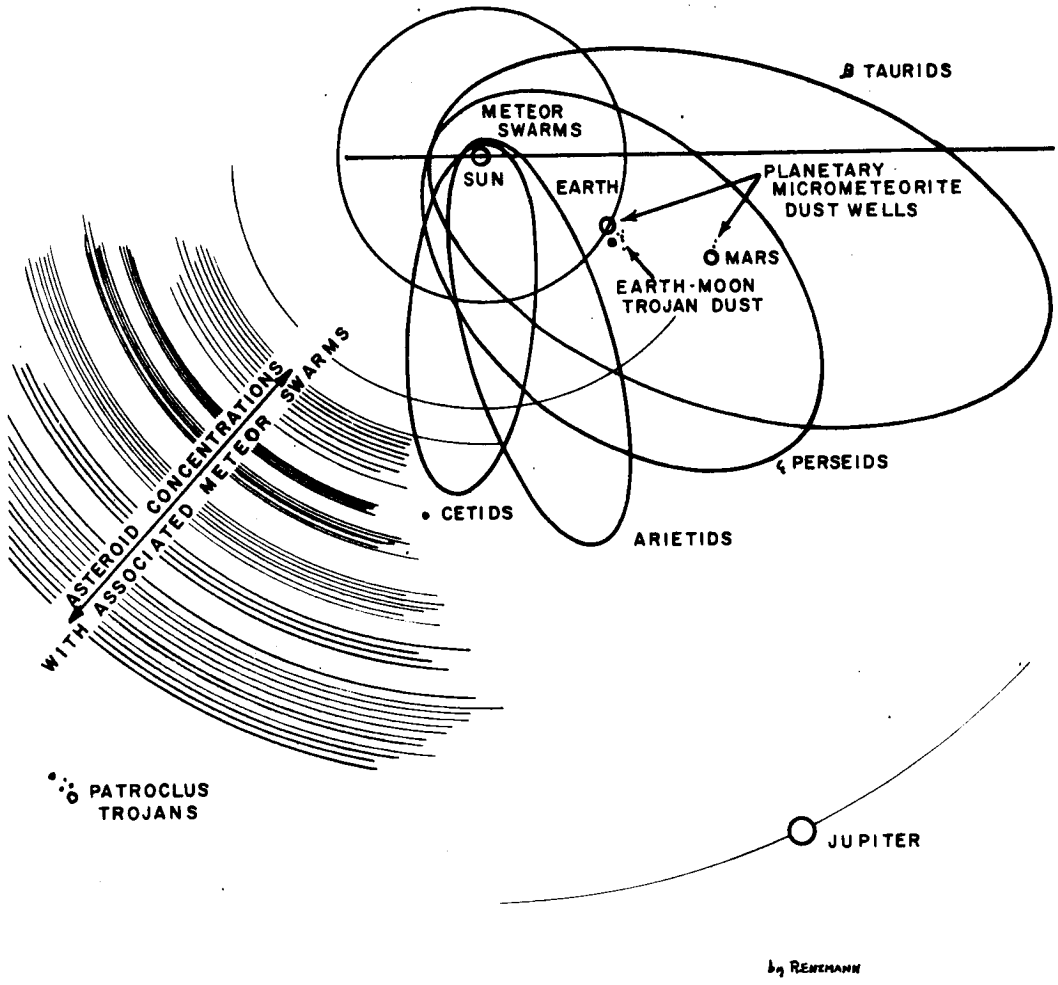


Figure 2 METEOROID DISTRIBUTIONS
63-8443

will be made. The dense Venusian atmosphere, as contrasted to the thinner atmosphere of Mars, will be dominant in the shaping of geomorphological features. On Mars, impact features might still be recognizable billions of years after formation. Mean surface pressure and surface ultraviolet flux will determine whether men can walk about with masks in lieu of pressure suits, and what protection they will need for their eyes and skin.

1. Observations of atmosphere of Mars. Infrared, visible, and ultraviolet telephotos and visual observations of clouds have, to a degree, related these to planetary geometry and surface topography. Estimates of cloud compositions, patterns, and movements have been made. Photometry has afforded estimates of albedo, composition of clouds, composition of the surface, and planetary heat balance. Polarimetry provides a measure of atmospheric pressure at the scattering level, and may indicate the character of the scattering particles. Visual and near infrared spectroscopy yields information on atmospheric composition, temperature, and pressure. Radiometry (infrared flux) makes it possible to determine the effective blackbody temperature of the emitting layer using the 7.5 to 13-micron window in the terrestrial atmosphere. Microwave flux between 3 mm and 70 cm also allows an estimation of effective blackbody temperatures. Radar has been used to indicate planetary rotation and surface roughness.

Mars is believed to have a meteorological situation more closely resembling that of Earth than any other planet in the solar system. Some important similarities and differences have been known for a long time, and others have been observed recently.

By infrared spectroscopy, CO_2 has definitely been identified and is thought to be about 2 percent by volume. H_2O has not been definitely identified but an upper limit on the amount has been placed at 10^{-2} to 10^{-3} gm/cm^2, or about 0.002 of that on Earth. Presumably, the remainder of the atmosphere is N_2 with traces of argon. Among the gases which have been unsuccessfully searched for are O_2, O_3, N_2O, and NO_2.

Atmospheric polarization studies of sunlight reflected from the Martian surface has, among other things, provided an estimated pressure of 90 mb for the surface (Dollfus, 1961). Another estimate based on similar measurements is 100 ± 50 mb. These estimates are approximately 0.1 of the Earth's surface pressure.

Estimates have been made of the solid surface temperature from the infrared flux (radiometry) in the 7.5 to 13-micron terrestrial window. The air temperature near the surface will be higher or lower than the surface temperature, depending on a number of factors among which time of day and nature of the surface are the most important. The following estimates have been made: (1) Mean daytime temperature over the entire disc for all seasons is approximately 240°K; (2) The warmest recorded temperature is ~300°K; (3) The diurnal

variation at the equator is ~55 to 90°K; and (4) A typical midlatitude seasonal variation is ~60°K. One radiometer's measurement of the equator-to-pole temperature gradient in the northerm hemisphere winter is 60°K. There may be a reversal of the gradient in the summer or at night. Detailed temperature maps have been made with a resolution of approximately 300 km. In the vertical, the temperature may decrease at the adiabatic rate (3.7°K km^{-1}) or less to a tropopause and then decrease at a lower rate above.

From photometry measurements, the albedo is estimated to be 0.05 in the ultraviolet, 0.12 in the visible (dark areas), and 0.15 in the visible (bright areas). The integrated bolometric albedo is 0.26.

The amount of cloud cover over the planet is, on the average, much less than over the Earth. There have been extensive visual observations which have resulted in the following division: (1) white clouds, (2) yellow clouds, and (3) blue haze. This color division is also indicative of their difference in composition. Polarization measurements on the white clouds resemble those on hoarfrost so there is speculation that they are composed of ice crystals. The yellow clouds are seen to arise over bright areas many times, and this has led to the speculation that they are desert dust storms. The blue haze is observed only in the blue-violet and continuously covers the whole planet except for occasional planet-wide breaks. This haze is thought to be due to scattering or absorption by particulate matter suspended in the atmosphere. The heights of the blue haze and white cloud may be of the order of 10 km while the yellow clouds should be lower.

The patterns and motions of the white clouds are quite variable. Efforts to imagine some sort of Earth-like air circulation from their patterns are successful at times and not at others. The clouds sometimes remain motionless for days and other times move with speeds up to approximately 25 m sec^{-1}. One explanation of all this is that due to certain factors, the most important of which may be the large diurnal range of temperature, the general circulation of Mars is appreciably different from that of the Earth despite other factors which suggest similarity. Another possibility is that the paucity of clouds prohibits them from being an adequate tracer of large-scale atmospheric circulation.

The large diurnal range of temperature (~55 to 90°K at the equator) compared with that of the Earth (~10 to 15°K), the low upper limit placed on the water vapor content, and the relatively small amount of clouds are convincing evidence that the atmosphere is much more transparent to infrared radiation than that of the Earth. A "greenhouse" radiative temperature model therefore does not apply. Most of the visible radiation from the sun probably reaches the surface. A large amount of solar ultraviolet also may reach the surface because of the apparent absence of O_3 in the atmosphere.

2. Observations of atmosphere of Venus. The slow rotation of this planet will probably result in a simple convective circulatory regime with complications due to turbulence. Knowledge of what is probably a simple circulation regime will make it easier to understand the more complicated regime on Earth. The results on the rotation of Venus so far are ambiguous. Most measurements indicate a slow rotation compared to Earth, but some suggest a rapid rotation. With the use of radar, JPL reports (from experiments at the 1962 inferior conjunction) a rotation of 230 days retrograde. The theory of a simple convective circulation between the subsolar and antisolar points of Venus is dependent upon a slow rotation rate. There is uncertainty also on the inclination of the equatorial plane to the orbital plane. Observations of apparent atmospheric cloud weather bands at visual wavelengths suggest a mean inclination of 23 degrees (Earth: $\sim$25 degrees). Infrared observations suggest smaller inclinations, and at least one interpretation of radar observations suggests very large inclinations. The orbital eccentricity (0.0068) is the smallest of the main planets, and therefore, the length of seasons (if present) will be equal.

By near infrared spectroscopy, CO_2 has been identified and is estimated to occupy from 2 to 10 percent by volume of the Cytherian atmosphere. N_2 is presumably the most abundant gas. There are disputed identifications of O_2 and CO. Searches for water vapor are inconclusive: a single balloon observation at 1.13 microns gives 2×10^{-3} gm-cm^{-2} above the clouds with a large probable error, while negative results at 8180 A give an H_2O volume mixing ratio of $<10^{-5}$ down to the 5.6 atm pressure level. There have been unsuccessful infrared searches for N_2O, NO_2, CH_4, and NH_3, among others. Mariner I indicates surface pressures of 20 to 30 atmospheres. By polarimetry, the visual cloud-top pressure on the sunlit side is estimated at 0.1 to 1 atm.

Microwave emission of assumed thermal genesis indicates a surface temperature of $\sim$800°K on the sunlit side and $\sim$650°K on the dark side. Infrared flux at 3.75 microns gives 236 $\pm$8°K in the dark hemisphere at the cloud-top level. In the 7.5 to 13-micron window, the flux gives 234 $\pm$5°K at the cloud-top level in both the sunlit and dark hemispheres. In this wondow, there appears to be a 20 to 30°K decrease in the temperature from the equator to the pole at the cloud-top level. Based on a predominantly N_2 atmosphere, the adiabatic lapse rate should be 7 to 9°K km^{-1}.

From photometric measurements are obtained the following results for the albedo of Venus: in the ultraviolet, 0.5; in the visual, 0.8; integrated bolometric, 0.75. This compares with a mean of $\sim$0.4 for the Earth.

The visual cloud cover of Venus seems to be complete and continuous. Nuances of structure are visible but are very difficult to follow for any length of time. One apparently successful attempt at this indicates a cellular pattern of clouds, quasi-symmetrical about the subsolar point. This would be evidence favoring a simple convective, general circulation between the subsolar and antisolar points. Temporary increases in the 7.5 to 13-micron radiation suggest

breaks in the cloud cover. Mariner II saw no breaks in cloud. Polarimetry indicates that the clouds are composed in part of transparent particles in the micron-size range. There is disputed spectroscopic evidence of ice crystals $(C_3O_2)_n$ and carbonate dust. The top of the visible cloud layer has been variously estimated between very low and high altitudes, but present estimates are restricted between 30 and 90 km. It is considered to be up to 20 km thick with possibly more than one layer. The difficulty in following the nuances in cloud structure from Earth makes it impossible to deduce wind speeds from cloud motions in the visible.

Of the solar radiation, the infrared is probably absorbed by CO_2 and H_2O; the visible and ultraviolet is probably depleted by scattering. Some of the visible may reach surface through breaks in the clouds. The outgoing infrared radiation from the surface directly to space depends on whether the greenhouse or aeolosphere model is assumed. With the greenhouse model, some emission should occur in CO_2 or H_2O windows, especially where there are breaks in the clouds. With the aeolosphere model, no such emission is expected. Either way the transmissivity appears to be considerably different from that of the Earth.

3. Atmospheric composition models. This section comprises a detailed analysis of static atmosphere models. This work, carried out by Dr. Hiroshi Kamiyama, presents detailed calculations of the structures of the atmospheres of Mars and Venus, including vertical distributions of gases, ions, and electrons.

a. Fundamental equations of hydrostatic equilibrium. Assuming that there is no movement, the atmospheric pressure p is given by the hydrostatic equation,

$$dp = -g\rho dh \tag{1}$$

in which g denotes the gravitational acceleration of a planet, h the height measured from the surface, and ρ is the density defined by

$$\rho = n_1 m_1 + n_2 m_2 + \dots = \Sigma_i n_i m_i \equiv nm , \tag{2}$$

where n_i and m_i denote, respectively, the particle concentration and the mass of the i-th gas, n the total concentration, and m the mean molecular mass. If it is valid to apply the ideal gas law

$$p = nkT \tag{3}$$

where T is the absolute temperature and k Boltzmann's constant, we can write the general equation in the following form:

$$\frac{dp}{p} = \frac{dn}{n} + \frac{dT}{T} = -\frac{dh}{H} \tag{4}$$

in which H denotes the local scale height and is defined by

$$H = \frac{kT}{mg} \quad . \tag{5}$$

If complete mixing exists in the planetary atmosphere, the various gases remain in the same proportions, and the mean molecular mass is a constant. Assuming a mean value of g in a layer of definite thickness considered, we may write

$$\frac{dT}{T} = \frac{dH}{H} \tag{6}$$

and from (4)

$$\frac{dn}{n} = -\frac{dH + dh}{H} \quad . \tag{7}$$

In a region where the diffusive equilibrium is attainable, the total pressure p is defined by

$$p = p_1 + p_2 + \cdots = \Sigma_i p_i \tag{8}$$

and the partial pressure p_i is given by

$$\frac{dp_i}{p_i} = -\frac{dh}{H_i} \quad , \tag{9}$$

where

$$H_i = \frac{kT}{m_i g} \quad . \tag{10}$$

In a certain region where the scale height is assumed to vary linearly with height, β being a constant,

$$H = H_o + \beta H \quad . \tag{11}$$

Then we have

$$\frac{dp}{p} = -\frac{1}{\beta}\frac{dH}{H} \tag{12}$$

and

$$\frac{dn}{n} = -\frac{1+\beta}{\beta}\frac{dH}{H} \quad . \tag{13}$$

Integrating (12 and 13),

$$p = p_o \left(\frac{H}{H_o}\right)^{-1/\beta} \tag{14}$$

and

$$n = n_o \left(\frac{H}{H_o}\right)^{-(1+\beta)/\beta} \quad , \tag{15}$$

where suffix o indicates the values at the starting point.

In the region where the scale height (or the temperature) is assumed to be constant, the pressure and the concentration are given from (4) by

$$p = p_o \exp\left(-\frac{h}{H}\right) \tag{16}$$

and

$$n = n_o \exp\left(-\frac{h}{H}\right) \quad . \tag{17}$$

b. Diffusion. In a high atmosphere on the planets, the constituent gases distribute according to the diffusive equilibrium because of the low pressure of the atmosphere. It is, of course, not yet possible to inquire into this problem in detail. It is, however, necessary to take account of the diffusional effect in the high atmosphere.

Considering the diffusion of a minor constituent, the concentration of which is n_1 and the vertical diffusion velocity of which is w_1, we may write a general equation

$$n_1 w_1 = -D\left[\frac{\partial n_1}{\partial h} + n_1\left(\frac{1}{T}\frac{\partial T}{\partial h} + \frac{m_1 g}{kT}\right)\right] \tag{18}$$

in which D is the diffusion coefficient and is given by

$$D = \frac{3}{4}\frac{1}{(8\pi)^{1/2}\sigma^2}\left(1 + \frac{m}{m_1}\right)^{1/2}\frac{g^{1/2}H^{1/2}}{n} \tag{19}$$

where σ is the collisional diameter of the particle and is taken to be about 3×10^{-8} cm for the gases such as nitrogen or oxygen. If, in the initial condition, the minor constituent is mixed completely, (18) is written, using (6) and (11), as follows

$$w_1 = -D\left[\frac{1}{n_1}\frac{\partial n_1}{\partial h} + \left(\beta + \frac{m_1}{m}\right)\frac{1}{H}\right] \tag{20}$$

For the completely mixing atmosphere, we can write

$$\frac{1}{n_1}\frac{\partial n_1}{\partial h} \equiv \frac{1}{n}\frac{\partial n}{\partial h} = -\frac{1+\beta}{H}, \tag{21}$$

so that equation (20) becomes in a simple form as follows

$$w_1 = \left(1 - \frac{m_1}{m}\right)\frac{D}{H} . \tag{22}$$

Then the vertical diffusion velocity has the final form

$$w_1 = 1.66 \times 10^{14}\left(1 + \frac{m}{m_1}\right)^{1/2}\left(1 - \frac{m_1}{m}\right) n^{-1} g^{1/2} H^{-1/2} . \tag{23}$$

Thus, in an atmosphere which is uniform in composition, the heavier particles ($m_1 > m$) diffuse downward and the lighter particles ($m_1 < m$) diffuse upward. In order to maintain permanent mixing in the atmosphere, there must be at least, with an appropriate interval, some mixing effects the vertical velocity of which w_m is larger than w_1.

c. Vertical distribution of the particle concentration in a homogeneous atmosphere. Although there should be some changes in the composition of the atmosphere due to some photochemical processes and the diffusional separation of the gases, it is useful to illustrate the vertical distribution of the particle concentration on the assumption that the atmosphere is homogeneous. After this first approximation, we will be able to consider the photochemical and/or dynamical processes, and build up a more reliable model of the atmosphere by means of trial-and-error.

According to the results derived from the observations, it is assumed that air is composed of 2.2 percent CO_2 and 97.8 percent N_2 on the surface of Mars, and of 20 percent CO_2 and 80 percent N_2 on Venus. Then, the mean molecular mass defined by (2) is 4.75×10^{-23}gr in the Martian atmosphere, and 5.22×10^{-23} gr in Venus atmosphere.

1) Mars. For simplicity, we use a constant value of 345 cm-sec^{-2}, which corresponds to the value at $h = 150$ km, for g, and assume the linear distribution of temperature as follows

$$T = T_o + \gamma h$$

where γ is taken to be -3.7°K/km between $h = 0$ and 10 km, -1.25°K/km between $h = 10$ and 90 km, -1.4°K/km between $h = 90$ and 130 km, and 5°K/km between $h = 130$ and 400 km, while T_o is the temperature at each boundary. At $h = 0$, T_o is assumed to be 270°K at the subsolar point. Then, we can estimate the vertical distribution of particle concentration by use of (5). The pressure is given by the ideal gas law (3). The calculated results are illustrated in figure 3 by the full line.

2) Venus. The information available for the conditions on Venus is much less accurate than on Mars. Then, it would be useful to estimate the vertical distribution of concentration or pressure in the two extreme cases.

a) Model I. The temperature on the surface is assumed to be 580°K. The lapse rate of the temperature is -8.8°K/km (for the air composed of 20 percent CO_2 and 80 percent N_2). Then, the temperature is 228°K at the altitude of 40 km corresponding to the location of the tops of the observed clouds. The pressure at this height is assumed to be 90 mb. Above this altitude, the temperature is assumed to be constant. The constant value of gravity, 8.35×10^2 cm-sec^{-2} which corresponds to that at the height of 150 km above the surface, is assumed throughout the atmosphere. This model corresponds to the Greenhouse model and Aeolosphere model.

b) Model II. The temperature is assumed to be 315°K on the surface and 227°K at the height of 10 km, where the top of the clouds is observed and the pressure is estimated to be 90 mb. It is assumed that the

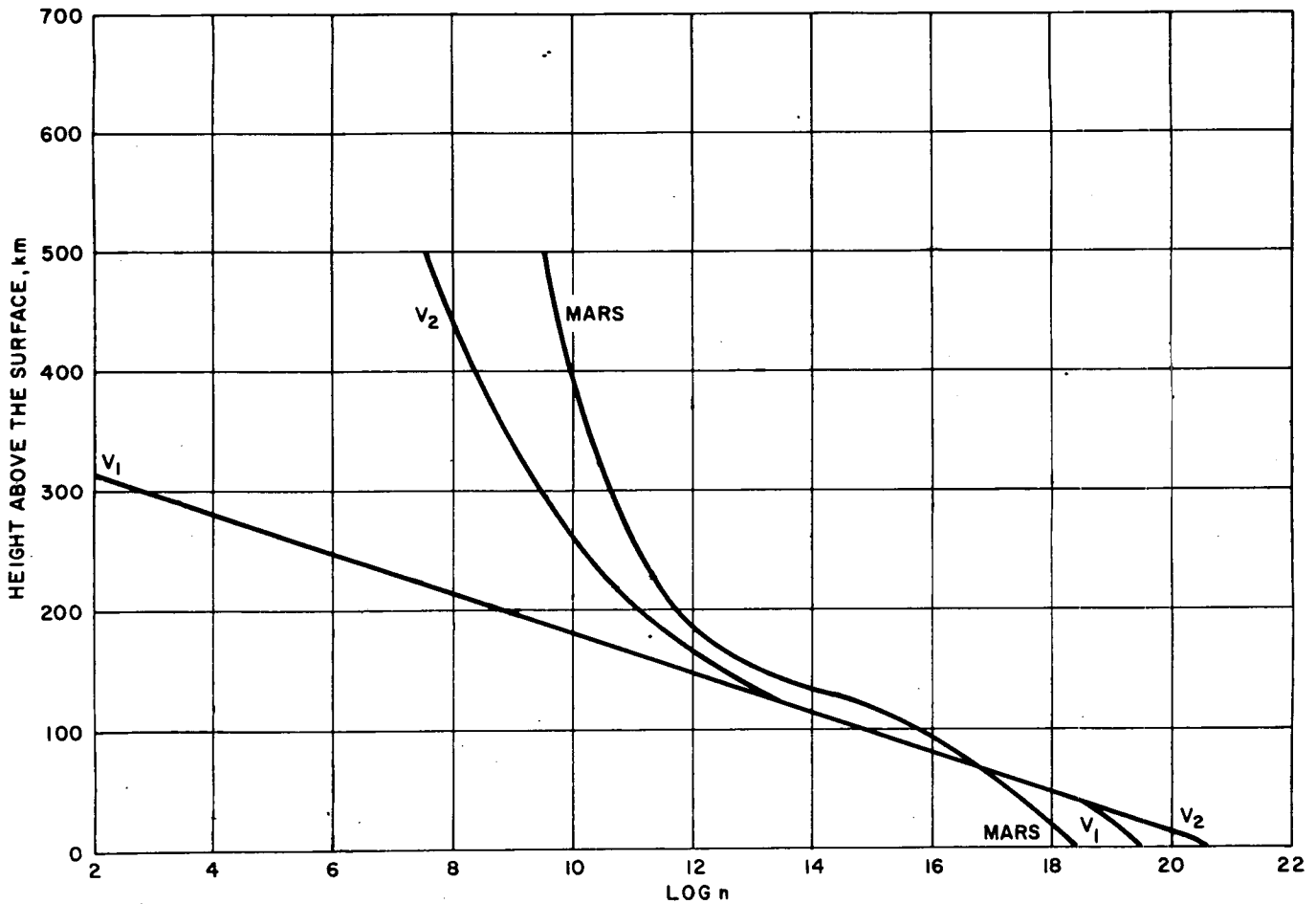


Figure 3 VERTICAL DISTRIBUTION OF NEUTRAL GAS CONCENTRATIONS
63-9219

temperature is constant in a region between 10 and 100 km, and increases with the linear height-gradient of 5°K/km up to 500 km. This model may correspond to the so-called Ionosphere model.

The calculated results are shown together in figure 3. According to the Aeolosphere model, the pressure in the lowermost region might be multiplied by a factor of 2 or more, because of the presence of large amounts of dust. This represents one of the extreme cases of the atmosphere in a lower region, whereas the Model II may be the other extreme case, because we have assumed that the top of the cloud is very close to the surface. On the other hand, in a region above 100 km, Model I may be one of the extreme (low) cases because of a constant low temperature, whereas Model II may be the other extreme (high) because of the rapidly increasing temperature.

d. Photochemical equilibrium. Possible primary photodissociations due to the solar radiation in an air composed of N_2, CO_2, and H_2O are as follows:

$$H_2O + h\nu\ (\lambda < 1850\,A) \rightarrow OH + H \text{ (with rate coefficient)}, \qquad (J\,24) \qquad (24)$$

in which the absorption cross section is $4 \times 10^{-18} cm^2$ at λ 1700 A and 6×10^{-18} cm^2 at λ 1200 A, and

$$CO_2 + h\nu\ (\lambda < 1692\,A) \rightarrow CO + O \qquad (J\,25) \qquad (25)$$

with the absorption cross section of about $10^{-19} cm^2$ just on the short wavelength side of the dissociation limit. N_2 is very difficult to photodissociate, but the photoionization process

$$N_2 + h\nu\,(\lambda < 796\,A) \rightarrow N_2^+ + e \qquad (J\,26) \qquad (26)$$

is followed by the dissociative recombination

$$N_2^+ + e \rightarrow N' + N''\,. \qquad (\alpha\,27) \qquad (27)$$

These reactions are followed by the secondary processes:

$$OH + O \rightarrow H + O_2 \qquad (\alpha\,28) \qquad (28)$$

$$O + O + M \rightarrow O_2 + M \qquad (\beta\,29) \qquad (29)$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (\beta 30) \qquad (30)$$

$$O_3 + O \rightarrow 2\,O_2 \qquad (\alpha 31) \qquad (31)$$

$$H + O_3 \rightarrow OH + O_2 \qquad (\alpha 32) \qquad (32)$$

$$H + O_2 + M \rightarrow HO_2 + M \qquad (\beta 33) \qquad (33)$$

$$HO_2 + O \rightarrow OH + O_2 \qquad (\alpha 34) \qquad (34)$$

$$H + OH + M \rightarrow H_2O + M \qquad (\beta 35) \qquad (35)$$

$$H + HO_2 \rightarrow H_2O + O \qquad (\alpha 36) \qquad (36)$$

$$CO + O + M \rightarrow CO_2 + M \qquad (\beta 37) \qquad (37)$$

$$CO + OH \rightarrow CO_2 + M \qquad (\alpha 38) \qquad (38)$$

$$CO + HO_2 \rightarrow CO_2 + OH\,. \qquad (\alpha 39) \qquad (39)$$

Some of the secondary compounds are also dissociated by the absorption of the solar radiation as follows:

$$O_2 + h\nu\,(\lambda < 1760A) \rightarrow O(^3P) + O\,(^1D) \qquad (J\,40) \qquad (40)$$

$$O_2 + h\nu\,(\lambda < 2420A) \rightarrow 2O\,(^3P) \qquad (J\,41) \qquad (41)$$

$$O_3 + h\nu\,(\text{Hartley continuum}) \rightarrow O_2 + O(^1D) \qquad (J\,42) \qquad (42)$$

$$O_3 + h\nu\,(\text{Chappuis continuum}) \rightarrow O_2 + O\,(^3P) \qquad (J\,43) \qquad (43)$$

Because of the relatively small amount of H_2O on both planets, the atmospheric structure, in a first approximation, can be illustrated by the reactions (25), (29), (37) and (40). (The photodissociation (41) is very weak compared with (40) when the amount of O_2 is small.) Because the rate coefficient for reaction (37) is much smaller than that for (29), we have, in the equilibrium state,

$$J25\,(CO_2) = \beta 37\,(CO)\,(O)\,(M)\ , \tag{44}$$

$$J40\,(O_2) = \beta 29\,(O)^2\,(M)\ . \tag{45}$$

Since J25 and J40 are the functions of the amount of CO_2 and O_2 above the height considered, the solutions are very complicated even if it is assumed that there was no diffusional motion.

Under such an assumption, using the following relations,

$$(CO) = (O) + 2\,(O_2) \tag{46}$$

and

$$(CO_2) + (CO) = \text{constant} = r(M)\ , \tag{47}$$

where r is the mixing ratio of carbon dioxide, we have

$$(CO_2) + 2(O_2) + \left\{\frac{J40\,(O_2)}{\beta 29}\right\}^{1/2} = r(M) \tag{48}$$

and

$$(CO_2) + \frac{J25\,(CO_2)}{37\,(M)}\left\{\frac{\beta 29\,(M)}{J40\,(O_2)}\right\}^{1/2} = r\,(M) \tag{49}$$

in which J25 and J40 are given by

$$J25 = \int_0^{1692A} I_{o\lambda}\,\sigma_{25.\lambda}\,\exp(-\chi)\,d\lambda \tag{50}$$

and

$$J40 = \int_0^{1760A} I_{o\lambda}\, \sigma_{40.\lambda} \exp(-X)\, d\lambda \quad , \tag{51}$$

where

$$X = \sigma_{25.\lambda} \int_h^{\infty} (CO_2)\, dh + \sigma_{40.\lambda} \int_h^{\infty} (O_2)\, dh \quad . \tag{52}$$

The calculated results for the photochemical equilibrium are illustrated in figure 4 for Mars and figure 5 for Model I of Venus.

e. Atmospheric diffusion and ionization. Now, we can make some estimations concerning diffusion. In a region where the vertical velocity due to the diffusion is very large, the photochemical equilibrium should be modified by transport of particles.

To estimate the height above which the diffusion is more effective than the photochemical processes, we define the recombination time, τ_{rec} and the diffusion time, τ_{dif} as follows:

$$\tau_{rec\ O} = \frac{1}{\{\beta 37\ (CO) + \beta 29\ (O)\}\ (M)} \quad \text{(for O)} \tag{53}$$

$$\tau_{rec\ CO} = \frac{1}{\beta 29\ (O)\ (M)} \quad \text{(for CO)} \tag{54}$$

$$\tau_{dif} \simeq \frac{H}{2w_1} \quad . \tag{55}$$

The calculated results for these times are illustrated in figure 6 for Mars, and in figure 7 for Model I of Venus. The rate coefficients are assumed to be independent of temperature and the following values are used

$$\beta 29 = 10^{-32}\ cm^6\ sec^{-1}$$

and

$$\beta 37 = 10^{-36}\ cm^6\ sec^{-1} \quad .$$

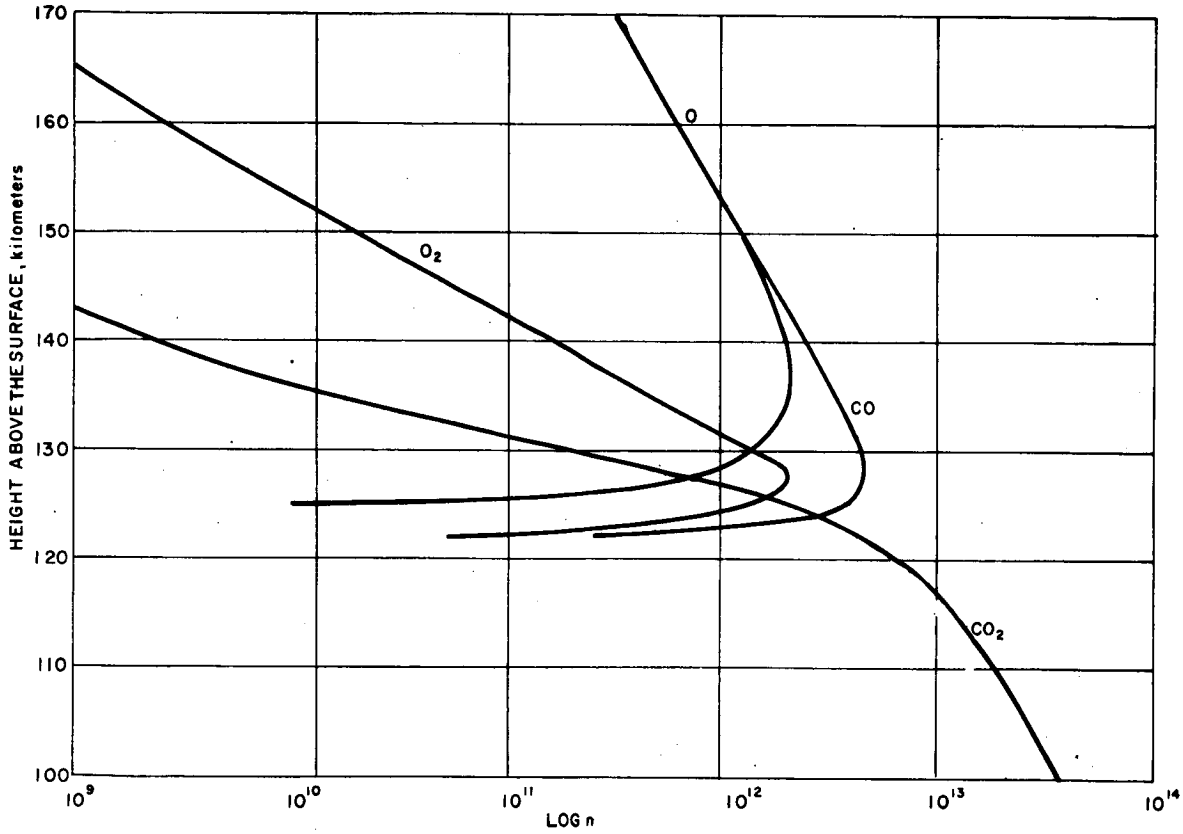


Figure 4 PHOTOCHEMICAL EQUILIBRIUM IN ATMOSPHERE OF MARS
63-9220

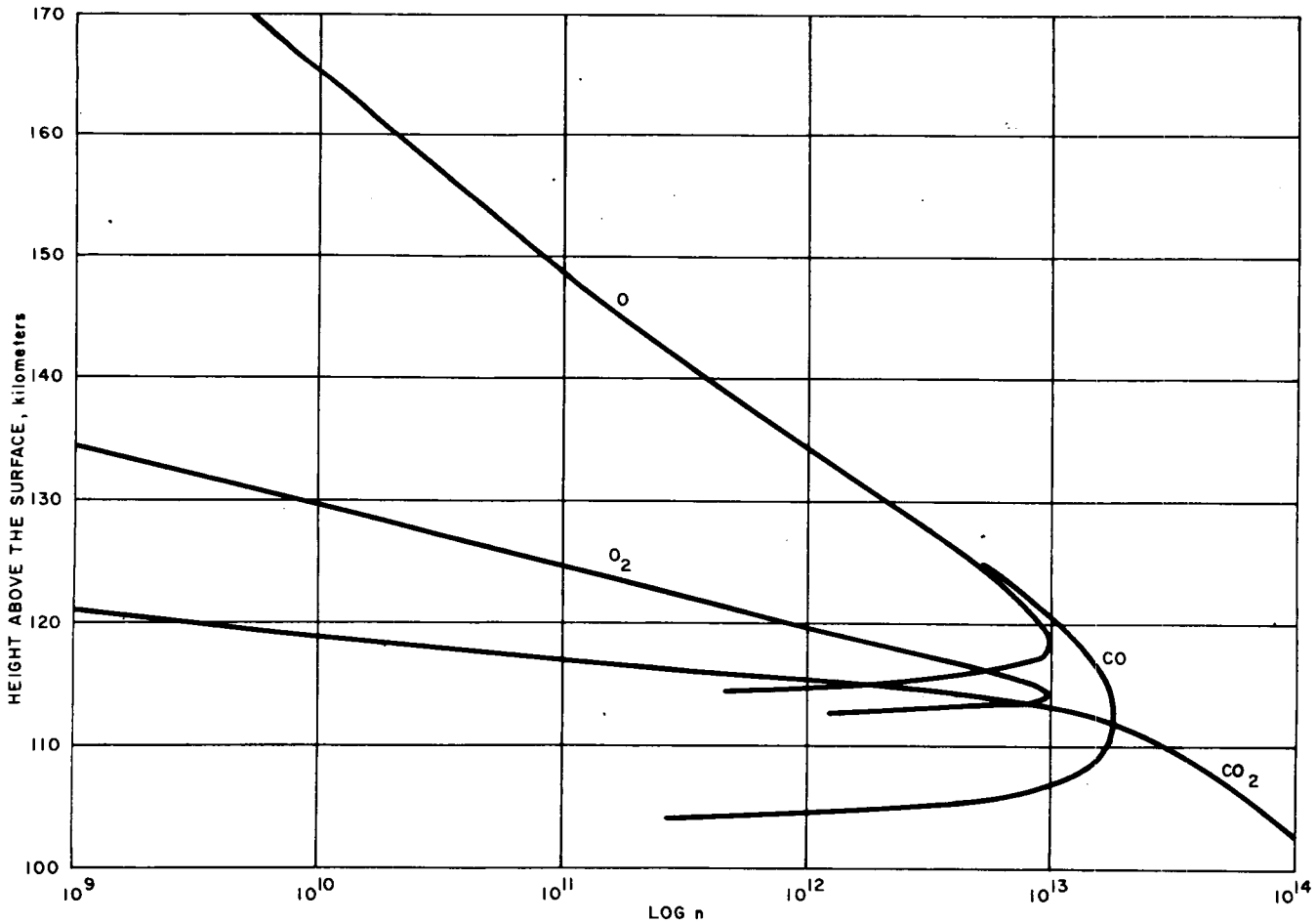


Figure 5 PHOTOCHEMICAL EQUILIBRIUM IN ATMOSPHERE OF VENUS - MODEL I
63-9221

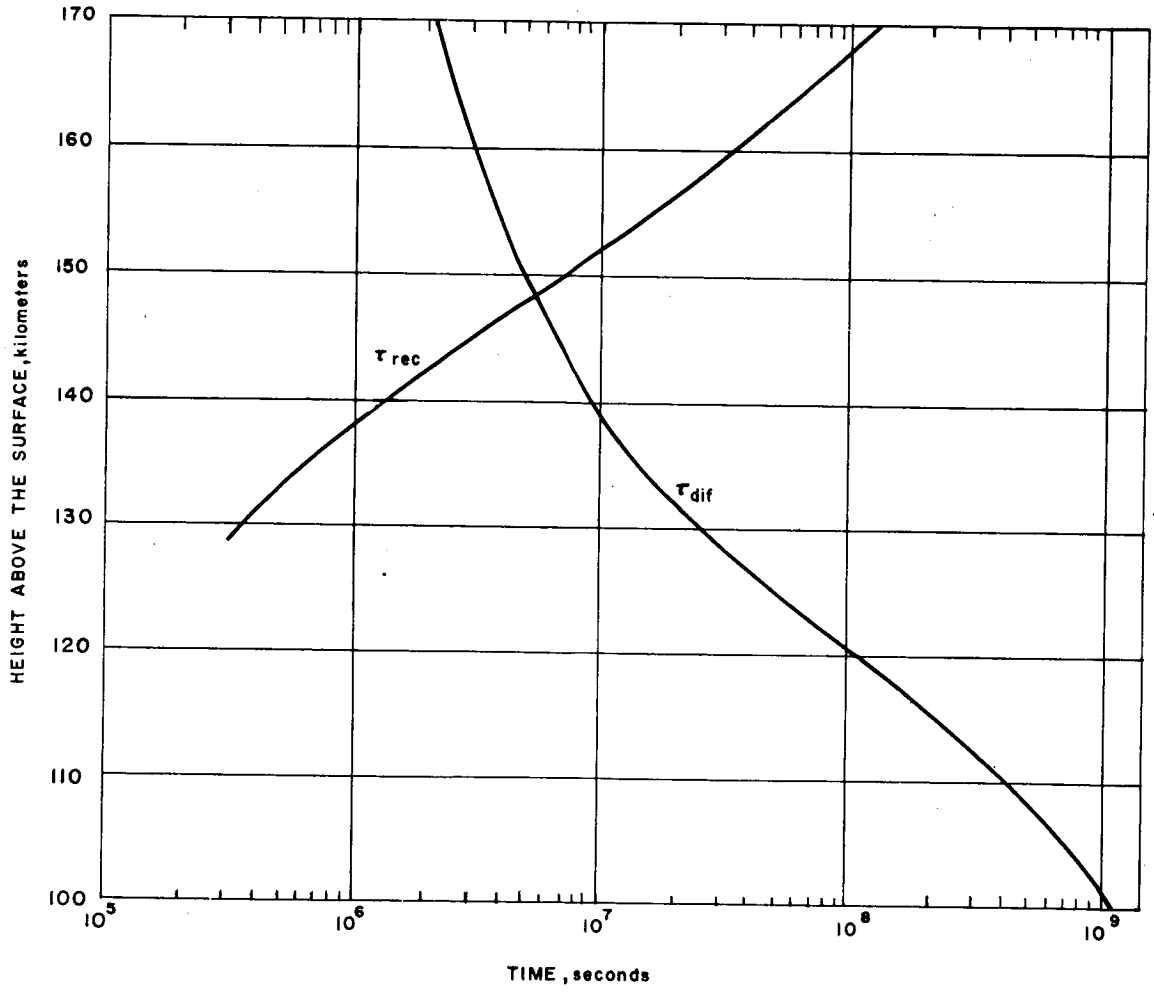


Figure 6 RECOMBINATION AND DIFFUSION TIMES FOR ATMOSPHERE OF MARS
63-9222

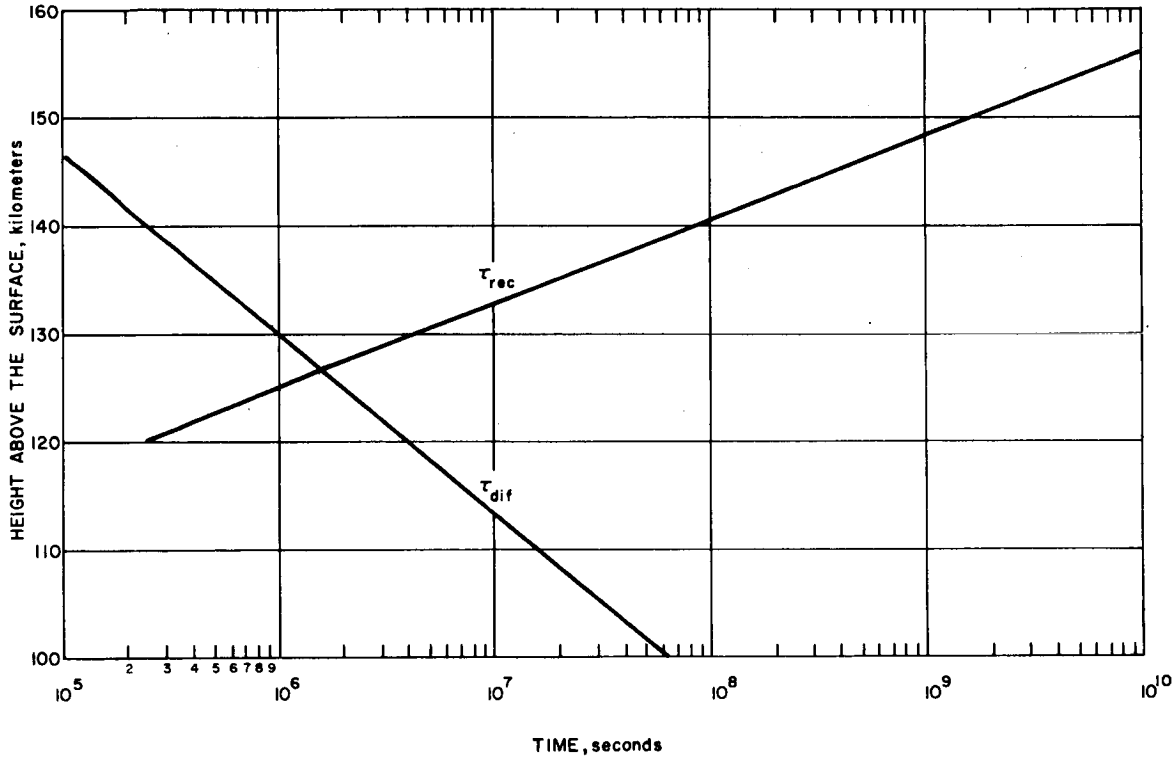


Figure 7 RECOMBINATION AND DIFFUSION TIMES FOR ATMOSPHERE OF VENUS--MODEL I
63-9223

From the results for r_{dif} and r_{rec}, it is reasonable to assume that the composition of the Martian atmosphere is governed by the photochemical reactions below 150 km and by the diffusive equilibrium above this level. The corresponding level on Venus is about 130 km in Model I, and 170 km in Model II.

In the region above this level, the vertical distributions of each constituent may be expressed by

$$n_i = n_{io} \left(\frac{H_i}{H_{io}}\right)^{-(1+\beta_i)/\beta_i} \tag{56}$$

for the atmosphere with a constant gradient of scale height, β_i, and by

$$n_i = n_{io} \exp -\left(\frac{h}{H_i}\right) \tag{57}$$

for the isothermal atmosphere in which n_i is the concentration of the i-th constituent, n_{io} the value at the base of the diffusive region, and H_i the scale height for the i-th constituent.

f. Ion composition. Some of the atmospheric gases are ionized by the absorption of the solar radiations

$$O = h\nu\ (\lambda < 796A) \rightarrow O^+ + e \text{ (with the rate coefficient J1)} \tag{58}$$

$$O_2 + h\nu\ (\lambda < 1027A) \rightarrow O_2^+ + e \text{ (with the rate coefficient J2)} \tag{59}$$

$$N_2 + h\nu\ (\lambda < 911A) \rightarrow N_2^+ + e \quad . \tag{60}$$

The atomic oxygen ion through (58) can transfer its charge to molecules due to an ion-atom interchange process

$$O^+ + O_2 \rightarrow O + O_2^+ \text{ (rate: k1)} \tag{61}$$

$$O^+ + N_2 \rightarrow O + NO^+ \text{ (rate: k2)} \quad . \tag{62}$$

These positive ions are followed by the following recombination processes

$$O^+ + e \rightarrow O + h\nu \qquad (\alpha 1) \tag{63}$$

$$O_2^+ + e \rightarrow O' + O'' \qquad (\alpha 2) \tag{64}$$

$$N_2^+ + e \rightarrow N' + N'' \qquad (\alpha 3) \tag{65}$$

$$NO^+ + e \rightarrow N' + O' \quad . \qquad (\alpha 4) \tag{66}$$

For simplicity, if we neglect the ambipolar diffusion, the electron concentration (e) is given by

$$\frac{d(e)}{dt} = J1(O) + J2(O_2) + J3(N_2) - \{\alpha 1(O^+) + \alpha 2(O_2^+) + \alpha 3(N_2^+) + \alpha 4(NO^+)\}(e) \quad , \tag{67}$$

where ( ) means the number density of the particles indicated. In the equilibrium,

$$(e) = \frac{J1(O) + J2(O_2) + J3(N_2)}{\alpha 1(O^+) + \alpha 2(O_2^+) + \alpha 3(N_2^+) + \alpha 4(NO^+)} \equiv \frac{Q}{\beta e} \tag{68}$$

where

$$Q = J1(O) + J2(O_2) + J3(N_2) \tag{69}$$

and

$$\beta e = \alpha 1(O^+) + \alpha 2(O_2^+) + \alpha 3(N_2^+) + \alpha 4(NO^+) \quad . \tag{70}$$

β is called the effective attachment coefficient.

The concentration of atomic oxygen ion (O^+) is given by

$$\frac{d(O^+)}{dt} = J1(O) - k1(O^+)(O_2) - k2(O^+)(N_2) - \alpha 1(O^+)(e) \quad . \tag{71}$$

In the equilibrium condition,

$$(O^+) = \frac{J1\,(O)}{k1\,(O_2) + k2\,(N_2) + \alpha 1\,(e)} \quad . \tag{72}$$

For the concentrations of molecular oxygen ion, molecular nitrogen ion and nitric monoxide ion, we have, in a similar way,

$$\frac{d\,(O_2^+)}{dt} = J2\,(O_2) + k1\,(O^+)\,(O_2) - \alpha 2\,(O_2^+)\,(e) \tag{73}$$

$$(O_2^+) = \frac{J2\,(O_2) + k1\,(O_2)\,(O^+)}{\alpha 2\,(e)} \tag{74}$$

$$\frac{d\,(N_2^+)}{dt} = J3\,(N_2) - \alpha 3\,(N_2^+)\,(e) \quad , \tag{75}$$

$$(N_2^+) = \frac{J3\,(N_2)}{\alpha 3\,(e)} \tag{76}$$

$$\frac{d\,(NO^+)}{dt} = k2\,(O^+)\,(N_2) - \alpha 4\,(NO^+)\,(e) \tag{77}$$

$$(NO^+) = \frac{k2\,(O^+)\,(N_2)}{\alpha 4\,(e)} \quad . \tag{78}$$

These ion concentrations with height are shown in figure 8 and 9.

In order to know the electron concentration, we may use the relation

$$(e) = (O^+) + (O_2^+) + (N_2^+) + (NO^+) \quad , \tag{79}$$

which means the electrical neutrality of the ionosphere. In expression (72), $\alpha 1\,(e)$ can be safely neglected compared with $\{k1\,(O_2) + k2\,(N_2)\}$ up to the altitude where concentrations of O_2 and N_2 are very small compared with that of O. Therefore, putting (74), (76), and (78) into (79), we have

$$(e)^2 - (O^+)\,(e) - (O^+)\left\{\frac{k1\,(O_2)}{\alpha 2} + \frac{k2\,(N_2)}{\alpha 4}\right\} - \left\{\frac{J2\,(O_2)}{\alpha 2} + \frac{J3\,(N_2)}{\alpha 3}\right\} = 0 \quad . \tag{80}$$

Then we have

$$(e) = \frac{(O^+) + \{(O^+)^2 + 4\phi\}^{1/2}}{2} \tag{81}$$

where

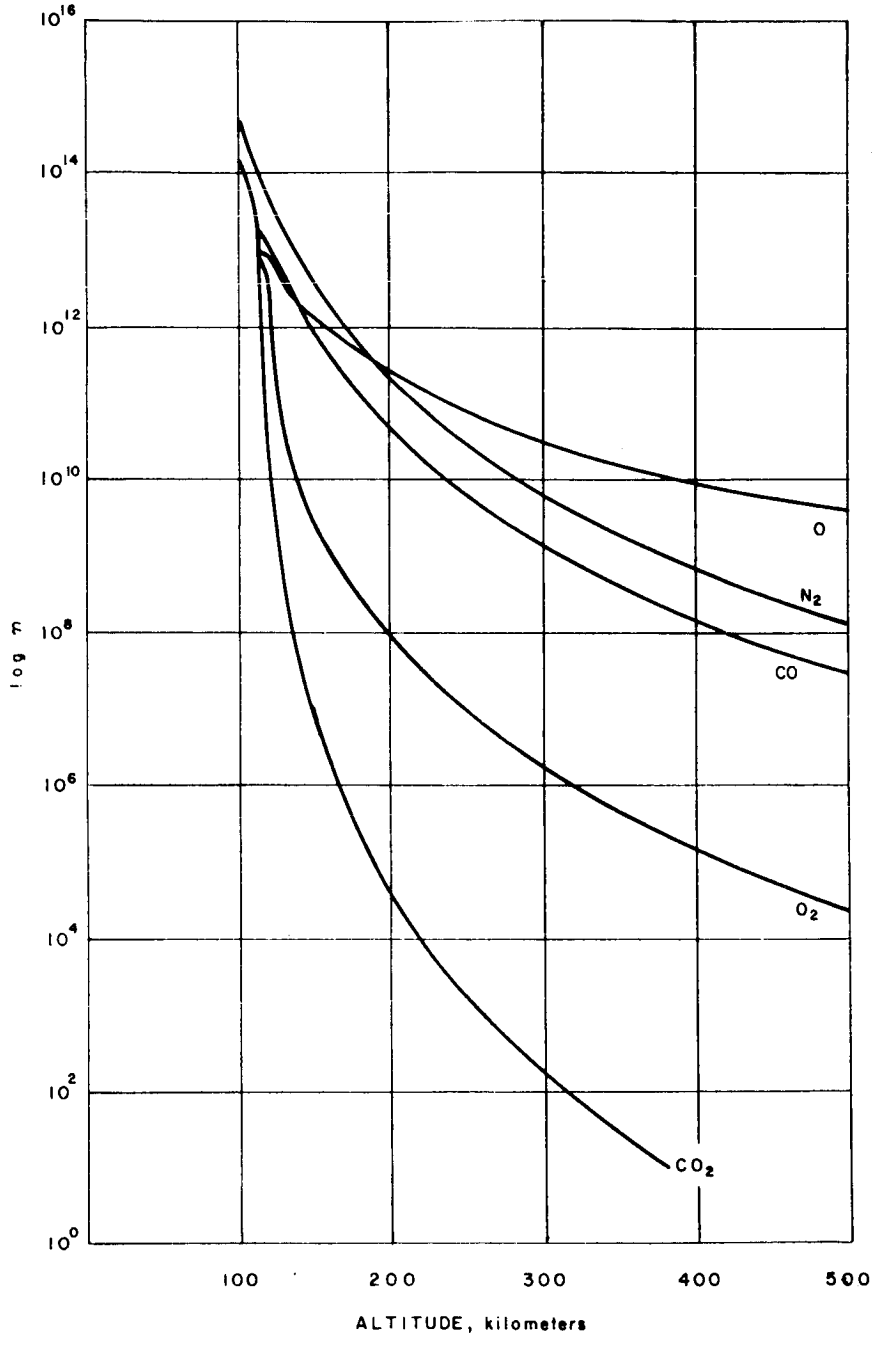


Figure 8 VERTICAL DISTRIBUTION OF ATMOSPHERE CONSTITUENTS -- VENUS MODEL II
63-9289

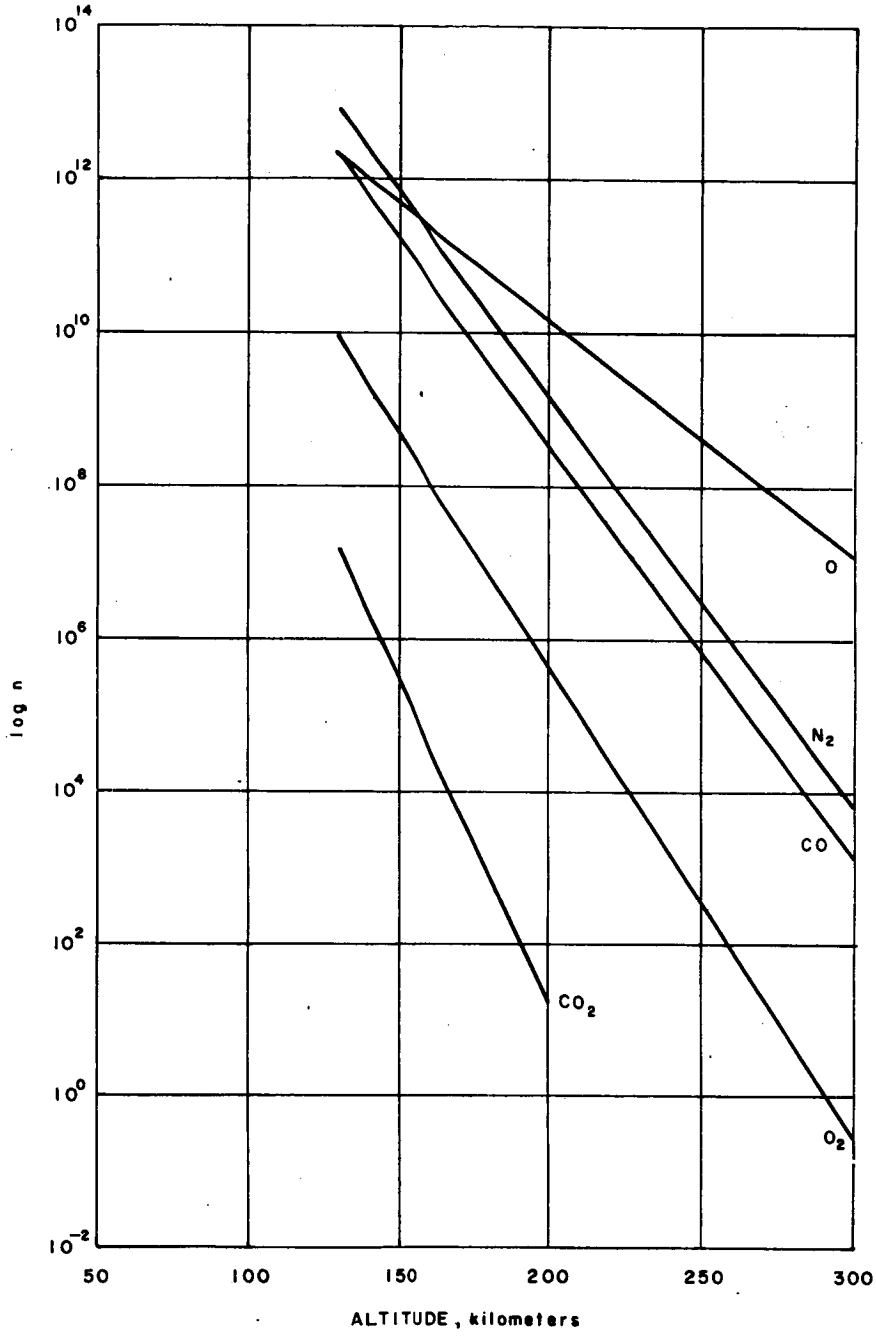


Figure 9 VERTICAL DISTRIBUTION OF ATMOSPHERE CONSTITUENTS -- VENUS MODEL I
63-9290

$$\phi = (O^+) \cdot f + g \quad ,$$

$$f = \frac{k1\,(O_2)}{\alpha 2} + \frac{k2\,(N_2)}{\alpha 4}$$

$$g = \frac{J2\,(O_2)}{\alpha 2} + \frac{J3\,(N_2)}{\alpha 3}$$

In the calculation, we assumed the solar photon flux at various wavelengths at the top of the Earth's atmosphere as shown in table 3. The flux at the top of the atmosphere on any other planet should be inversely proportional to the square of the distance from the sun, so that the flux indicated in the table must be multiplied by the factor of 0.431 for Mars and by 1.911 for Venus.

g. Computations. Many computations have been carried out and the results are shown in graphical form. The calculations indicate the production rates of electrons from atomic oxygen due to solar radiation. The X-rays of 10 to 20 A show a small influence with maximum around 250 km. Softer X-rays of 80 to 110 A have a predominant influence around 300 km. All other ultraviolet wavelengths have a rather high maximum at 800 to 1000 km.

The transmission curves (figure 10) indicate the solar radiation available as function of altitude. It clearly shows that soft X-rays as well as Lyman-α (1215 A) can penetrate deep into the Martian atmosphere.

The result of such computations leads to figure 11 which shows that the ionization due to O_2 controls the electron production at 130 km, whereas the ionization of O and N_2 leads to the high electron concentration above 600 km.

The ionic species O_2^+, N_2^+, NO^+, and O^+ as well as the electron concentration curves are shown in figure 12 as a function of altitude, and are demonstrated in figure 13 as the percentage distribution. It is concluded from this representation that O_2^+ dominated in the lower ionosphere, followed by NO^+, and finally O^+, similar to the conditions in the Earth's atmosphere. N_2^+ plays a very minor role.

The electron concentration reaches a value of 10^5 to 10^6 electrons/cm^3 around 1000 km. Such absolute values are comparable to the Earth's atmosphere where they are formed between 300 and 500 km. On the basis of the model atmosphere selected in this section, we can conclude that there will exist an ionosphere on Mars and that the ionic composition and the absolute concentrations are comparable to that in the Earth's atmosphere. The difference between the two planetary atmospheres is basically one of the altitude distribution. The same ionic species and concentration occur at a much greater altitude on Mars than on Earth.

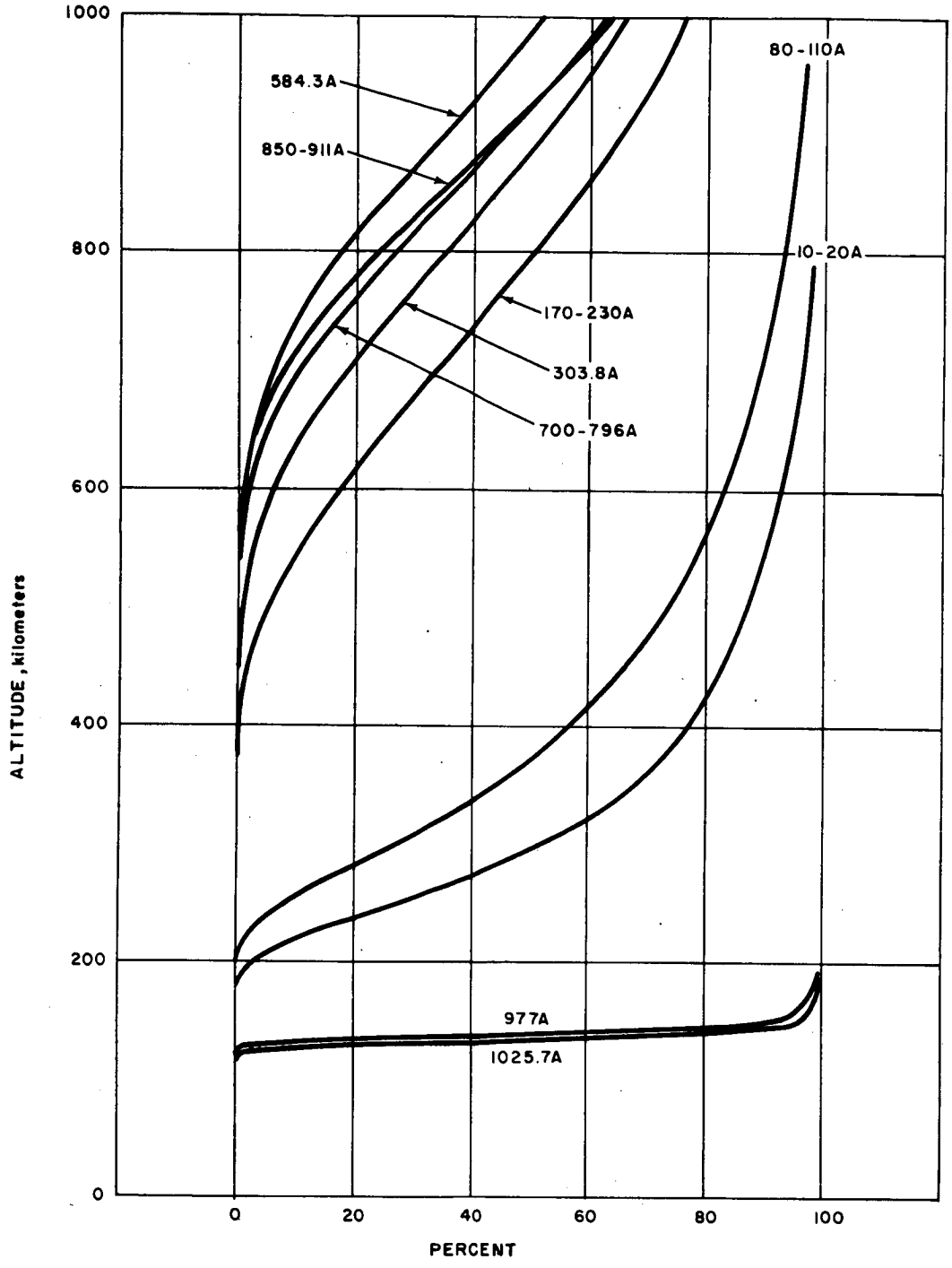


Figure 10 TRANSMISSION CURVES FOR SOLAR RADIATION IN MARTIAN ATMOSPHERE
63-9226

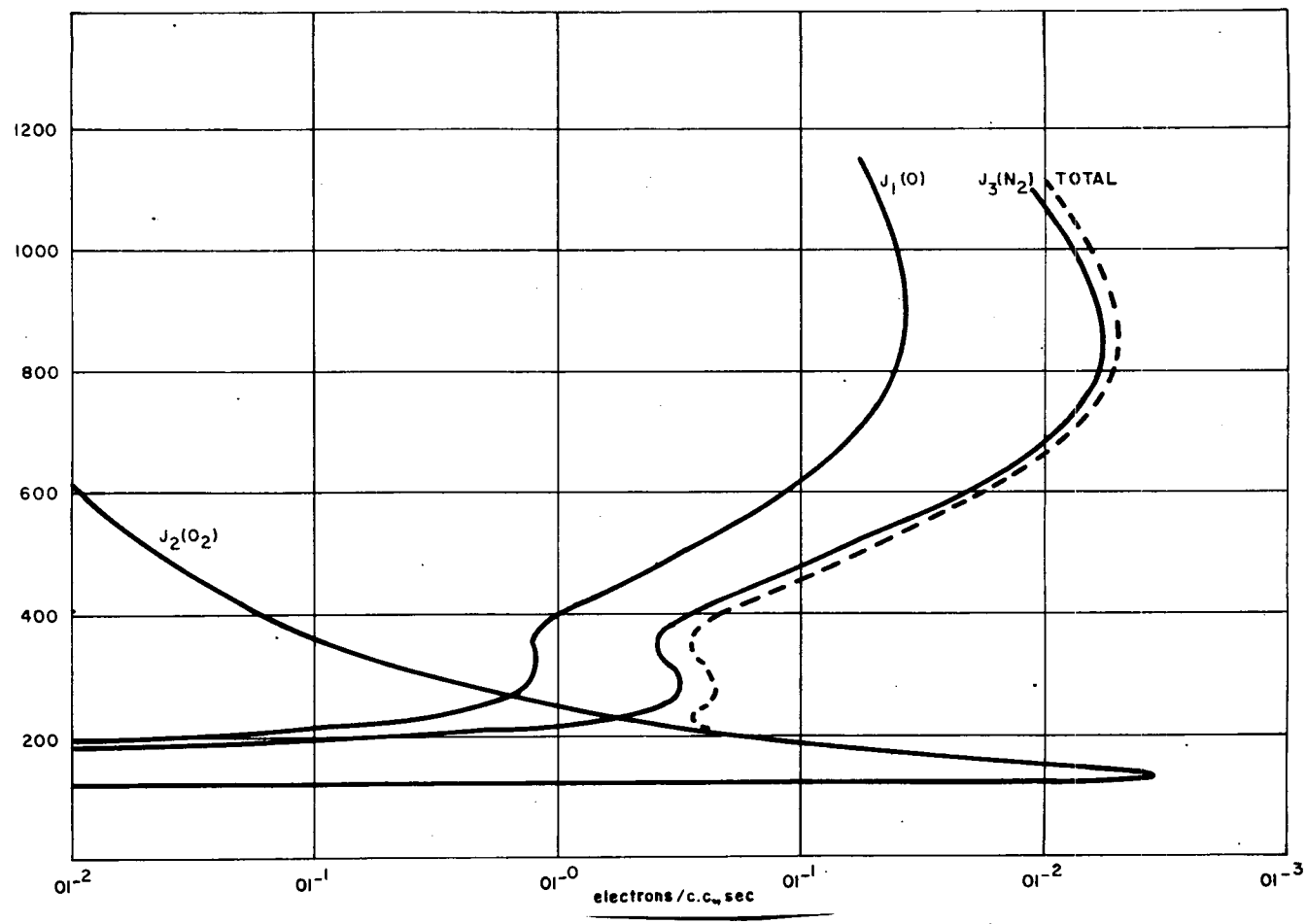


Figure 11 PHOTOIONIZATION RATE BY SOLAR RADIATION
63-9227

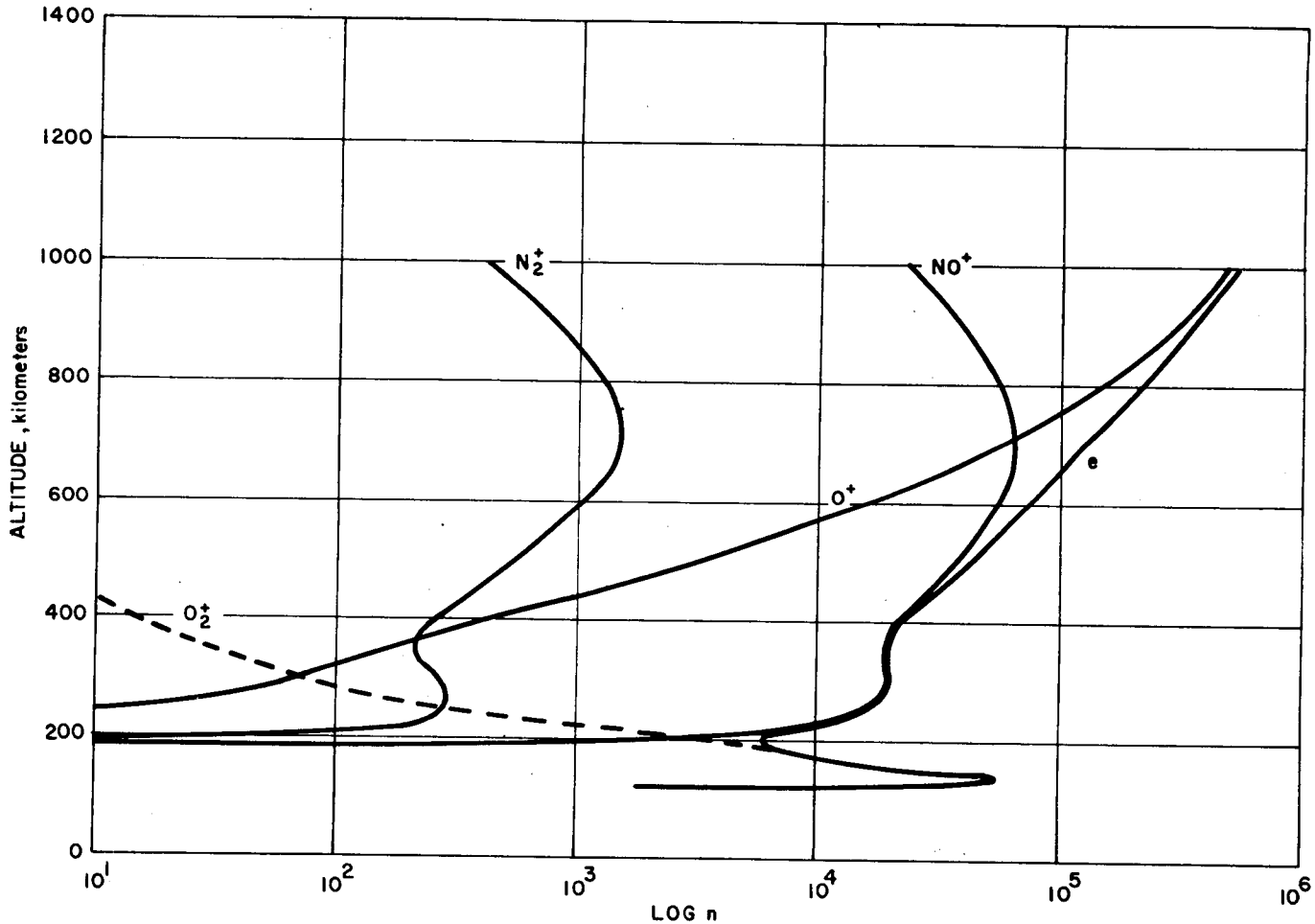


Figure 12 VERTICAL DISTRIBUTIONS OF POSITIVE IONS
63-9228

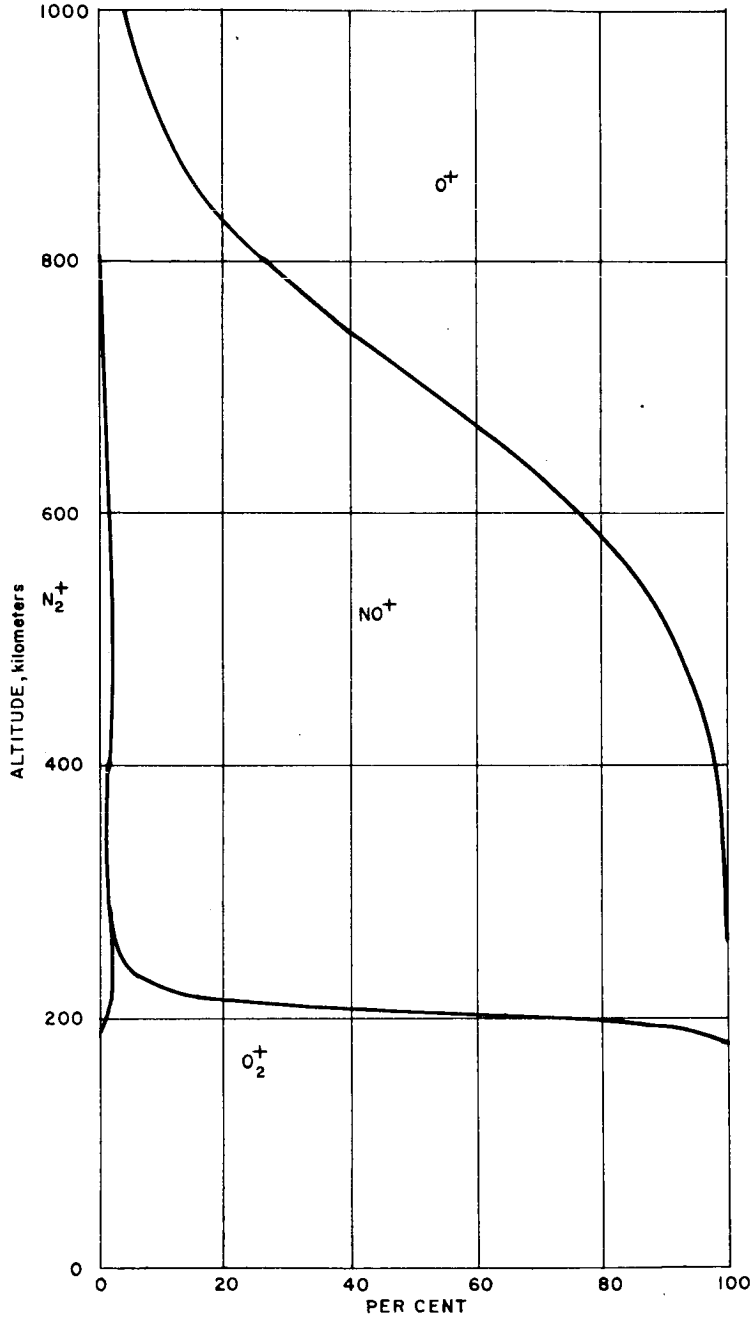


Figure 13 POSITIVE ION COMPOSITION OF MARTIAN ATMOSPHERE
63-9229

4. Suggested atmosphere measurements.

a. Solar radiations.

1) The intensity of the solar radiation in the Schumann-Runge continuum (especially at 1370 A) as a function of altitude will give the information concerning the distribution of molecular oxygen.

2) The height-change in the intensity of Lyman - α (1215.7 A) radiation will indicate whether there is a sufficient amount of NO molecules or not. If there is a sufficient amount of NO, it will be a cause of the lower ionosphere which absorbs severely the energy of radio waves.

3) The height change in the intensity of HeI resonance line (584.3A) will indicate the atmospheric density at about 1000 km above the surface.

4) The same in the HeII line (303.8 A) may be indicative of the air density at about 800 km above the surface.

5) The soft X-rays in a range between 10 and 100 A may be a measure of the air density at about 350 km above the surface.

6) The change in the intensity of Lyman-β radiation (1025.7A) with height will give the information concerning the height at which the photodissociation of CO_2 occurs, and the amount of O_2.

b. Atmospheric pressure.

1) From the change of atmospheric pressure with height, we can know the atmospheric densities at various altitudes.

2) Assuming the mean molecular mass of the air, we can derive the atmospheric temperature from the measurements of pressures at several defined altitudes.

3) If we know the atmospheric temperature from the other information (the measurement of pressure gives us a knowledge of the mean molecular mass), it may be an evidence of the photodissociation of CO_2, because N_2 and CO_2 have the same molecular weight.

c. Relative abundance of positive ions.

1) The relative abundance of positive ions should be indicative of the atmospheric composition. The atmospheric composition is one of the fundamental bases for the study of the ionized region and the uppermost region of the atmosphere.

2) Over Mars, the violet layer absorption at 4250 A shows forenoon banding, seems to be a scattering phenomenon, and indicates only 7 percent surface contrast at this wavelength.

d. Electron density.

1) The measurements of the electron density as a function of altitude are important for various purposes.

2) From the measurement of the height change of the electron density in a very high region, we can derive the atmospheric temperature in this region, because the electrons in this region should be distributed according to the diffusive equilibrium.

e. Chemistry.

1) The injection of sodium vapor into the atmosphere will give us an evidence of the photodissociation of CO_2, because Na reacts strongly with O, and the intense emission results from the excited Na.

2) The photographic observation of the emission from the excited Na will give us information about the atmospheric winds.

3) The injection of ethylene gas into the atmosphere will show some evidence of the dissociations of molecules. The red-color glow which comes from $N-C_2-H_4$ indicates the existence of atomic nitrogen, and the blue-color glow which comes from $O-C_2H_4$ indicates the existence of atomic oxygen.

f. Airglow.

1) The height distribution of the intensity of the green line (5577A) will give some information about the height where the photodissociation occurs.

2) From the measurement of the distribution of the intensity in oxygen red lines (6300 A and 6303 A), we can know the region in which the dissociative recombination of O_2^+ predominates. This measurement may be difficult because of the low intensity of the emission.)

3) The measurement of the Meinel bands of OH in the infrared region will give us some information concerning the amount of water vapor in the planets' atmosphere.

5. Cloud compositions. Cloud particles can have detrimental effects on reentry heat shields. Therefore, cloud characteristics of planets with atmospheres should be determined at an early date in a planatery exploration program. The quantities of most importance are (a) chemical composition,

(b) refractive indices, (c) mean radii of particles, (d) number of particles per unit volume, and (e) the physical state of particles (are they solid, liquid or gaseous?). Chemical compositions can be measured spectroscopically, and refractive indices derived from this. When scattering characteristics and chemical compositions are known, particle sizes can be derived. Note that scattering is a function of angular geometry, particle sizes, and refractive index of the particles. A light scattering photometric experiment seems quite feasible to instrument for a descent or landing capsule. By measuring the backscattered light (from an internal light source) at 90 and 180 degrees, sufficient information could be obtained to determine cloud particle sizes if their composition were simultaneously determined.

TABLE 3

IONIZATION PARAMETERS

Wavelength (A)	Photon flux at the Earth ($10^8/cm^2/sec$)	Cross-section ($10^{-18} cm^2$)	Gas to be ionized
1025.7 ($L\beta$)	26	1.7	O_2
977.0	30	3.7	O_2
850 ~ 911	95	11	O_2
850 ~ 911		25	N_2
700 ~ 796	50	18	O_2
700 ~ 796		19	N_2
700 ~ 796		5	O
584.3	29	18	O_2
584.3		19	N_2
584.3		13	O
303.8	28	17	O_2
303.8		10	N_2
303.8		10	O
170 ~ 230	33	11	O_2
170 ~ 230		6	N_2
170 ~ 230		7	O
80 ~ 110	2.4	2	O_2
80 ~ 110		0.5	N_2
80 ~ 110		1.1	O
10 ~ 20	0.02	0.6	O_2
10 ~ 20		0.3	N_2
10 ~ 20		0.3	O

4.3 Atmospheric Dynamics

The dynamic properties of the atmospheres of Mars and Venus are important to all phases of the Voyager program. Landing a vehicle on the surface of Mars, or simply sending a probe into the atmosphere of Venus, demands knowledge of the following

1. Cloud characteristics (because of the danger to heat shields)

2. Maximum wind velocities, turbulence

3. Aerodynamic drag at all altitudes

4. Possible sferic (lightning bolts) damage during descent

5. Possible damage to vehicle by atmospheric dust particles.

On the surface it is important to know

1. Maximum aerodynamic drag likely so that the lander may be stabilized in one location

2. Potential dangers of sferics toward which the lander might behave as a lightning rod

3. Danger of dust, snow, and other airborne particles to the vehicles structure, its ability to communicate, and ability to collect samples for analysis.

The dynamic characteristics of the Martin atmosphere would strongly influence the morphology of any living plants or animals. The winds would also be of physiological importance to human explorers. If atmospheric pressures should permit use of masks or partial pressure suits, or even with fully pressurized suits, the character of dust carried, the chill index, and drag of the winds will have immediate effect on the explorers. Following heat-generating electromagnetic flux, corpuscular flux, and gravity, kinetic forces from winds will be coupled to the human body. On both Venus and Mars it is thought that aeolian (wind) movement of solid matter is the dominent manner in which exogenetic solar energy is coupled to the respective lithospheres. The degree and rates are of utmost interest to geologists and geomorphologists.

In addition, it is hoped that observations of dynamic atmospheric movements over the surfaces of Venus and Mars will give the meteorologists on Earth some additional information on what may be simpler circulatory regimes. In time this may make it possible to better analyze the exceedingly complex circulatory regime on Earth. The importance of better weather prediction needs no emphasis in this work.

In the next section a few observations concerning the atmospheres of Mars and Venus are given. This is followed by models which may be applicable to the description of any of the expected circulatory regimes on Mars or Venus. It is hoped that the analysis of data returned by the orbiters and landers during the unmanned Voyager expeditions will make it possible to indicate better landing sites and vehicle construction during later expeditions.

1. Dynamic atmospheric observations on Venus. The blackbody temperature of Venus should be about 140°C. The surface is at about 800°C. Its rate of rotation is at most ±3 cycles/annum. If it were airless, there would be extreme temperature differences between the two hemispheres; however, this is not the case. Atmospheric temperatures as measured ultraviolet, visible light, infrared, and in the radar-radio spectrum indicate similar temperatures at what is thought to be similar levels of both hemispheres.

The troposphere must be many kilometers deep on Venus. It would be thinnest on the dark side, thicker over the illuminated hemisphere, and thickest at the subsolar spot. The subsolar spot has a yellowish tint, should be the seat of strong updrafts, and may well be colored by silicate dust from an aeolosphere. Polar caps are a distinct feature of the planet. These are frequently ringed by a dark collar; they form or disappear in the course of 12 hours or less. They are probably clouds resulting from the dominant circulatory regime. It is not believed that they indicate the planets axial inclination.

Photographs by Kuiper in ultraviolet have shown some interesting detail, namely, the presence of three light and three dark bands parallel to the terminator. He suggests that these may represent ascending and descending air currents. It is felt that this strong evidence for formation of a number of convection cells in a general hot-pole to cold-pole circulation. No such detail has been found on red photos: this suggests that the banding in the photographs is of clouds at a higher altitude.

Further evidences bearing on the possibility of planetary waves and convection of the Venutian circulatory regime are

a. The V, shadings, gibbous patterns, and wheel-spoke markings suggest planetary waves and convection.

b. The irregular extension of the cusps and cusp caps suggest planetary waves.

c. The Schroter effect (6 day irregularities in dichotomy or splitting in half of the disc) could only be due to atmospheric bulges.

d. Irregularities in the terminator might be due to ridges, troughs or large concentric circulations.

2. Dynamic atmospheric observations on Mars. Mars shows atmospheric characteristics that are more Earth-like than any other planet in the solar system. Mars, however, lacks continental and oceanic domains, and, therefore, its general circulation may be simpler than that of Earth. Some features indicating convection and waves in the atmosphere of Mars are

a. There is an assymetry in the percentage of cloud cover of the northern and southern hemispheres. The southern summers are longer because of marked orbital assymetry. A belt of dark areas south of the equator, and the greater extent of light areas in the northern hemisphere may be a result of this differential heating.

b. Banding parallel with the equator is frequently seen. This may indicate equatorial trade winds and the presence of convection cells extending from the equatorial zone to the polar frigid zones.

c. The presence of planetary waves is indicated by the W clouds (named for their shape) by what seem to be tropospheric ridges (where clear weather dominates) and troughs (where clouds dominate) in positions typical of planetary waves.

d. The presence of polar anticyclones with three to four prongs. These are essentially regions of clear weather with sharply defined boundaries; and, just as on Earth, they rotate closely about the pole, sometimes overlapping it and sometimes displaced toward the equator. The trefoil-like polar anticyclones of Mars seem to be most common during the polar summer months.

e. The presence of great sworls covering areas up to thirty degrees in extent. These resemble major cyclonic patterns of the Earth. Once formed, they seem to remain over one or the other hemisphere of Mars and seem to movepoleward. Photographs of Mars suggest that there are planetary waves with associated ridges and troughs. Wave numbers seem to vary from 3 to 8. Occasionally these possible planetary waves seem to cross the equator. This may be due to differential heating of the hemispheres. On Earth, larger weather patterns seem to be most frequently associated with wave numbers of 4 to 6, and stable patterns lasting a week or more seem to be associated with wave numbers of 3 to 4. Several photographs of Mars, Slipher (1962), seem to indicate wave numbers of relatively stable, large-scale patterns with wave numbers of 3. This is manifested by both the large-scale "cyclones" stretching from the "subtropical" to the edge of the "frigid" zones, and the shape plus rotational behavior of relatively persistent polar anticyclones.

3. Dynamic atmosphere models. Circulation is the result of energy imbalance. Neither Venus, Earth, nor Mars have areas showing progressive long-term heating; so it may be assumed that energy is transported and transformed by circulation of their gaseous envelopes which radiate while they move.

Four circulation regimes are described in the paragraphs that follow. In all regimes, the atmospheres perform the following functions: transport thermal energy from planetary sources to planetary sinks and transform thermal energy to kinetic energy and vice versa. Observations on Earth suggest that the switch from regime to regime is relatively abrupt and might be compared with a quantum jump. It should be noted that these models are to be applied to the tropospheres of Venus and Mars. In the Earth's atmosphere, most attention and most observations have been devoted to circulation in the troposphere. This is essentially where weather is generated; however, there are circulations at other levels. These circulations are not necessarily (in fact, practically never) the same as that in the troposphere of the Earth. The diagram in figure 14 indicates that not only may other regimes be present, but that these may be coupled in part to the troposphere or other levels to give a fraction of a circulatory regime.

a. Convective regime (nonrotating or rotating planets). The convective regime is the simplest. In a planet keeping one face continually toward the sun, or in a planet rotating very slowly, there will be a hot-pole (subsolar point) source to cold-pole (anti-solar point) sink circulation. This would result in convective circulation from the source to sink, with a return of cooled air to the source at a lower level.

Hot-pole to cold-pole circulation probably dominates on Venus; its effects are practically undetectable on the Earth and may cause significant diurnal wind storms over the surface of Mars.

A purely convective regime should form in an atmosphere with a single heat source (area being heated) and sink (area being cooled) which are antipodal and symmetrical. The planet should rotate so slowly that Coriolis forces are unimportant. Its surface should be featureless. The total energy transfer should not be so high that eddies (waves) form. It is conceivable that there could be a planet of just the right size, and with an atmosphere of just the right thickness, composition, etc., to establish a single convection cell from a hot pole to a cold pole. It is more probable that several convection cells and fractions of cells (resulting in local turbulence) would result.

b. Rotating planets. Rotation introduces two complications into the equations governing the general circulation: (1) Coriolis forces and (2) movement of the subsolar point. In theories of the general circulation on Earth, the second complication is circumvented by assuming that $\dot{q}$, the production rate of nonadiabatic energy, is independent of the longitudinal angle ϕ. This is justified since the diurnal variation of the surface temperature is reduced by the greenhouse effect on Earth (atmospheric transparency to short wavelengths and opacity to long wavelengths.) The lower atmosphere is heated at night by radiation from the Earth's surface, smoothing time variation of $\dot{q}$. On Mars, this assumption may not be justified as has been pointed out by Ohring and Cote. (ref. 1). The large range of temperature at the equator (55 to 90°K) is evidence

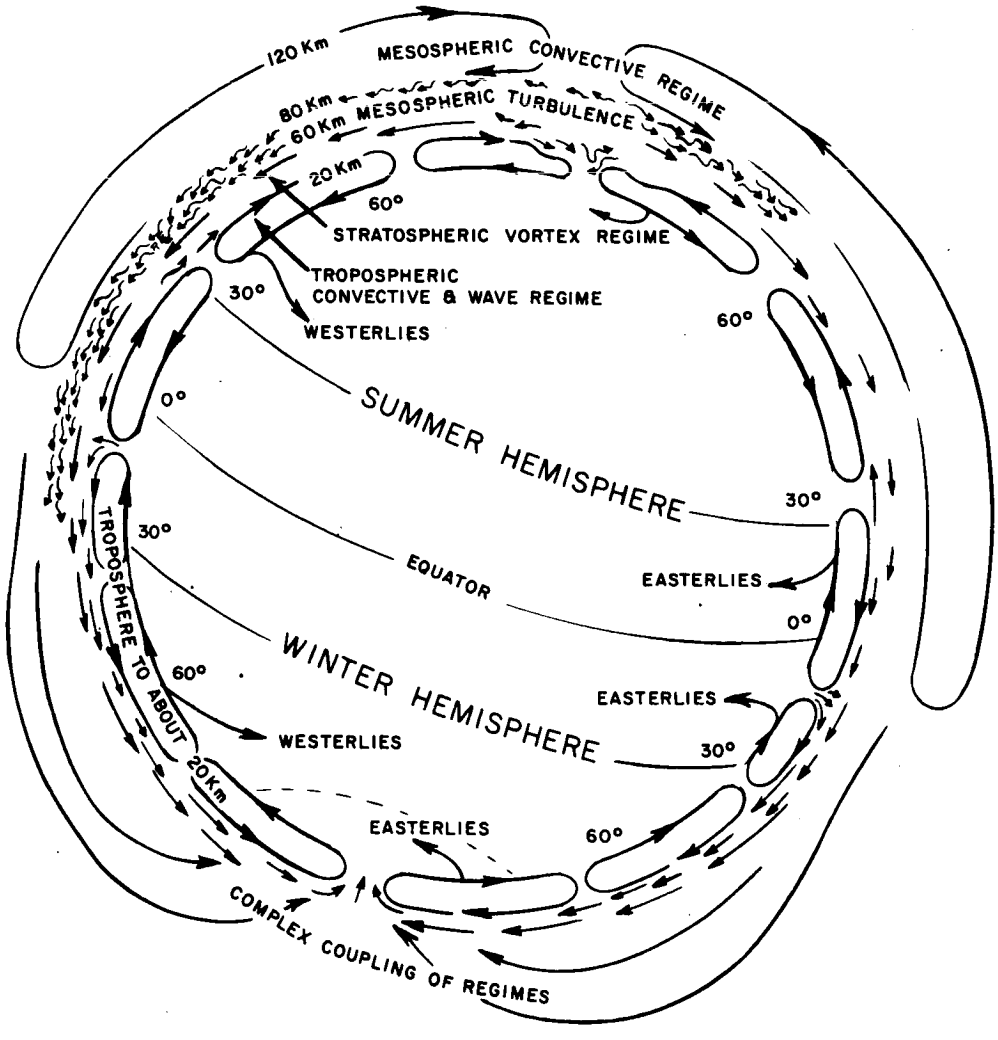


Figure 14 TERRESTRAIL ATMOSPHERIC REGIMES
63-9192

that it may not be valid. However, Mintz (ref. 2) as a basis for his theory of the circulation, assumes that it would. Therefore, an extension to his theory in order to account for a diurnal variation in $\dot{q}$ would consider the resulting thermal tides as being superimposed upon the general circulation (based upon the greenhouse assumption.)

Circulatory regimes on a rotating planet may be expected to be very complicated if the diurnal variations in $\dot{q}$ may not be neglected. If they may be neglected, then the circulatory regimes will simply represent modes of transporting energy from the equator to the (rotational) poles. (Mintz, ref. 2).

c. Lamillar or smooth-symmetrical-vortex regime (rotating planets). The symmetrical-vortex-regime is the simplest that could form on planets that rotate with their equatorial planes reasonably near the ecliptic (figure 15). Air being heated at the warmer equatorial belt would spiral toward the pole and descend there. Circulation from the pole back to the equatorial region would be at lower levels. In a symmetrical-vortex-regime, there is no fractionation of circulation into cells of less than a hemisphere in extent. Cloud patterns on Venus and Mars suggest that circulations over these planets are more complex. A vortex regime implies that the planet rotates at a precipitable rate. For example, there is an element of the vortex regime in a planet that rotates twice a year, but this is a vortex of such slight curvature that its very existence must be obscured by turbulence. On planets with a simple vortex regime, there would be a single convection cell stretching from equator to pole in either hemisphere, and one equatorial belt of prevailing westerlies or easterlies.

d. Multiple-cell convection. The single cell convection regime will be hydrodynamically unstable if the temperature of the air moving at higher levels is much greater than that moving at lower levels. There will be a tendency for the heat to flow from the upper levels to lower levels which, if sufficiently great, will cause a single convection cell to break down. One possible mode of response to this tendency is the establishment of multiple cell convection regimes. Each individual cell comprising such a regime will be similar to a single cell convection regime but will be bounded by two latitudes.

The regions separating different cells of a multiple cell convection regime will be highly turbulent because of the rapid change with latitude of the vertical wind motion. Energy will be transferred from lower latitude cells to higher latitude cells by means of eddy diffusion.

e. Standing-waves, transient-waves, and the terrestial-regime (non-rotating and rotating planets). Hemispheric convection can break into cells. Over the Earth, three tend to form equator to pole. The zones where air moves vertically mark planetary bands. The winds between the bands are called Equatorial Trades, North and South Temperature Zone prevailing westerlies, and polar easterlies at the margins of the Frigid Zones. This simple pattern is

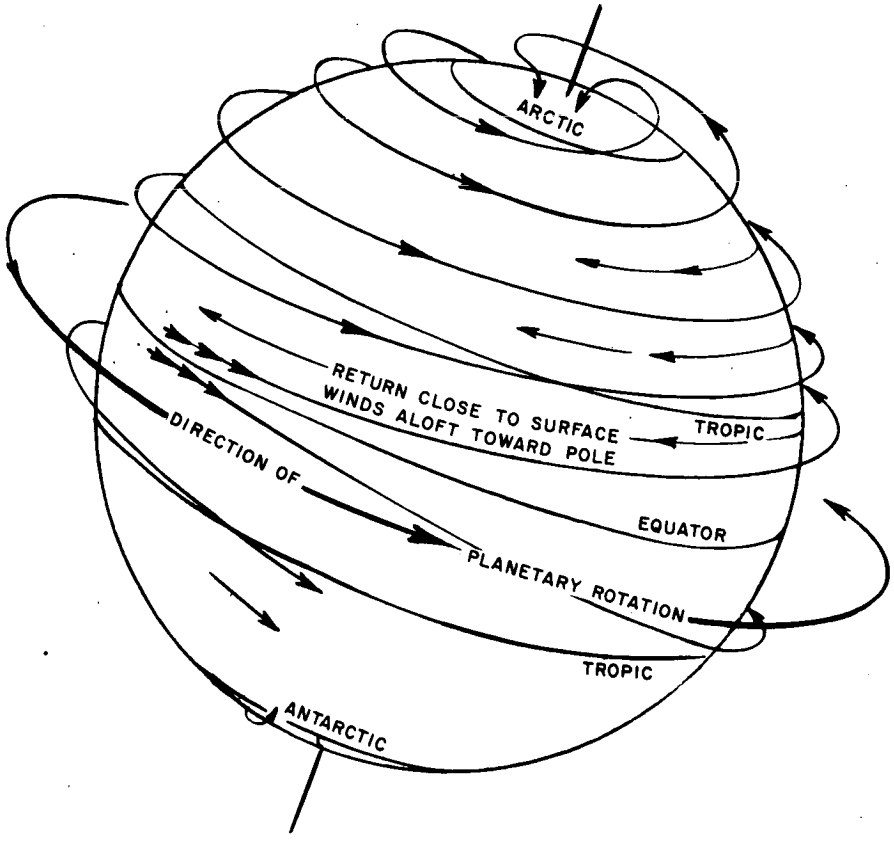


Figure 15 SYMMETRICAL LAMINAR VORTEX REGIME
63-9197

complicated by Coriolis forces and horizontal movements of air from equator to pole. Indeed, it is not certain whether more energy is transported poleward by convection or horizontal movement. Horizontal movements upset the ideally circular or canted pattern of the temperate westerlies, in particular. The westerlies tend to move in a sinuous manner, hence, the term "prevailing westerlies." Notice that the sinuous westerlies are fixed between belts of planetary highs and lows. These highs and lows are controlled to an extent by 2nd-order geomorphic features, and the continental and oceanic domains. These give rise to semipermanent highs and lows with such names as Aleutian Trough, Mid-Pacific-High, Bermuda High, Azores Low, etc. These highs and lows may be thought of as standing waves. A standing or transient wave regime has its pattern shaped by the rotation rate of the planet (which determines the inclination of the troughs and ridges and hence the waves), the number of convection cells from equator (heat source) to pole (heat sink), and the net energy that has to be transported per unit time from source to sink.

f. Wave regimes. The simplified model that follows first presumes that the motion is symmetric about the axis connecting solar and subsolar points, i.e., that if f is any function describing atmospheric motion and if ϕ denotes the longitude about the axis and, therefore

$$f(\phi) = f(\phi + \delta)$$

where δ is any displacement in longitude. This symmetry is possible since the basic equations exhibit this symmetry, as shown in figure 16. However, the symmetry of the equations does not necessarily preclude assymmetry in ϕ. It is conceivable that we might have, for example,

$$f(\phi) = f\left(\phi + \frac{2\pi}{n}\right)$$

where n is an integer. We may refer to n as the wave number of a regime which exhibits this sort of symmetry. For a nonrotating planet, the occurrence of a wave regime may be imagined as a sort of compromise between the direct motion between solar and subsolar points and the swirling motion characteristic of water draining out of a bathtub.

Presence of a wave regime may also be triggered asymmetries in the surface properties of the planet. For example, the geographical distribution of continents and oceans.

g. Eddy-diffusion-regime to turbulent-regime (nonrotating and rotating planets). One possible mode of heat transfer from the solar point to the subsolar point is that in which no large-scale circulation patterns are discernible. Instead, the energy is carried by eddy diffusion or by turbulent mixing. One may imagine the eddies as extending in size up to diameters of 1/4 the planet's radius

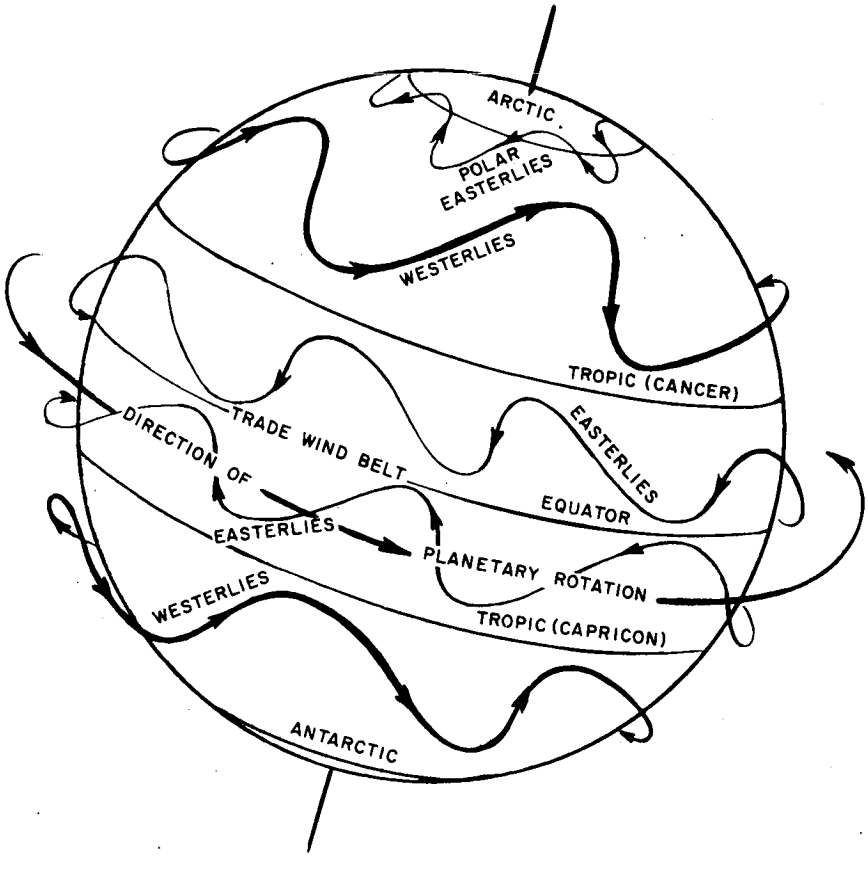


Figure 16 WAVE REGIME
63-9196

and moving either towards or away from the subsolar point. If a portion of the planet's surface is covered by an eddy diffusion regime, one may expect highly variable and erratic weather conditions in the region.

As the amount of energy that has to be transported from source to sink by the atmosphere grows larger and larger, the turbulence can be imagined to grow until all patterns disappear.

4. Circulation on Mars and Venus. In principle, one should be able to predict general circulation patterns in planetary atmospheres if the following information is known

a. The radiation from the sun absorbed by the atmosphere at each point per unit time

b. The constitution of the atmosphere

c. The water vapor (or any other evaporative matter) being added to the atmosphere per unit time, and the average amount being precipitated as functions of time and position. This requires, in particular, the knowledge of the locations and extent of vapor sources

d. The rate at which energy is transferred from the atmosphere to the bulk of the planet

e. The angular velocity of the planet about its axis

f. The nature of the interaction between horizontal winds and the planet's surface (this includes knowledge of the stresses as functions of wind speed and of the rate of production of small scale turbulence)

g. Surface temperatures on the planet as a function of time and position

h. Surface pressures on the planet as functions of time and position.

i. The acceleration of gravity at the planet's surface.

Whether or not the list given above contains redundant information for the purposes of predicting gross features of the atmospheric circulation is difficult to ascertain. It should be pointed out, however, that even though a large portion of this information is known for the Earth, a satisfactory theory of the general atmospheric circulation on the Earth has not yet been devised. This seems to be the consensus of opinion of many eminent meteorologists (Brunt ref. 3 Phillips, ref. 4; and Godske et al, ref. 5), and although much work is presently being done on the subject (ref. 6), a complete understanding entirely based on physical principles is still not at hand. When one considers this fact and, in

addition, the fact that the amount of information which could be utilized in the formulation of a theory for atmospheric circulation on Mars or Venus is severely limited, the difficulty of predicting the atmospheric circulation for these planets becomes apparent. This emphasizes the fact that a large theoretical effort should be directed towards this problem if a reliable prediction is to be made before the first Voyager expeditions.

Notable beginnings towards the solution of this problem have already been made by Mintz (ref. 2), Miyamoto (ref. 7), and Ohring (ref. 1). The general basis for a formulation of the theory of atmospheric circulation is the equations of hydrodynamics for a compressible gas on a rotating globe. The first of these equations equates the acceleration of unit mass of gas in the atmosphere to the forces acting on it. These forces consist of gravitational forces, pressure forces, Coriolis forces, and frictional forces. Centrifugal forces due to the planet's rotation are generally lumped with the gravitational forces. The resulting equation then takes the form

$$\frac{d\vec{V}}{dt} = -\frac{1}{\rho}\nabla p - g\vec{k} - 2(\vec{\Omega} \times \vec{V}) + \vec{F} \tag{82}$$

where

$\frac{d}{dt}$ means $\frac{\partial}{\partial t} + \vec{V} \cdot \vec{\nabla}$

$\vec{V}$ = smoothed wind velocity at a fixed point

g = acceleration of gravity

Ω = angular velocity of planet's rotation

$\vec{k}$ = unit vector in direction normal to planet's surface

p = pressure

ρ = density

$\vec{F}$ = frictional forces

The coordinate system in which (1) is expressed is one which rotates with the planet. Generally, the variation of g with altitude is ignored. This is justified as long as the bulk of the atmosphere occupies a spherical shell the thickness of which is small compared with the planet's radius.

The frictional forces F are not explicitly given. This presents one of the principal obstacles in the formulation of the problem. Part of the frictional forces are due to viscosity and are given by

$$\nabla \cdot (\mu \nabla \vec{V}) + \nabla \vec{V} \cdot \nabla \mu + \frac{1}{3}\mu \nabla (\nabla \cdot \vec{V}) - \frac{2}{3}(\nabla \cdot \vec{V})\nabla \mu \tag{83}$$

where μ is the coefficient of viscosity. Other contributions to F are caused by turbulence. The turbulence appears as a frictional term because of the usual definition given to V. One usually understands the V utilized in (82) as representing a smoothed velocity. The manner of defining such a smoothed velocity is somewhat arbitrary. Various alternatives are discussed by Godske et al. (ref. 5). In all cases, the effect of such smoothing is to add additional terms to the force equation. These terms are usually called eddy viscosity terms. Although one understands how these terms enter into the equation, it is difficult (and, to a certain extent, unjustifiable) to express them in terms of the smoothed variables and their derivatives. The approach generally used by meteorolgists is to take these terms roughly in the form of (83). The viscosity becomes a (diagonal) tensor with two distinct components, the two components being called the lateral and vertical eddy viscosities. These frictional terms are generally taken in the simplified form

$$\mu_{El}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)\vec{V} + \mu_{Ev}\frac{\partial^2}{\partial z^2}\vec{V} \quad , \tag{84}$$

terms involving derivatives of the viscosity and the divergence of the velocity being neglected.

An obvious shortcoming of the use of (84) is that we have no way of predicting the values of μ_{El} and μ_{Ev} from basic principles. To a certain extent, these coefficients may be measured by studying the diffusion of radioactive particles in the atmosphere. Phillips (ref. 4) in his study of the general circulation on Earth adopts the value

$$\mu_{El} = 10^5 \ m^2 sec^{-1} (\text{all } z) \ .$$

The term involving μ_{Ev} is of importance only near the ground as friction from the motion over the ground causes the velocity to vary rapidly with distance above the ground. Rather than to try to incorporate the complex boundary conditions at the ground and to consider the detailed behavior in the boundary layer, the term involving μ_{Ev} is often replaced by the semiempirical term (Phillips, ref. 4)

$$-K\,|\vec{V}|\cdot\vec{V}\,(g\rho/p) \tag{85}$$

where K is of the order of 0.003 at the ground and vanishes at heights corresponding to 500 mb.

The above remarks indicate that, even for the Earth, a valid representation of the frictional force is difficult to obtain. It is clear, therefore, that any representation of the frictional force for the atmospheres of Mars or Venus will be speculative.

In addition to equation (82), other relations governing the circulation of the atmosphere are the conservation of mass equation

$$\frac{d\rho}{dt} = -\rho\nabla \cdot \vec{V} \tag{86}$$

and the equation equating the increase in entropy of the atmosphere to the non-adiabatic energy added to the atmosphere (or dissipated in the atmosphere) divided by the absolute temperature. This equation is given by

$$C_p \frac{d}{dt} \{ \ln (p^{1/\gamma} \rho^{-1}) \} = \dot{q}/T \tag{87}$$

where

C_p = specific heat (per unit mass) at constant pressure

γ = C_p/C_v

C_v = specific heat (per unit mass) at constant volume

T = temperature

$\dot{q}$ = rate of nonadiabatic heating per unit mass.

Equation (87) assumes that the atmosphere is an ideal gas and of homogeneous composition. This is a reasonable approximation for the Earth's atmosphere and we have no reason to believe that it will not be equally valid for those of Mars or Venus. The parameters γ and C_p may be computed from first principles if the composition of the atmosphere is known.

The nonadiabatic heating per unit mass consists primarily of two parts; (a) the radiant energy absorbed from the sun, and (b) the energy transferred from adjacent particles of air. The latter portion is due primarily to eddy diffusion as direct thermal conduction is neglibible. The usual expression used for $\dot{q}$ is

$$\dot{q} = \left(\frac{dQ}{dt}\right)_{rad} + C_p A_T \nabla^2 T$$

where A_T is the semiempirical eddy diffusion coefficient. On Earth, it is of the magnitude of 10^5 m^2/sec. Again, we have little means of estimating its value on Mars or Venus. The radiative heat may be found to a good approximation if one assumes the atmosphere to be at rest and knows the composition of the atmosphere and the spectral intensity of the incident sunlight. It is generally felt that a detailed knowledge of this term is not necessary for a gross understanding

of the general circulation. However, the presence of clouds may shield large portions of the atmosphere from radiant heating. Thus, a certain amount of knowledge of the average geographical distribution of cloud cover may be needed for the development of a satisfactory theory of general circulation. Astronomical observations are probably sufficient for this purpose.

It is important to note that, in the coordinate system fixed on the planet, the sun and therefore the point on the planet nearest the sun (the subsolar spot) is moving. Thus, the radiant heating varies with time; it is roughly periodic with a period equal to the length of the planet's day.

The basic problem of predicting the general circulation of the atmosphere once the basic equations have been established is to find a stable solution for the winds, the pressure, and the density as functions of position and time. This does not necessarily imply a steady-state solution since large-scale turbulence (cyclones and anti-cyclones) will probably play an important role in maintaining the general circulation.

One may regard the motion of the atmosphere as representing the tendency of the planet to maintain thermal equilibrium. Since the heating due to radiation is not symmetric about the planet a large temperature differential could result if no avenue were open for the atmosphere to redistribute its thermal energy. The general circulation of the atmosphere may be considered as the most efficient way of accomplishing this, without violating the law of physics. We may speculate on the possible modes by which the atmosphere attempts to maintain thermal equilibrium. A region of the planet in which such a mode is predominant is called a regime. Just what modes are actually utilized by an actual atmosphere and the regimes in which the various modes predominate can only be ascertained by a detailed solution of the basic equations or by a systematic set of meteorological observations in the planet's atmosphere.

5. Suggested measurements -- Mars. Measurements desired are as detailed on the priority lists in table 4. Observations of circulatory patterns will best be made from the orbiter; initial ground observations could be made from one spot. At a later date, very serious consideration should be given to using a mobile station. This might move over the ground, or be moved by a balloon during the day which descends at night to take measurements. The nature of the violet layer which absorbs at 4250A and the so-called violet or blue clearing may represent an ionosphere of sorts. The ability of the atmosphere to transport solid particles will give a measure of erosional/depositional rates on Mars. An early rough estimate of this might be secured by changes in the polar cap albedos as dust collects on their surfaces. The presence of local adiabatic circulation and cloud formation may be done from both the orbiter and the lander. White clouds have been observed to hover over dark features on the surface. The dark features may represent thermal humps.

It is implied by many researchers that the dark areas of Mars may be low areas or basins. This may not be the case at all. Slipher (ref. 8) has indicated that the "desert" areas have a composition indicative of felsite. Into this work and other evidences may be read the possibility that the dark areas have basaltic material in them, which probably indicates high rough ground. The changing dark areas and presence of C-H bonds may be restricted to the slopes of mountains. These mountains may be the result of impact craters, faulting, or perhaps vulcanism. Perfect "seeing" of Mars indicates that such areas as Syrtis Major are not uniformly dark, but very much spotted. In the arid regions of Earth, mountain slopes and the areas immediately adjacent to them tend to be the best watered. This could well be the case on Mars.

6. Suggested measurements -- Venus. Measurements desired are detailed on the priority lists in table 4. Observations of circulatory patterns might best be carried out on a number of wavelengths from an orbiter. Conceivably, an atmospheric flyer could be used to take TV photos of dust storms in a hypothetical aeolosphere, provided there is a gap between the cloud bottom and the supposed dust storms below.

Information concerning the dynamics of the atmospheres of Mars and Venus are of particular importance to later unmanned and manned probes. To Earth-bound scientists, data concerning circulatory regimes and observations over a number of years would be very helpful.

4.4 Magnetism and Electrodynamics

Interplanetary and planetary magnetic fields are of interest to geophysicists, communications engineers, geochemists, and even biologists. In this section, features of interplanetary and planetary magnetic fields will be described, and experiments desired in the vicinity and on Mars and Venus will be listed in their approximate order of importance. Interestingly, these features can almost be tabulated in the order that the Voyager craft would measure them during its approach from interplanetary space. It is suggested that the magnetometer take measurements at a low rate during its transit of interplanetary space. On approaching the planet, the lander might increase its sampling rate at a predetermined distance, perhaps 25 Mars radii, or the instrument might be thresheld to respond to a magnetosphere-like transition zone. It is imagined that the sampling rate would then increase in steps appropriate for measurements in the magnetosphere (if present), ionosphere, atmosphere, and finally the surface. The Mars and Venus orbiters probably will have eccentric, precessing orbits. This will make it possible for them to define ring currents, radiation belts, and magnetopause, if such exist.

Magnetic fields associated with plasma masses ejected from the sun, magnetic fields associated with sun spots, magnetic fields associated with petrographic anomalies, and magnetic fields associated with the ionosphere have been described by models which are reasonably acceptable to the geophysicists of the world (figure 17). To date, no one has constructed a particularly satisfactory theory for the magnetic field of the Earth. It would be of great significance if such a model could be prepared. Observation of other planets in the solar system may yield empirical data which will make it possible to build such a model.

Planetary magnetic fields might be produced by permanent magnetism, moving charges, rotation of a massive body, and electric currents (Jacobs, ref. 9). Permanent magnetism is considered impossible since the Curie point for iron is reached at a depth of about 25 km on Earth. Below this depth, all ferromagnetic materials will have lost their magnetic properties. Through the exact relationship between Curie point and pressure is not known, this theory wouldn't explain the Earth's secular variation in any case. In the motion-of-charges theory, the Earth is supposed to have a negative charge over the surface and an equal positive charge in the interior. A field would be produced by the rotation of the Earth. This theory requires a large vertical potential gradient, 10^8 times greater than that observed in the atmosphere. The rotating-sphere theory, sometimes called the fundamentalist theory, supports the idea that in a rotating ferromagnetic body, the magnetic moments of the atoms are associated with their angular momentum. These forces on individual atoms cause a net lining up of the magnetic moments along the axis of rotation. Laboratory measurements have confirmed this effect for high rotational velocities, but the effect would be unlikely for the rotational velocity

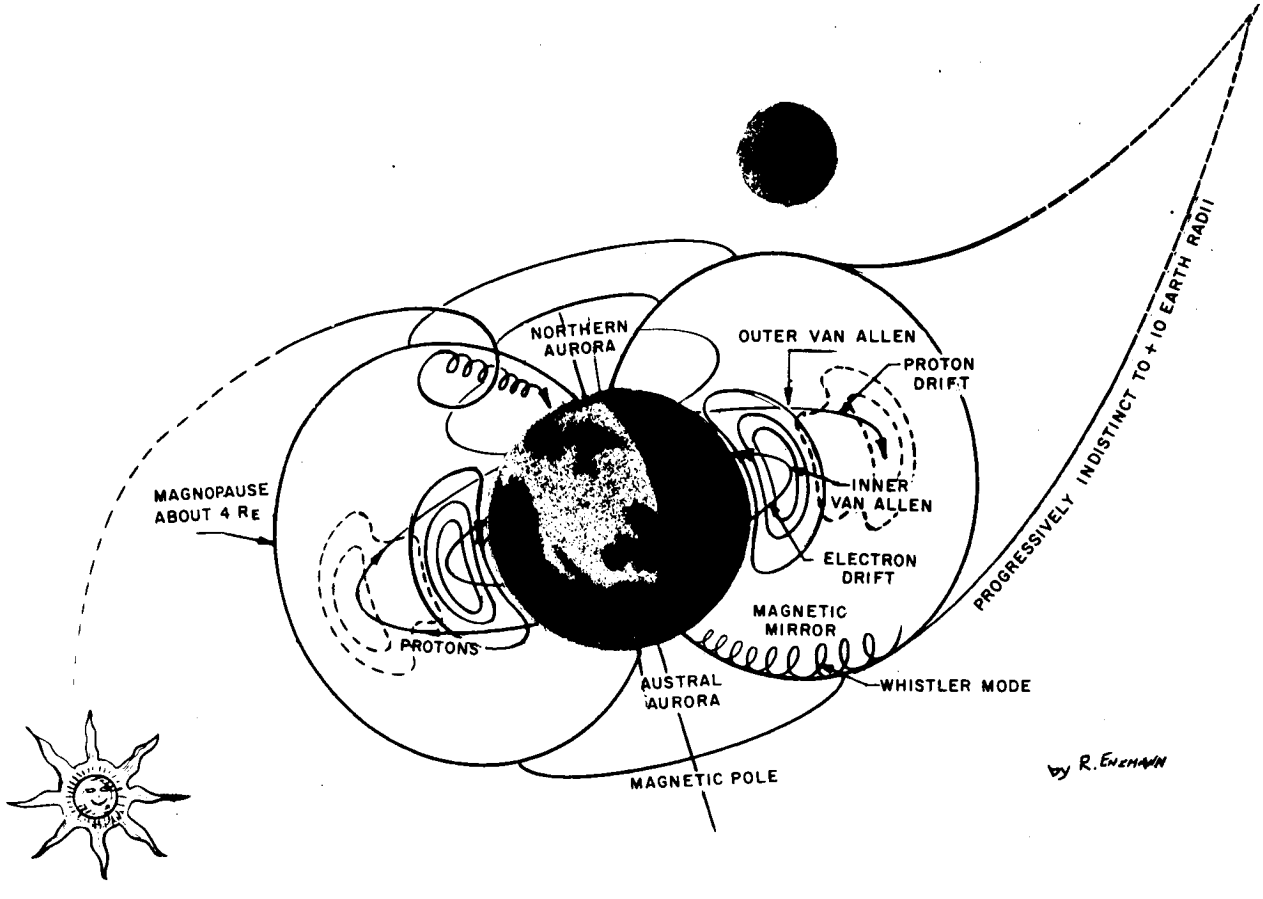


Figure 17 PLANETARY MAGNETIC PHENOMENA
63-9194

of Earth or Mars (Runcorn, ref. 10). The fourth theory concerning thermo-electric currents in the core as the source of the magnetic field was first considered by Elsaser (ref. 11). An extension of this is the dynamo theory which purports that the field is produced and maintained by an induction process, the magnetic energy being derived from the kinetic energy of the fluid motions in the Earth's core. To date, this theory appears the most promising, but universal acceptance awaits more investigation.

1. Observations.

a. The sun. A general solar magnetic field has been suspected since the eclipse of 1878. Its magnitude was first estimated to be 50 gauss by Hale in 1913 by observing Zeeman splitting. After extending measurements over a period of years, Hale and others made a new estimate of 25 gauss. Thiessen (ref. 12) using a combination of a Fabre-Perot interferometer and photo-electric recorder, found that the sun's field was only 1.5 to 2.5 gauss. Kiepenheuer (ref. 13) got a zero result with maximum possible value of 1 gauss. Babcock (ref. 14) from a study of Zeeman split-absorption spectra, deduced a field of 1 gauss or less. A weak solar field is also indicated by the structure of filaments and prominences. These are disturbed by sun spots, but only slightly by the sun's general field. Analysis of the curvature of the filaments indicates a magnetic field of about 3 gauss. Similar estimates may be made by means of the curvature of coronal plumes near the solar poles. These results suggest a magnetic field as low as 0.03 gauss. It does not seem that the sun has a strong magnetic field. Babcock (ref. 14) found that the polarity of the sun's general field reversed. The field is now thought to be parallel to the Earth's magnetic field.

All sun spots have a magnetic field with strengths ranging from 100 to over 4000 gauss, and seeming to be a function of area. Sun spots seem to be sources of, and otherwise associated with, ionospheric storms, great bursts of X-ray and ultraviolet energy, plasma bottles, plasma clouds causing Forbush decreases of galactic cosmic flux on Earth, and storms of solar cosmic rays (corpuscles) of potential danger to astronauts.

Galactic cosmic ray (corpuscular) flux is not a significant barrier to manned space explorations. Solar cosmic ray flux is a great hazard. The study of magnetic fields guiding the hazardous corpuscles (mostly protons and electrons) is in its infancy. Both theoretical work and interplanetary data are needed to describe the geometry and history of plasma clouds, or masses of charged particles with self-generated magnetic fields, which guide the hazardous particles. Magnetic bottles of plasma rooted to the sun may be hazardous, while plasma clouds detached from the sun may not be. It is possible that at some distance between the Earth and Mars, solar cosmic rays will cease to be a major hazard to life during sun spot maximum, as shown in figure 18.

b. Vehicle configuration. The configuration selected for entry into the Mars atmosphere is the Avco E-5 shape which has been designated the Voyager V-2 vehicle. The blunt configuration is necessary to provide adequate deceleration for atmospheric measurements and a successful landing. The reference design ballistic coefficient (M/C_DA) is 0.9 and was determined by a tradeoff between descent system requirements and available payload weights. The aerodynamic characteristics utilized for the V-2 shape are from wind tunnel, shock tube, and ballistic range test programs.

c. Vehicle dynamics. Six-degree-of-freedom trajectories have been generated to determine dynamic histories for the V-2 vehicle as a function of entry conditions, model atmosphere, and vehicle parameters. Angle-of-attack effects on heating and loads have been determined and are included in vehicle weight calculations.

The center of gravity location is such that the vehicle has a single trim point at zero angle of attack and would be satisfactory for a tumbling entry. Trajectory results indicate a possible maximum angle of attack of 30 degrees in the region of peak heating and peak loads. A drogue parachute, which is deployed at M = 2.5 to provide sufficient descent time, also improves dynamic characteristics in the low supersonic range.

d. Entry heating and loads. Convective and radiative heating pulses have been obtained as a function of entry conditions and atmospheric model. The design conditions for the heat shield yield radiative heating which is relatively small compared to the convective heating. The blunt nose under these heating conditions does not compromise the design and, in fact, is beneficial. The maximum axial deceleration for entry is approximately 180 Earth g's.

3. Thermal design (Mars lander). The extended mission life made possible by the use of an RTG requires special consideration inthe thermal design of the lander for its transit journey as well as for operation on the planet.

During transit, the lander with its combined sterilized can and meteoroid protection is placed in the shade. This allows good radiation to space which is maintained (except for relatively short periods during midcourse corrections) up to the time of separation at a range of 1,000,000 km from Mars. After shedding the can, the lander is subjected to a sun input the intensity of which is very much lower than near Earth.

On the planet the heat from the RTG is advantageous in keeping the instrument box warm in the extremely cold environments. The main design problem thus occurs during transit, namely, the requirement to distribute the heat from the RTG over the surface area of the lander. This is accomplished by using a ventilating fan blowing over the RTG as well as conduction along the top of the instrument box. The design is based on pure radiation so that loss of pressure and/or fan does not cause catastrophic failure.

Satellite measurements of the Earth's field indicate a good correspondence with a dipole field. On the sunlit side of the Earth, Pioneer I (Sonett et al, ref. 15) and Explorer 12 (Cahill and Amazeen, ref. 18) indicate a field following an inverse-cube field decrease with distance out to the magnetosphere boundary. On the other hand Explorer 10 (Smith, ref. 23), launched toward the dark side of the Earth showed evidence for a large departure from the dipole field at distances of 5 to 6 R_e. The field deformation is thought to be caused by a westward directed ring current at about 10 R_e.

The terrestrial magnetopause is the boundary between the volume of space influenced by the Earth's magnetic field and interplanetary space dominated by the solar wind. When the solar wind strengthens, or when a rooted or detached plasma cloud envelops the Earth, the magnetopause is forced closer to the surface of the Earth. Changes in intensity and position of the Earth's field will also cause slight changes in the shape and position of the magnetopause.

e. Earth's electrosphere. The Earth's ring current is thought to be produced by the westward drift of protons and the eastward drift of electrons trapped in the geomagnetic field (Apel et al, ref. 24). The net effect is a westward current causing a decrease of the horizontal magnetic component on the Earth. A magnitude of 30 to 400 is typically given for the ring current effect (D_{ST}). Time variations are considerable, particularly during magnetic storms. However, Explorer VI indicated the main phase decrease at 4 R_e was essentially coincident with the storm field at Huancayo, Peru (Smith and Sonett, ref. 23). We have then some measure of the ring current effect. The most difficult task is separating local effects from the total effect observed. A program is currently underway by Sugiura of NASA to do this for the IGY period.

Van Allen belts show time variations that are exceedingly complicated. An excellent review of current knowledge has been given by Farley (ref. 25). It must be borne in mind that many observations are required before an adequate description of a Martian belt could be made.

Aurora is a strikingly beautiful geophysical phenomenon which is best developed at high latitudes of Arctic and Austral polar regions of the upper atmosphere. These are called the Auroral zones; they girdle the northern and southern polar regions. The maximum frequency of Aurora is located at about 65 degrees geomagnetic latitude in the northern hemisphere and perhaps at 70 degrees in the southern hemisphere. Comprehensive studies have been made by many authors concerning the character of associated spectra and interrelationships with other geomagnetic phenomena. The Auroral may appear as homogeneous bands, homogeneous and pulsating arcs, diffuse and pulsating surfaces, glow, etc. (Stormer, ref. 26; Harang, ref. 27 Chamberlain, ref. 28; Chapman, refs. 29, 30). The Aurora may reach the ground and have been reported to reach heights of 700 km. Maximum luminosity is at about 60 to 150 km above the Earth's surface. Auroral activity is at a maximum during sun spot maximum. Much of it is attributed to photon emission

by oxygen and nitrogen which has been excited by a high energy corpuscular flux. Heppner (ref. 17) found that auroral activity and magnetic bays were closely related. The magnetic H component at College, Alaska, changed from positive to negative as homogeneous auroral bands changed to rayed or diffuse forms. This indicated that auroral particles ionize neutral particles in the D and E regions of the ionosphere changing their conductivities.

A direct association between X-rays and visible Aurora was found by the balloon experiment over Minneapolis (Winkler, Peterson, Arnoldy, and Hoffman, ref. 31). The X-ray is thought to be generated by bremsstrahlung radiation produced by the slowing down of electrons. This result shows that the electrons with energies above 50 kev are incident on the low atmosphere at the time of auroral display. The Van Allen belt influences low atmosphere at the time of auroral display. The Van Allen belt influences the Aurora (Van Allen, ref. 32) particularly during magnetic storms. Trapped particles in the inner belt at about 2000 to 4000 km above the equator are mostly protons. The particles in the outer belt at about 3 to 4 Earth radii above the equator are mostly electron with energies of 20 to 200 kev. It has been suggested that the outer radiation belt is the source of auroral particles. However, the distribution of the trapped particles in the outer radiation belt appears to be too close to the Earth, and it seems that the outer belt supplies the particles responsible for the subauroral zone effect (Chamberlain, ref. 28, 328 p.). Recent satellite observations (Explorer II) (Arnoldy and others, ref. 33; Rothwell and McIlwain, ref. 34) show that the trapped particles in the outer radiation belt number decreased at the sudden commencement or during magnetic storms and afterward increased. The X-ray flux which occurred at the same time is coincident with the particle number lost in the radiation belt. This fact implies that the Auroral particles would be supplied from the outer radiation belt. However, since Aurora occurs continuously, the belts must be continuously replenished, perhaps by the solar wind, but the problem has yet to be solved.

An electric field is generated in the ionospheric E region when a wind of the neutral ionosphere blows across an inhomogeneity. This field is generated by a charge-separation mechanism which exists because the electron gyrofrequency is greater than the electron collision frequency, while the ion gyrofrequency is less than the ion collision frequency. Thus, the ions will tend to be carried along by the wind, while electrons will be held in place by the magnetic field. The electric fields are then capable of driving very strong electrojet currents along the auroral zone. The variability of the electrojet is complex and indeed is yet to be fully understood. Some statistical properties are known; for example, the jet is most intense at local magnetic midnight in the auroral zone, is more active in sun spot maximum than minimum, and inside the zone is more intense in summer than winter.

The dynamo theory conceives the conducting ionized region as the armature of the atmospheric dynamo, the Earth being its permanent field magnet and tidal forces in the atmosphere moving the conducting, layer-like rotor. The tidal

forces are produced by the sun and moon. Usually the currents in the ionosphere are represented by equivalent current systems deduced from magnetic recordings. This method is rather arbitrary, but is a good first approximation. Dynamo-type current systems have a strong 12- and 24-hour wave component which would be one way of interpreting magnetic variations observed on other planets.

f. Magnetic storms. One of the more interesting features of magnetic field variations observed on Earth is the storm sudden commencement (geomagnetic) or SSC. It is characterized by an abrupt change (within 1 to 3 minutes) in magnetic field strength which is then followed by the well known geomagnetic storm. For convenience a geomagnetic storm is divided into two parts: (1) The initial phase is an increase in the horizontal (H) intensity at the beginning, and on Earth its magnitude increases with geomagnetic latitude, reaching a maximum at the auroral zone, (2) The main phase (Dst), beginning when the variation in intensity reverses, gives a decrease in H. Maximum magnitude of the Dst varies between 30 to 400 gammas, with recovery to normal taking place gradually over a period of one or more days.

The sudden commencement is generally observed about 20 to 36 hours after the occurrence of a major solar flare, and it is now known that the two events are positively related. The most widely accepted explanation of this relationship is due to Gold (ref. 35) (1959) (see also Section 2). Briefly, the flare ejects a plasma at a high (but not relativistic) velocity which distorts the sun's magnetic field and actually carries the field lines along with it. As the plasma velocity (and energy) decreases, the magnetic field lines close around the plasma, effectively forming a magnetic bottle. The magnetic envelope of the plasma constitutes a shock front propagating outward from the sun. Upon encountering Earth, the shock front distorts the Earth's magnetic field very suddenly, and the distortion is observed at the surface as an SSC. Alternatively the SSC might be considered as being caused by a magnetohydrodynamic wave disturbance generated by the sudden increase in solar wind.

The magnitude and sign of the SSC changes with location on Earth, and indeed not all observatories will detect a given sudden commencement. However, the geomagnetic storm which follows the SSC is generally observed at all stations. Consequently, the chances of detecting an SSC on Mars or Venus is small, especially if the data sampling is not continuous, but the probability of observing the associated magnetic storm is high. Sudden-commencement-type storms occur much more often during and following years of high sun spot activity, so the timing of Voyager is favorable for such studies.

It is not expected that magnetic storms would begin simultaneously on Earth, Mars, and Venus because of their relative orientation with respect to the sun and the finite propagation time of the magnetically constrained plasma.

Thus, the observation and study of magnetic storm occurrence on all three planets should contribute significantly to the understanding of the solar flare process of plasma ejection and solar terrestrial relationships as well. For example, observation of several storms over a period of time, with the three planetary observatories at different relative orientations with respect to one another and the sun, should allow an estimate of the extent, configuration, and propagation velocity of the solar plasma.

Avco RAD has been actively engaged in studying solar terrestrial relationships and interpreting the transient variations in the Earth's field caused by the solar wind.

g. Cyclic phenomena. Current systems in the ionosphere, dependent on the sun for exogenetic forces will be expected to have a daily cycle. The S_q (solar quiet day) current system is one type observed on Earth. A magnetometer observing this daily variation would have a maximum in phase with the subsolar point. For middle latitudes on Earth (ϕ_m = 50 degrees) the amplitude of this variation in the most active component is between 50 and 100 gammas depending upon the season. Perturbations in the planet's field in the form of giant pulsations or hydromagnetic waves could maximize when the planet's rotational axis and magnetic axis are aligned in the planet-sun direction. This type of field disturbance would be highly dependent on season and geographic latitude.

Other types of daily cycles would be composed of disturbance effects. Knowing the "steady state" solar field effect, subtraction would yield the disturbance field to a first approximation.

Magnetic disturbances dependent on exogenetic forces would have a spectacular yearly cycle. For example, on Earth the level of magnetic activity in the polar regions has two to three times the magnitude in summer as in winter.

Solar activity undergoes a cycle of about 11 to 17 years. During the minimum phase, solar flare eruptions are rarely observed and the Earth is affected by few plasma clouds. For a 2- to 3-year period centered around sun spot maximum, the opposite situation occurs. Due to the variable nature of the Earth's field, a long period of observations at one location is necessary for a complete definition of the cycle. A sun-spot cycle effect would not be observed readily on Mars. However, disturbed conditions in phase with Earth observations (long period) would be in sympathy with our knowledge.

2. Suggested measurements. Investigation of the Earth's magnetic field has been a geophysical problem of prime importance for many years, and even today our understanding of it is not yet complete. Thus, in a program of scientific exploration of other planets, measurements of their fields is even more important. Inclusion of magnetic experiments in the Voyager program will not only give us a first knowledge of the fields of other

planets, but may provide the key to the generation of planetary magnetic fields and their interaction with the solar and interplanetary fields, and consequently lead to a better understanding of our own terrestrial field.

The program should indude at least the following measurements:

a. Interplanetary magnetic fields, particularly those associated with rooted magnetic bottles which guide corpuscles potentially lethal to man.

b. Mars and Venus magnetosphere boundaries

c. Field structure, ring currents, radiation belts, and any existing anomalies

d. Ionospheric currents

e. Temporal field variations.

All these measurements can be made with the same instrumentation. The relative importance of these measurements is indicated in the priority list in table 5 at the end of this section. Early Voyager measurements will indicate the direction which later researches should take. Results could be applied to the priority matrix to indicate how each expedition's results can be optimized.

Other references to this section include refs. 16a, 17a, 31a, 36, 37, 38, and 39.

TABLE 4

ATMOSPHERIC STATICS AND DYNAMICS

Information Desired	Comments	Measurements	Values on Scale of 1 to 10
Pressure, surface	Venus: 30 to 60 atmospheres Mars: 15 to 120 mb estimated for surface	With atmospheric probes and landers With all landers	10
Position of pole of rotation to orbital plane Rate of rotation	Needed for Venus for definition of circulatory regimes and indication of their influence on surface. Values for Mars are well known		10
Temperature Planispheric charts as a function of seasons	Seasonal averages at all latitudes and longitudes wanted for Mars and Venus. On Mars, near surface tropospheric temperatures and surface lithospheric temperatures are most important. On Venus, action of subsolar point and expected surrounding convection rings and atmospheric waves are of most importance	Orbiter optical, infrared, and radar measurements will give temperature estimates	9
Albedo	In the center of the optical band Venus about 0.76 and Mars about 0.15. The value for Venus may be due to silicate dust from an aelosphere	Orbiter TV photos will better define this	5
Compositions	The compositions of the atmospheres of Mars and Venus are thought to be predominantly nitrogen. This is geochemically an atmosphilic element. Oxygen and H_2O are not. Composition is wanted in bulk and as a function of altitude	Atmospheric probes and landers should measure compositions from exosphere energy Km (if possible) to the surface.	9
Wind velocities Turbulence	Wanted as a function of latitude, longitude, altitude, and season on Mars, with emphasis on behavior of troposphere. Same on Venus with emphasis on subsolar spot and ionospheric layers of both illuminated and dark sides. Important to geological erosion and deposition of Venus and Mars	Orbiters and landers to be used. On both Venus and Mars balloons with radio monitors and relays should be considered	8
Clouds Composition Ceilings Patterns	For effects on reentry heat shields. Layers present on Mars. Does dust mark top of Troposphere? Venus: Is troposphere clear below cloud layer? Record for evidence of circulatory regimes		10 7 5
Layers Aerosols Relation to surface features Precipitation Horizontal visibility	Thicknesses, altitudes, compositions, histories, and typical structures should be recorded. Origin from surface or from space as micrometeorites Check on theory that noctilucent clouds originate from metoarite dust in Earth's upper atmosphere could possibly be proven or disproven on Venus and/or Mars. Telephotos show strong association over Mars. On Venus troposphere may be 60 miles thick and surface features should have less influence. Liquid H_2O and cool H_2O vapor may precipitate from tropospheric clouds of Mars. H_2O may precipitate never to reach the ground in upper atmosphere of Venus. Influence on later work by landers and probes	Use orbiters, probes, and landers (Data on circulatory regimes highly desired to improve understanding of meteorology o Earth's atmosphere)	3 1 6 4 1

TABLE 4 (Concl'd)

Information Desired	Comments	Measurements	Values on Scale of 1 to 10
Heat balance	On Venus, the atmosphere seems to be a major heat reservoir. On Mars the ground is a more significant reservoir	Measure for comparison with Earth	10
Atmospheric electricity	Sferics - distribution and intensity for Venus and Mars wanted Dynamo currents - distribution and intensity for Venus and Mars wanted Electrojets - distribution and intensity for Venus and Mars wanted Aurora - distribution and intensity for Venus and Mars wanted Presence of electron flux to space wanted for Venus and Mars to test theories on endogenetic energy generation in body of Earth. Night airglow - presence of 50 to 70 Km oxygen green layer and 200 to 300 Km russet (red) oxygen reactive layer Conductivity		9 4 2 5 8 1
Photochemistry Ozone Photosynthesis X-rays	Presence and characteristics of ozonospheres of Venus and Mars are desired. Possibility of this occurring at surface of Mars is energy in UV band so strong that it would destroy chlorophyll. Is equivalent of D layer found in atmospheres of Venus and Mars	During reentry and by "shadows" as diagrammed. Photocells. Use ionosonde surface on topside	10 10 4
Ionospheres	Can equivalents of $G/F_2/F_1/E/Es/D$ of Earth be found in atmospheres of Venus and Mars?	Ionosondes	9
Propagation of sound	Speed of sound as function of altitude wanted. Use of atmospheric seismic measurements to measure structure of atmospherical Venus may be necessary. If aerodynamic drag prohibits use of landers, seismic methods may be used through atmosphere to measure body of planet.	Seismo-acoustic methods	2
Exosphere and micro-meteorites	Presence and nature of gegenschein and Zodiac light of Venus and/or Mars would help in understanding these features of Earth.	Orbiter and on Mars the lander. TV may show these luminous structures	2

TABLE 5

MAGNETISM AND ELECTRODYNAMICS
(MARS AND VENUS)

	Information Desired	Measurements			Desired Accuracy		Comments		Value On Scale 1 to 10
		Minimum	Mean	Maximum					
Mars	Interplanetary magnetic field filaments and magnetic bottles	1 γ	50 γ	200 γ		Every 5000 miles of a threshold showing a plasma filament is passed, speed up the count to delineate plasma structure.	Structure of Sun's distant corona for stability; for dissipation of plasma bottles, indicate hazards in space to manned flight.	Deduce background noise of vehicle in flight	5
	Martian magnetosphere boundary beginning of 25 R_M	1 γ	-	-		4 samples per R_M from 25 R_M to F_2 region (25 R_M is for distance when approaching boundary at subsolar point)	Existence of Martian magnetic field and position in space (B)	Boundary would be expected to be turbulent with a disorder field. Data rate would depend on vehicle velocity.	10
	Magnetosphere boundary to ionospheric levels[2]	1 γ	-	-		4 samples per Mars radius about every 400 km from magnetosphere to ionosphere.	Establishing nature of field (B)	Martian ring current, radiation belts and any other anomalous features would be measured.	28
	Ionospheric levels[2] to surface	1 γ	-	-		Continuous from 500 km above expected F_2 layer where F_2 is defined as dominant ultraviolet absorption.	Search for ionospheric currents (B)	Magnetometer would employ balancing circuitry to obtain total field intensity	7
	Surface daily variability in field	1 γ	-	150 γ		5-second sample per component per hour, half hour or quarter hour. Earth command for increased rate during storms.	Same as no. 4 (B)	These data could be obtained several days after vehicle landed. The data rate would depend on the amount of and causes of variability to be studied.	6
Venus	Interplanetary magnetic field	5 γ	50 γ	200 γ		Every 5000 miles and if a threshold showing a plasma filament is passed, speed up the count to delineate the plasma structure.	Interplanetary mapping and local environment of vehicle (B)	Use to verify previous probes	6
	Venusian magnetosphere boundary beginning at ≈ 6 R_V	5 γ	-	--		Continuous samples per R_V from magnetosphere to top of ionosphere which is taken as F_2 layer.	Existence of Venusian magnetic field and position in space (B)	6 R_V is from magnetosphere expected at subsolar point (all other approaches would give greater values)	4
	Magnetosphere boundary to surface	5 γ	-	--		Continuous	Establishing nature of field (B)	Search for field and/or current regions	7
	Surface daily variability in field	1 γ	-	--		5-second sample per component per 2 minutes	Search for time-varying fields (B); search for highly magnetic rock types	Data rate depends on life time of vehicle on surface	3
	1 Determined by instrument sensitivity and environment 2 Height of parachute deployment 3 Measured by Mariner No. II								

4.5 Cosmic Rays

Cosmic rays are of interest to geophysicists; to biologists, because they are pathogenic and also believed to cause mutations; to communications engineers, because of their ionospheric effects; to the geomorphologist, when he studies materials unprotected by atmospheres; to the physiologist, preparing crews for long space flights, and to others.

The term "cosmic ray" applies to corpuscles (subatomic particles) with energies ranging from less than 10 to over 10^9 mev. Most of the particles are protons, some are alphas, and a small percentage are heavier nuclei, Ginzburg (ref. 40). Recently primary electrons have been discovered (Kiepenheuer, ref. 41; Ginzburg and Fadkin, ref. 42; Ginzburg, refs. 43, 44, 45). Cosmic rays originate from galactic supernova, Ter Haar (ref. 46); the galactic equatorial plan and its associated field, the sun, and extragalactic sources, Ginzburg (ref. 40). Fermi (ref. 47) suggests that collision of particles with galactic plasma clouds may accelerate the particles. Peters (ref. 48) suggests they were accelerated electromagnetically. In brief, galactic cosmic rays are principally protons and alpha particles accelerated by an electromagnetic field. On reaching the Earth, they collide with atmospheric nuclei producing cascades, which continue until the particles decay or lose their energy by collision with air molecules. Some of the most energetic primaries reach the surface. Cosmic ray detectors usually measure secondary components which are largely mesons and neutrons. Solar cosmic rays potentially lethal to man are accelerated in, and guided by magnetic bottles which are apparently "rooted" to the Sun (figures 19 and 20). Once the plasma bottle is detached, it is thought that these particles will cease to be a danger to man. This may happen between Earth and Mars.

1. Observations and models. When primary cosmic rays reach the vicinity of the Earth, they are deflected by the geomagnetic field. Detection of these particles at a specific point on the Earth is dependent upon (1) their magnetic rigidity, (2) the geomagnetic coordinates of the detector, and (3) the zenith angle at which the particles are incident at the top of the atmosphere (Shea, ref. 49). If the Earth's magnetic field can be approximated by a dipole, the minimum magnetic rigidity that a primary particle must have to be recorded on the Earth's surface decreases with increasing latitude, being 14.7 BV for vertically incident particles at the geomagnetic equator, and theoretically zero for particles incident at the poles (Neher, ref. 50). The absolute surface intensity at the equator is much less than that at the poles. A planet without a magnetic field will not have this latitude effect.

Cosmic ray intensity, as a function of latitude and longitude, will indicate the presence, orientation, and intensity of the magnetic field (figures 18 and 19).

The primary spectrum of cosmic rays is composed of protons (91.5 percent), alpha particles (7.8 percent), and other nuclei (Atomic Number > 26) (0.7 percent).

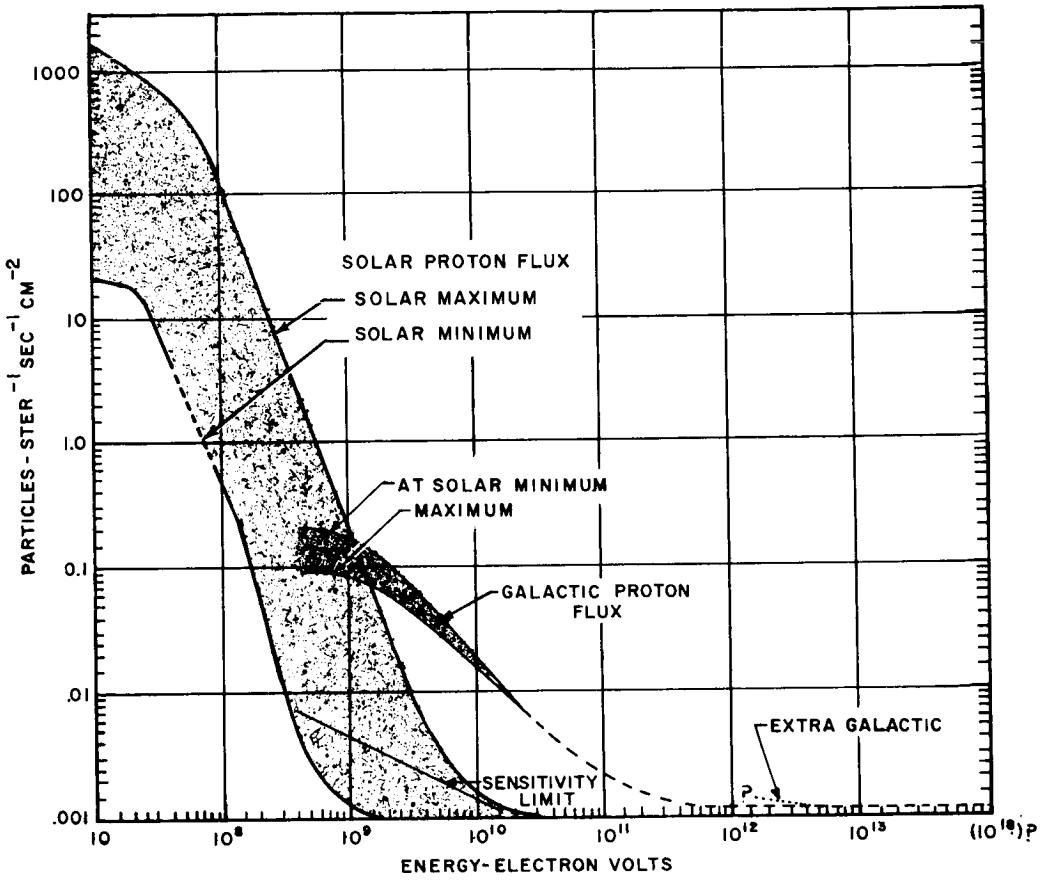


Figure 18 SOLAR AND GALACTIC COSMIC-RAY FLUX
63-8440

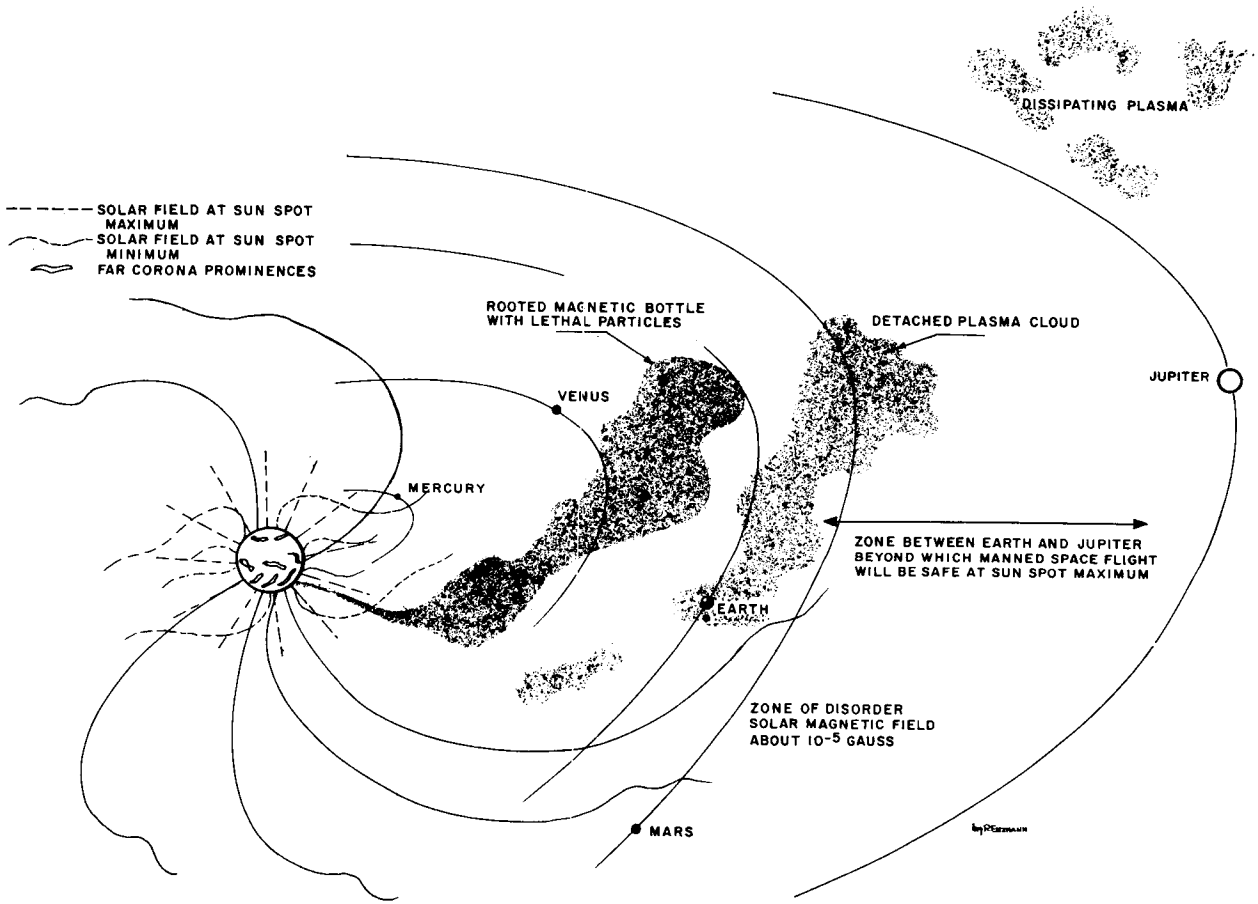


Figure 19 SOLAR MAGNETIC AND COSMIC-RAY PHENOMENA
63-9191

The differential rigidity (momentum/charge ratio) spectrum (Rossi, ref. 51) approaches a power law with a constant exponent and can be represented by

$$\frac{dj}{dP} = KP^{-\gamma}$$

where $\frac{dj}{dP}$ is the number of primary particles per unit rigidity interval, P is the rigidity and K and γ are constants. The average exponent for sun spot maximum is 2.48 for the range 3 to 16 BV with the slope decreasing at about 3 BV to a peak at about 1.2 BV (Webber, ref. 52). The rocket flights of Meredith, Van Allen, and Gottlieb (ref. 53) show that γ becomes negative at rigidities lower than 1 BV. Within experimental error, the primary spectrum at sun-spot minimum is identical for protons, alpha particles, and heavy nuclei, with a predicted total intensity of particles in space as 3900 ± 300 particles m^{-1} $sterad^{-1}$ sec^{-1}. It is not presently known if the spectrum at sun spot minimum represents the true galactic spectrum, or a spectrum with a slight solar modulation (Webber, ref. 52).

Cosmic rays produce secondaries which interact with more nuclei, producing additional secondaries resulting in cascade (figure 20). Cascading begins at ~55 km (21 mb) reaching a maximum at ~20 km (56 mb), which is called the Pfotzer maximum, and mostly of π mesons (Puppi and Dallaporta, ref. 54).

To relate the secondary intensity to primary intensity, the multiplicity function m(P,h) has been defined as the number of secondaries appearing at altitude h due to one primary of rigidity P incident on the top of the atmosphere and is expressed as

$$m(P, h) = -\frac{1}{j(P)} \frac{dN(\lambda, h)}{d\lambda} \frac{d\lambda}{dP}$$

where j(P) is the primary differential rigidity spectrum and $N(\lambda, h)$ is the observed intensity of the secondary radiation at latitude λ, and height h (Singer, ref. 55). At the Earth's surface, the multiplicity factor is less than 1 since only the most energetic particles can initiate a cascade that will continue through the entire atmospheric layer. On Mars, it should be greater than 1.

Secondaries are π and μ mesons, neutrons, protons, electrons, and photons. The π mesons are produced directly from a primary collision and give rise to both the μ mesons and the electron-photon component. π mesons decay into a μ meson and neutrinos (Lattes, Occhialine, and Powell, ref. 56). The μ meson has a high absorption length (340 $gm\text{-}cm^{-2}$) and does not interact with the atmosphere. Absorption of a μ meson occurs only by ionization or decay to an electron by Bremsstrahlung. Maximum μ meson production is at about 200 mb,

but these particles are abundant at sea level. The more energetic ($E > 70$ Bev) are also detected underground. The nucleonic component (neutrons and protons) is produced from both primary and secondary collisions. The rigidity spectrum is similar to that of the primary spectrum with both protons and neutrons produced equally at high energies. At lower energies ($E < 0.5$ Bev) neutrons predominate since they do not lose energy by ionization (Puppi and Dallaporta, ref. 54; Messel, ref. 57).

The neutron intensity is inversely proportional to the atmospheric pressure and must be reduced to a common pressure before analysis. Conversely the meson intensity is in anticorrelation with both atmospheric pressure and surface temperature (Elliot, ref. 58; Lockwood and Yingst, ref. 59).

Almost all of the cosmic ray intensity measured underground is from the μ meson component with a very small percentage ($\sim$1 percent) consisting of protons (Mylroi and Wilson, ref. 60; George, ref. 61). The intensity decreases with depth approximated by a power law with exponent 1.7 from 0 to 300 meters of water equivalent (Puppi and Dallaporta, ref. 54).

In the past three decades, the cosmic ray intensity has been found to exhibit several variations as a function of time. These have been divided into two classifications: long-term and short-term intensity time variations.

The long-term variation is associated with the 11-year sun spot cycle with the cosmic ray intensity inversely related to the solar activity (Forbush, ref. 62). There is not a complete one-to-one correspondence between these two phenomena, however, as the minimum in the cosmic ray intensity lags the sun spot maximum by approximately 6 months (Webber, ref. 52).

There are four short-term variations: (1) sudden decreases, (2) 27-day variations, (3) diurnal variations, and (4) increases associated with solar flares.

Forbush events are associated with solar flares which eject plasma clouds. If the Earth becomes enveloped by this plasma, the total cosmic ray intensity is reduced very rapidly since the galactic particles cannot easily penetrate the magnetic boundaries of such clouds.

Chree and Stagg (ref. 63) found that magnetic disturbances recur at intervals of 27 days corresponding to the synodic rotation period of the equatorial region of the sun. There seems to be a 27-day recurrency in the cosmic ray intensity (Monk and Compton, ref. 64; Broxon, ref. 65; Venkatesan, ref. 66). Studies during the last solar minimum indicated a correlation between the central meridian passage of a solar unipolar magnetic region and a maximum in the cosmic ray intensity (Simpson, Babcock, and Babcock, ref. 67). However, as the solar activity increases, these variations either vanish or are obscured by the Forbush events (Shea and Lockwood, ref. 68).

In the past few years, several researchers have attempted to find a diurnal variation in the cosmic ray intensity (Lindholm, ref. 69; Elliot and Dolbear, ref. 70; Forbush and Venkatesan, ref. 62; Rao and McCracken, ref. 71). Since the galactic intensity is believed to be ~98 percent isotropic, it has been difficult to find a statistically significant daily variation. The discovery of such a variation may indicate that some cosmic rays are either produced or accelerated from a specific section of the galaxy.

During the past 21 years, 12 large increases in the cosmic ray intensity have occurred almost simultaneously with intense solar flares (Forbush, ref. 72; Meyer, Parker, and Simpson, ref. 73; McCracken and Palmeira, ref. 74; Trainor, Shea, and Lockwood, ref. 75; McCracken, ref. 76). These correlations have led to the assumption that these increases are produced by relativistic ($E > 1$ Bev) protons emitted from the sun (Forbush, Gill, and Vallarta, ref. 77; Yagoda, ref. 78).

It is not known what distinguishes a flare that emits relativistic protons from other solar flares. A correlation between flares that produce Type IV radio disturbances with solar particle production has been found by Hakura, Takenoshita, and Otsuki, ref. 79, and Hakura and Goh, ref. 80.

Low-energy solar cosmic rays are limited by the terrestrial magnetic field to polar latitudes greater than 60 degrees geomagnetic. Particles in the 1 to 100 mev range penetrate the atmosphere to the D region increasing the absorption coefficient in the HF spectrum. Obayashi (ref. 82) concludes that the transit time between the occurrence of the causitive flare and the commencement of a polar cap absorption event (PCA) depends upon the heliographic longitude of the flare. Only flares on the visible disc or just beyond the limb of the sun produce PCA disturbances.

If it is assumed that either a radial magnetic field or a very weak field ($B < 10^{-5}$ gauss) exists in the Earth-Sun region, solar particles will travel directly from the Sun to the Earth. However, if a nonradial field with $B > 10^{-5}$ gauss is present, these particles will be deflected and the apparent source, as seen from the Earth, will appear to be different from the actual source McCracken, ref. 76). If the Earth is located within a plasma cloud rooted to the sun when a flare produces relativistic protons, these particles will spiral down the field lines to reach the Earth in minutes. The magnetic plasmas that guide relativistic protons outward from the sun do not remain indefinitely attached to the solar disk as illustrated in figure 19. It is not known at which point they become detached.

The tremendous abundance of lower energy relativistic particles (1 to 2 Bev) has resulted in a spectrum exponent greater than 6 on several occasions (Meyer, Parker, and Simpson, ref. 73; Lockwood and Shea, ref. 83).

In order to protect men and delicate instruments from these harmful relativistic particles during sun spot maximum, the spacecraft must be properly shielded.

2. Suggested measurements. In cosmic ray studies relative changes of intensity with respect to time and position are of most importance. From these measurements, comparisons can be made between data obtained on planetary surfaces and orbiting satellites. Correlations can then be made with various solar phenomena for the purpose of planning safety factors necessary for a manned expedition. It should be strongly emphasized that for any of the following experiments, a complete and accurate ephemeris is essential to the usefulness of the data.

A cosmic ray detector should be mounted on the rocket vehicle to record changes in the primary intensity during the interplanetary flight. During solar minimum, this intensity will be mostly galactic in origin; however, as the solar cycle progresses to maximum, both galactic and solar particles will be recorded. Sampling should be done as often as necessary to give statistical significance to the data. A scaling mechanism should be utilized to record rapid short time changes in the event of solar flare production, plasma densities, and Forbush decreases.

With respect to the rigidity (or energy) spectrum, the lower limit is determined by the vehicle absorption. The ideal experiment would use a pulse height analyzer to facilitate the determination of a differential spectrum. However, weight and telemetry limitations will probably allow only the determination of an integral energy spectrum. The orientation and changes in the magnetic field should also be measured.

A rocket placed in orbit above the atmosphere of a planet should measure the primary intensity and the magnetic field as a function of latitude and longitude. The magnetic field of Venus must be less than 10 to 15 percent of the Earth's field (excluding local anomalies) (IG Bulletin, ref. 84). Since the Earth's magnetic field deflects solar protons ($E < 1$ Bev) from the equatorial regions toward the poles, the solar intensity does not contribute to the observed cosmic ray intensity above the Earth's atmosphere in low and midlatitude regions. Without a magnetic field, or with a small field, the solar proton intensity will not be deflected as much. If, in turn, the atmospheric pressure is less than that of the Earth, the radiation on the surface of the planet will be appreciable.

It is not known whether or not Mars has a magnetic field. The total air mass of the Martian atmosphere has been estimated to be between approximately 100 and 350 mb (Yagoda, ref. 85). This is in the vicinity of the Pfotzer maximum on the Earth. Consequently the secondary production of galactic cosmic rays may result in a large intensity on the surface of the planet. If there is no magnetic field, the secondary particles resulting from solar protons will further increase the surface intensity; however, the solar flux may be less than the flux

outside the magnetosphere of the Earth, since Mars is at a greater distance from the Sun. Any experiments on Mars should be equipped to record a high cosmic ray intensity with or without the presence of a magnetic field. In addition, the composition of the secondary component and the time variations of the surface intensity should be obtained to determine the shielding necessary for a manned expedition to Mars.

Theories concerning the atmosphere of Venus suggest atmospheric pressures ranging from 300 to 1000 mb at the surface to 4000 mb (Kellogg and Sagan, ref. 86). Marineu II indicated surface pressures of 30 to 60 atmospheres suggesting that the Pfotzer maximum will be many tens of kilometers above the surface. The absence of a magnetic field would mean that solar protons would not be deflected and would be almost exclusively incident on the illuminated hemisphere. Compositions of secondaries reaching the surface and their variations with time should be measured.

A list of priorities for measurements at Mars and Venus is given in table 6. It should be mentioned that many of the expected values listed are only estimates based on either theoretical predictions or initial rocket and satellite studies. References for these tables include IG Bulletin, ref. 84; Frank et al, ref. 87; Freier and Webber, ref. 88; and Biswas et al, ref. 89.

The measurement of the cosmic ray intensity in space and in the vicinity and on the surface of Mars and Venus will aid scientists in determining the proper shielding necessary for future experiments involving both instruments and manned spacecraft. In addition these experiments will be valuable in extending the basic knowledge of the magnetic structure of interplanetary space.

Refs. 89a, 45a, 69a, and 69b were also used in the preparation of this section.

TABLE 6

COSMIC RAYS (VENUS AND MARS)

Information Desired	Comments	Measurements	Value on Scale of 1 to 10
(A Sun Spot Minimum) Interplanetary quiescent background Galactic and solar at Venus, Earth, and Mars orbits	Expected At Earth orbit 9 $(10^2)/m^2$ sterad sec (minimum) 3.9 $(10^3)/m^2$ sterad sec (mean) 4.2 $(10^3)/m^2$ sterad sec (maximum) Values at Venus and Mars follow inverse square laws approximately. The galactic flux is the greatest.	1/hour	4
Interplanetary background at Sun spot maximum Galactic and Solar	The increase is in solar flux and is almost entirely of protons. Expected values at Earth orbit $10^{12}/m^2$ sterad-sec (maximum)	1/15 minutes	7
Nature of Forbush decrease at Venus, Earth, and Mars orbits wanted.	A. Forbush decrease believed due to exclusion of Galactic cosmic rays by solar plasma clouds.	1/hour	9
	B. With Forbush decrease, there should be an increase of solar corpuscles when plant on vehicle is in plasma cloud.	1/15 minutes in cloud	9
	C. Lethal cosmic rays expected when plasma is rooted to Sun; when root is broken, danger to life thought past.	1/15 minutes in cloud	10
	D. Maximum extension of rooted bottles should be found.	1/15 minutes in bottle	10
Solar particles Relativistic	At Earth orbit: $10/m^2$ sterad-sec (min.) 90% drop expected $20/m^2$ sterad-sec (mean) at Mars orbit and $40/m^2$ sterad-sec (max.) 100% drop at 2 to 3 (A. U.)	As necessary to show trends	6
Nonrelativistic	$10^2/m^2$ sterad-sec to $10^6/m^2$ -sec Main danger to astronauts expected from non-relativistic particles		
Secondaries	Average of (10^{12} counts/sterad-sec m^2) largely mesons in either atmosphere, hydrosphere or lithosphere		
Magnetic influences Mars magnetosphere latitude effects of field Local anomalies Van Allen and Ring Currents	If any magnetic fields are present about or close to Mars and Venus, the effect on cosmic rays should be determined in case Venus field will be weak but may be present Expected where planetary fields are strong	1/degree as orbiter circles planet 1/10 km from surface to 25 planetary radii from planet's surface	8
Atmospheric influences	Measurements desired from 5 mb every km to surface in Venusian atmosphere and from sub-solar spot in 5-degree increments to antisolar spot. In atmosphere of Mars from 1/10 mb every 1 km to the surface.	Every km	5
Pfozer maximum	This may occur in upper atmosphere of Venus or in solids of lithosphere of Mars	Increase measurements at and about maxima	4
Solid-state reactions	Equivalent of "metamict" action by cosmic rays in ionosilicates and oxides of Mars should be compared with structures found in silicate meteorites and rocks of the moon.		
Temporal effects 11 to 17-year cycle 27-Earth day solar rotation Mars diurnal changes	Effects in Venus and Mars orbits are desired for comparative study with Earth phenomena and protection of astronauts.	Over period indicated average values wanted	3
Composition	Mostly protons, but expected to include nuclei to Fe and heavier Primary electrons probable Primary neutrons in question	Cerenkov detector could be used	5

4.6 Communications and Electromagnetics

Communications engineering concerns transmission of information between distant points. Communications techniques used during the exploration of Mars and Venus will be based on terrestrial experience, current work in interplanetary space, and observations of these planets. Measurements made during the explorations will continually improve techniques and theory. The suggested measurements for these planets are designed to show phenomena with terrestrial counterparts, although new and different conditions affecting communications over and from these planets are probable. In this section the few observations bearing on communications on Mars and Venus are detailed; parametric models based on terrestrial phenomena are outlined; and suggestions as to measurements to be made listed in apparent order of importance are made.

1. Observations and models. Venus rotates very slowly, either forward, retrograde, or once per Venusian year. Mariner II indicated that its magnetic field was not greater than 5 gammas, with a surface temperature of about 800 °F and surface pressures of perhaps 60 Earth atmospheres. Venus' ionosphere would be best developed in the sunlit hemisphere, particularly at the subsolar yellow spot. In the absence of a significantly strong magnetic field, charged particles from the sunlit hemispheric source would only spread to the dark side sink by diffusion. Critical frequencies, number of layers, thicknesses of layers, details, and ion source to sink movements would vary with angular distance from the subsolar spot. The ashen light variously described as gray, red, brownish, coppery, and russet-colored might represent photochemical reactions of oxygen, nitrogen, or a combination of gases in very high auroras. The troposphere of Venus must be miles deep and practically anhydrous (see section on geochemistry). This could result in extraordinarily strong sferics on both the light and dark side. Absorption, refraction, and ionospheric phenomena are expected to be the major areas of concern on Venus.

Mars has an atmosphere which is tenuous (see section on atmospheric statics). It is not known whether or not it has a magnetic field. If it has, there should be an ionosphere over both the sunlight and dark hemispheres. Solar exogenetic energy incident on the upper atmosphere of Mars and the tenuous nature of this atmosphere indicate that any ionosphere would be more prone to scatter rather than reflect incident radio waves. The band of short-wave frequencies which could be used for reflecting signals over the horizon would be narrower than is the case on Earth, or perhaps nonexistent. Absorption of radio waves in the ionosphere of Mars may also be much more marked.

Experimental results and theory are sufficiently advanced to permit the design of communication links between Mars orbiters and landers, to an extent, Venus orbiters and landers, and to Earth. A great deal of geophysical data are needed to plan effective communications between Venus orbiters and landers on

the surface and to plan for communications during manned landings on Mars. The following may be considered for communication across the surface and to and from Mars: radio ground wave propagation, radio propagation over the horizon, radio relays (passive and active), wire communications, short-range electronic acoustic communications, using the atmosphere as a propagating medium, and pure acoustic methods. Wireless propagation over the horizon is considered in some detail with a series of simple and completely general models: electromagnetic diffraction, critical frequencies, absorption, refraction, Faraday-rotation and cotton-mouton-effect, troposcatter, and noise source.

The need for research on other phenomena and potential communications devices is outlined.

a. Electromagnetic diffraction. Figure 20 was plotted for horizontally polarized S-band radiation at 1 watt. Curve 1 represents values for a perfect sphere. Curve 2, showing multiple humps, represents field strengths over oceanic waters. Curve 3 represents diffraction over the edge of a solid metallic, equilateral, triangle. Curve 4 represents field strengths in free space. It should be noted that power transmitted over the horizon of the "sphere" is caused by surface irregularities acting as edge diffractors. Edge diffraction is a reradiation phenomenon, not a bending of the ray, and transmission as a function of distance is controlled by the electrical conductivity or dielectric constant of the diffracting (reradiating) increment. If the ionosphere of Mars is weak or absent, wireless communication over considerable distances beyond the horizon may still be possible by use of diffraction phenomena.

b. Critical frequencies, Mars. Chamberlain (ref. 90) indicated that Mars has an ionosphere which Kamiyama's model in the section on atmospheric statics describes qualitatively. During daytime at about 130 km the reaction $CO_2 \rightarrow CO + O$ is rapid. Above 130 km, the reaction $O + O + M \rightarrow O_2$ is rapid [Chamberlain (ref. 90)] and the composition is largely N_2, CO, O, and O_2; below 130 km, CO_2 and N_2 dominate. Ultraviolet ionizes both O and O_2 producing electrons. In an atmosphere with no strong mixing or diffusion, an electron density profile might have the following gross features:

1) A sharply increasing electron density gradient (dN/dh); in effect, a ledge at about 130 km. Below this the electron density would be close to zero

2) A maximum electron density (N_{max}) of approximately $10^5/cm^3$ at noon at about 130 km

3) Decrease in electron density with height that is approximately parabolic from N_{max} at about 130 km to about 200 km.

The 130-km maximum and parabolic decrease to 200 km is equivalent to Chamberlain's (ref. 90) E_1 region which has a F_1 peak at about 320 km, with

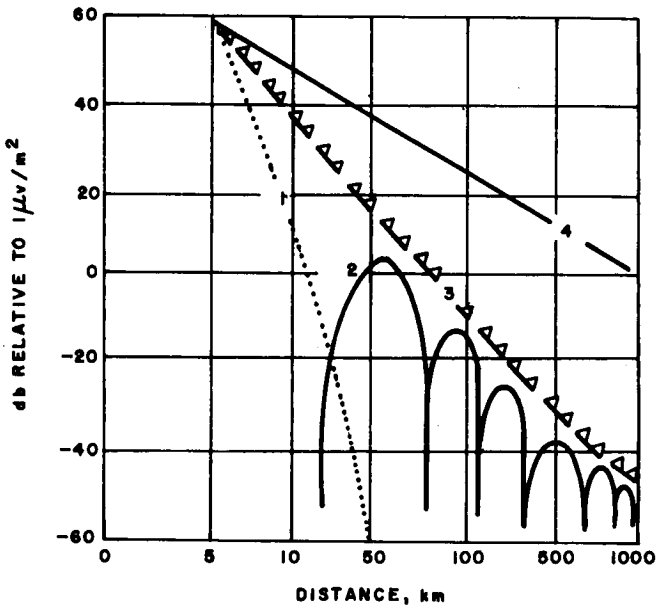


Figure 20 PROPAGATION OF HORIZONTALLY POLARIZED ELECTROMAGNETIC WAVES
63-9578

a maximum density of about $10^5/cm^3$, and a critical frequency of 2.9 mc at noon. The E_1 layer should reflect at its critical frequency, but if charged particle collisions are numerous and rapid, substantial absorption may take place. Furthermore as electrons O and O_2 diffuse and mix, the steepness of the E_1 ledge would be reduced, resulting in higher absorption than in a static atmosphere.

Typical critical frequencies for the Earth's ionosphere are 15 mc at solar maximum, and 11 mc at solar minimum See figure 21 where typical critical frequency of the F_2 layer is shown with barometric maxima indicated by dotted lines. High-frequency channels which can be propagated by ionospheric reflection over Mars are more limited than on Earth. Ionospheric electron densities may be measured during descent or from the surface. These measurements should have range from 0.1 through 10 mc. Topside orbiter sounders like Earth satellite Alouette could provide further information concerning the upper ionosphere, but would be insensitive to absorption which should appear below 100 km.

If Mars has a magnetic field, the magnetoionic medium will cause incident electromagnetic waves to split into two or three components on reflection (reradiation) (Ratcliffe, ref. 91). The gyrofrequency is given as f_H where f_o = critical frequency of the ordinary wave, and f_x = the critical frequency of the extraordinary wave

$$f_H = 2(f_x - f_o) = \frac{eB}{mc}$$

where

f_x = frequency of extraordinary ray

f_o = frequency of ordinary ray

e = electron charge

B = magnetic field intensity

m = mass of electron

c = velocity of light.

This provides an indirect measurement of the magnetic field strength. It should be noted that during reentry phenomena, known as plasma spikes, will be associated with the vehicle; the magnetic field strength is directly related to the frequency of the plasma spikes. A Langmuir probe [Boggess et al (ref. 92)] used during reentry would give an electron-density versus height profile.

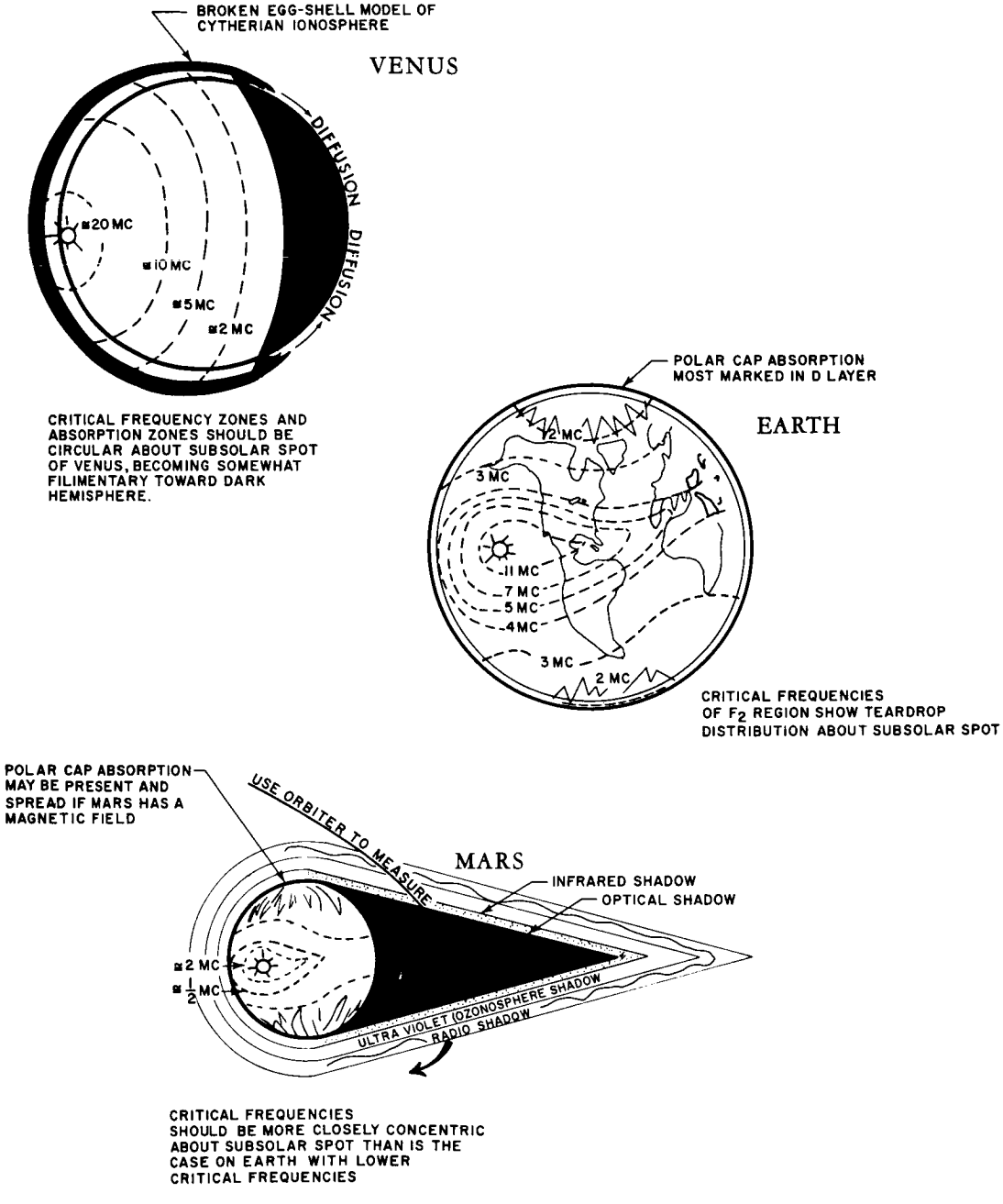


Figure 21 MODEL PLANETARY IONOSPHERES

c. Critical frequencies, Venus. The static atmospheric structure of Venus is even less known than that of Mars. Solar electromagnetic and corpuscular flux is greater, and the planet has only a weak magnetic field if any. Therefore, ionization and high electron densities are likely to be marked over the illuminated hemisphere. They should be at a maximum about the subsolar yellow spot. Measuring instruments should be chosen with the possibility of critical frequency having a multidecade range. The measurements may be made with a few fixed frequencies by assuming that obliquely propagated signals are refracted by the same features that operate in the Earth's ionosphere, and using the secant law for oblique propagation to estimate critical frequencies.

d. Variations of critical frequency with time on Venus and Mars. The Earth's ionosphere is affected by solar-related, geomagnetic storms which bombard the ionosphere with charged particles, mostly protons and electrons. These storms are manifested by lower F-layer critical frequencies, with short-wave fadeout over the sunlit hemisphere, sporadic E-layer increase, and increased absorption in polar latitudes, Such sudden ionospheric disturbances are related to the 11- to 17-year sun spot cycle. Their temporal manifestations are complex but some variations can be predicted [Hill et al (Ref. 92)]. They are thought to occur when the Earth is inside a magnetic bottle that is still rooted to the sun. Sudden ionospheric disturbances can be expected to occur on all planets within a single bottle. Time delays between observations between Venus, Earth, Mars, and intermediate points will measure propagation time in interplanetary space.

e. Absorption. In addition to reflecting HF, LF, and VLF bands, some ionospheric regions (notably the D) attenuate signals as a function of electron density, positive ion concentration, and the solar zenith angle. A maximum may be expected at noon and a broad minimum lasting through local night with the lowest values preceding sunrise. Nondeviated absorption is a result of electron ion collision by electrons set into oscillation by incident radio waves before they can reradiate the radio frequencies. Absorption may be measured by recording radio noise from outside a planet's atmosphere, such as galactic background or amplitude from a radio star. Power needed to maintain high-frequency communications through an absorbing medium may be computed by:

$$L = 8.7p \sec \phi \int_0^{h_r} K \, ds \qquad (90)$$

where

p = number of penetrations through the absorbing medium

ϕ = the angle of incidence of the radio wave

$$K = \frac{2\pi e^2}{mc\mu}\left(\frac{N\nu}{\nu^2 + 4\pi^2 (f \pm f_H \cos a)^2}\right) \tag{91}$$

h_r = height of reflection

μ = refractive index

e = charge of an electron

N = electron-number density

ν = electron-collision frequency

m = mass of an electron

c = velocity of light

f_H = gyrofrequency

a = angle between the direction of propagation and the magnetic field

f = wave frequency (where the ± sign in the denominator corresponds to the ordinary and extraordinary components, respectively).

In the high-frequency spectrum the factor ν^2 in the denominator is much less than $4\pi^2 (f \pm f_L)^2$ for all frequencies above 1 mc in the terrestrial ionosphere where absorption occurs. Neglecting ν^2, the denominator of equation (91) is independent of height and may be moved outside the integral (90), giving the inverse square frequency law for absorption. It is not possible to generalize and apply this to all atmospheres, for at times

$$\nu^2 \gg 4\pi^2 (f + f_L)^2 \quad , \tag{92}$$

and equation (92) becomes

$$k = \frac{2\pi e^2}{mc\mu}\left(\frac{N}{\nu}\right) , \tag{93}$$

indicating absorption is independent of frequency. Transmitting at a higher frequency would not reduce the power required. Intense polar cap absorption is often caused by bombardment of the D region by low energy solar cosmic rays which increase the amount of ionization in this layer.

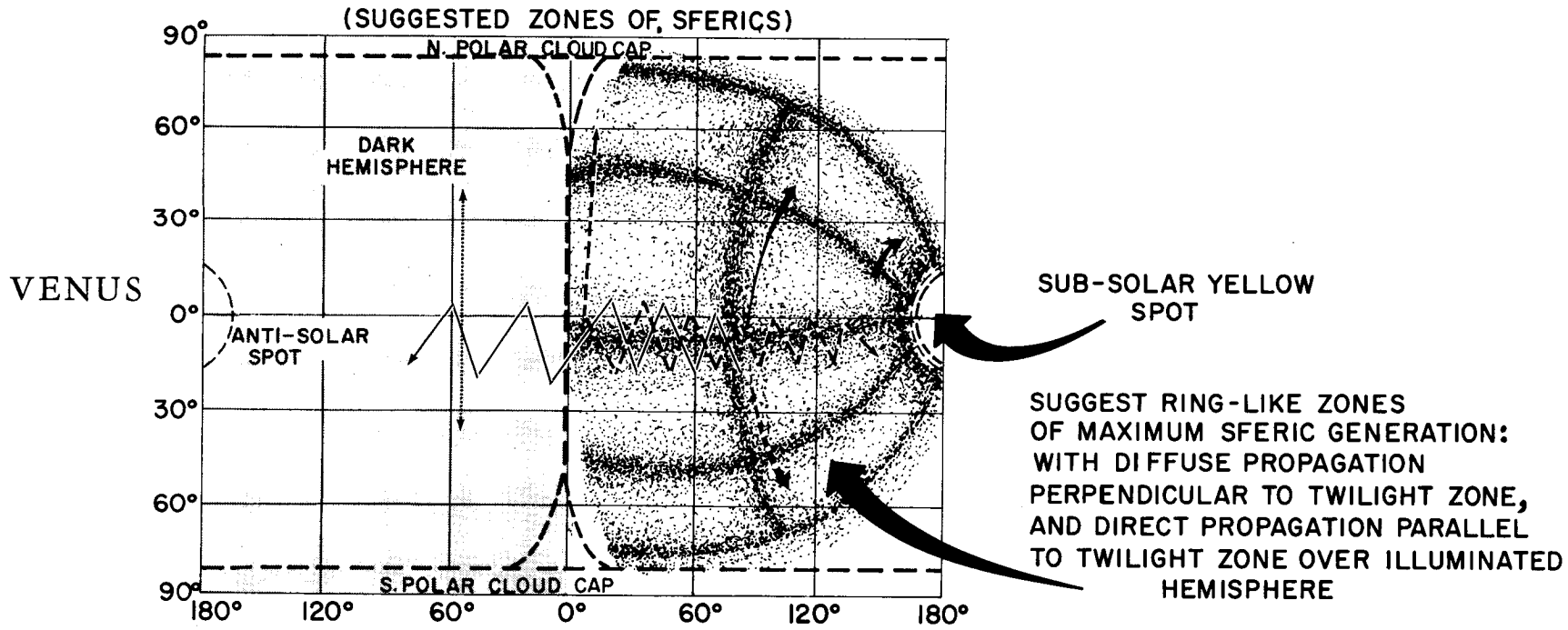
f. Refraction. Refraction is expected to be of major importance on Venus. The atmosphere is enormously thick and dense; the ionosphere on the illuminated hemisphere is expected to be strongly ionized. Optical mapping of the surface from an orbiter is an unlikely method, though there is a possibility that some optical mapping may be done with an atmospheric flyer below the cloud layer. It is probable that mapping of 2nd-, 3rd-, and, hopefully, some 4th-order geomorphic features will have to be done from an orbiter with radar frequencies. After the first atmospheric probes have returned their data, it will be possible to write general equations for refraction. These will be combinations of tropospheric, stratospheric, mesopsheric, and ionospheric terms, which will vary from the dark to illuminated hemispheres.

g. Faraday rotation and Cotton-Mouton effect. These effects are minor though important when trying to make radar maps of terrain. Faraday rotation is at a maximum when the direction of propagation of a radio wave is parallel with the magnetic field in the medium it traverses. The wave is doubly refracted in the magneto-ionic medium. (This may be thought of as a split into two elliptically polarized components with opposite directions of rotation and different phases. If the wave frequency is greater than the gyromagnetic and plasma frequencies, the two components will be nearly circularly polarized and their sum will be linearly polarized waves. However, because of the phase difference, the angle of the linearly polarized wave will change such that the resulting electrical field rotates as it progresses through the medium.) Faraday rotation will be more marked as frequencies progressively less than 100 mc are used. Note that the doubly refracting properties of a magneto-ionic medium can be used to measure its electron content (Daniels and Bauer, ref. 94).

The planetary magnetic field of Venus is less than 5 gammas; however, strong ionic currents on the illuminated side, or from hot side to cold side may well cause local magnetic fields. These could cause local Faraday rotation and Cotton-Mouton effects. On Mars there may be a magnetic field strong enough to develop a magnetopause and ionosphere similar to that on Earth.

h. Noise sources. Sferics may be major noise sources on both Mars and Venus. This noise will not be accompanied by man-made noise. Noise power across the frequency spectrum would be of value. What are believed to be dust storms have at times obscured the entire surface of Mars (Sinton, ref. 95). Under such conditions, it is likely that static charges on the particles will cuase electrical noise. In the terrestrial polar regions, this problem arises from the action of blowing snow under sub zero conditions (Herman, ref. 96) and can cause signal-to-noise levels to drop appreciably in the high-frequency bands. The aridity of Mars and Venus may seriously degrade signal-to-noise ratios during lander to orbiter communication (see figure 21A).

-98-



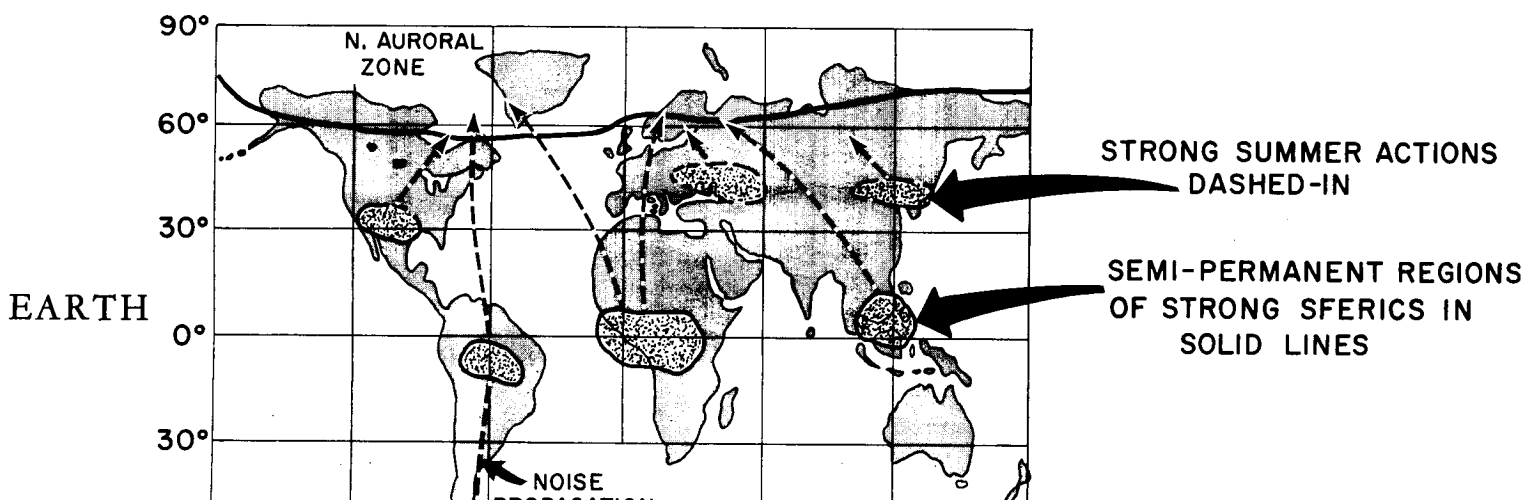
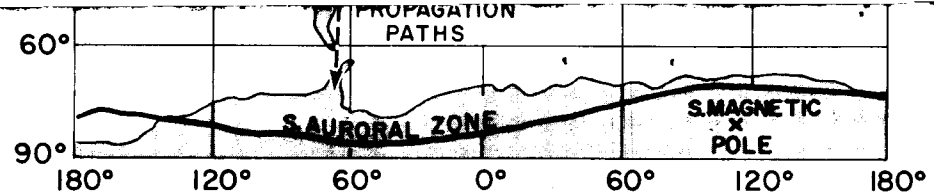
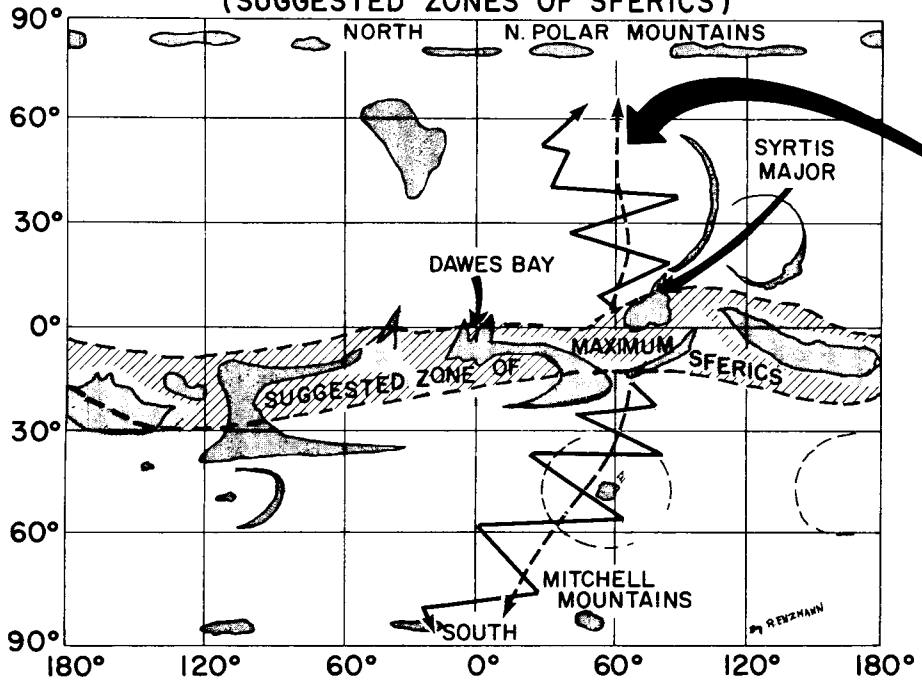


Figure 21A ATMOSPHERE SFERIC A
63-9576



(SUGGESTED ZONES OF SFERICS)

MARS



NOISE PROPAGATION WILL BE BETTER DIRECTED IF MARS HAS A MAGNETIC FIELD

63-9576

2. Suggested measurements. The desired measurements are, in approximate order of importance to communications:

Composition of the atmospheres of Mars and Venus

Presence and geometry of ionospheres

Presence, strength, and orientation of planetary magnetic field

Strength of solar electromagnetic and corpuscular flux incident on the upper atmospheres

Presence of surface ducts, of importance on both Mars and Venus. (On Venus, water differentiation to the upper atmosphere may cause ducting aloft, while on Mars the movement of water vapor close to the ground may cause ducting, of advantage or perhaps disadvantage to explorers)

Types of electromagnetic noise, amplitude, and periodicity. See also table 6A.

Information gained on Mariner flights or early Voyager flights will be used to further define communications needs for both unmanned and manned exploration. The end objective is not just perfection and betterment of exploration techniques, but improving mankind's knowledge of his environment, particularly the Earth. With data from similar, though indeed different, planets, conditions about the Earth will be better understood.

Refs. 97 and 98 were also consulted in the preparation of this section.

TABLE 6A

COMMUNICATIONS AND ELECTROMAGNETICS
(MARS AND VENUS)

Information Desired	Comments		Measurements	Value on Scale of 1 to 10
Refraction	1/10° min. to 10° max through atmosphere		Lander to Orbiter when convenient Minimum of 3	9
Absorption	1 db to 150 db			8
Ground wave propagation	on Mars 13 km to 50 km	Yields minor geophysical data Useful for manned landing or unmanned with mobile unit	3 measures over each ground type	2
Faraday rotation	Mars and Venus zero to n turns		4x/day every 10° from horizon through Zenith to horison	5
Ionosphere: D_s, D, E_s, E, F_1, F_2, G..... Gyro frequencies	Present or absent	With no magnetic field, Venusian ionosphere must be thickest at hot pole and possibly absent at cold pole.		10
Troposcatter	Regular 5°	Over planet if Mars has a magnetic field, differing from hot to cold pole on Venus	Measurements can be approximated with lander-orbiter combination, but are best done with Lander plus mobile unit	-
Peterson communication or M-HOPS	180° max	M-HOP could appear on Venus with concentric fadeout from hot spot		2
Ground ducts Advective ducts Elevated ducts	Mars and Venus: Occasional 10° ? Occasional 10° ? Occasional 10° ?	Ducts could be present over surface of Mars and/or Venus		4
Sferics	1/100 earth intensity to 10X earth	May show nature of ashen light, may also appear at hot spot from Van der Graaff effect	Continuous with threshold on monitor	6
Magnetic field	0 γ Mars 200 γ			5
Ionospheric phase-velocities				1
Communications a) Line of sight b) Ionosphere c) Westford needles d) Ducts e) Troposcatter	Mars and Venus Estimated Maximums: 50 km 180° ? 180° ? 10° ? 5° ?	Long waves should be more important on Venus Communications will need some study on Mars before manned or unmanned mobile unit is landed	Measures can be approximated with a lander-orbiter lander mobile unit combination	3

4.7 Planetary Morphology and Geology

The geological sciences which evolved over the centuries as a vast body of general observations, religious dogma, superstition, and outright imagination, have been slowly pruned and systematized. Mankind will now have an opportunity to perform unmanned and manned explorations of other planets. The problem is to maximize information gained with respect to time and cost. The best way to approach the geological study of Mars and Venus is to note that geology deals essentially with the lithosphere, and therefore concentrate on learning as much about is as possible. This may be done best through the geomorphology and geochronology of Mars and Venus. This approach will eventually make it possible to write historical geologies, and if present, paleogeologies of these planets.

Geomorphology may be studied from the point of view of orders. An undisturbed planet would be a perfect sphere. A planet showing oblateness would show a 1st-order feature. (This is a suggested deviation from standard terminology. Oblateness is a measure of a planets primary figure; however, it is needed data, bears strongly on morphological questions, and will be measured for all later planets studied.) Oblateness is a result of balance between the centrifical force of rotation and the centripetal force of gravity on a deformable planet. Note that asteroids (Ceres, Vesta, etc.) are without Mohorovicic layers, are solid throughout, and could not show marked deformation unless they were within the Roche limit of a larger body and close to the point of break-up. On terrestrial-type planets (Mercury, Venus, Earth-moon, Mars, and possibly Pluto) oblateness is present, though slight if rotation is significantly fast. The slow rate of rotation of Venus may mean that it shows no significant 1st-order feature. On Jovian-type planets (Jupiter, Saturn, Uranus, Neptune) oblateness is marked. A large part of this is due to distortion of massive atmospheres, but much must also be manifested in these lighter planetary bodies. Second-order features (the continental and oceanic domains), as expressed by geomorphic features and gravitational anomalies, are only known for Earth. However, they may be represented on Venus by plateaus; and the dark band north of the equator of Mars might be a 2nd-order geomorphic feature girdling the globe. On Earth, the 2nd-order features are the granitic continental prisms, and the basaltic ocean basins. They represent the end effects of external and internal energies operating on the crust of the Earth. On Earth, endogenetic forces tend to dominate; otherwise the continents would be eroded into the ocean basins faster than they are restored, and the Earth would be covered by a universal ocean. Third-order geomorphic features have dimensions on the order of major mountain ranges (geanticlines) and basins (Gulf of Low California). On Earth, they tend to show cyclic developments which might be idealized as ocean floor, geosynclines marginal to continents, continental shelves, coastal plains, oldlands, and mountains. The sequence is supposed to represent stages in the filling of a fold in the

subcrust of the Earth and its subsequent rise to form a mountain chain--which is in turn eroded to a peneplain. It can be seen that if there were no sediments, as in the deep sea, that a downfold in the Earth's crust would just remain as a submarine valley (note: not trench). It can also be seen that in very thick rocks, a fold could not form and faulting would predominate. It is suggested that faulting may be more predominant on Venus than on the Earth. Faulting, extrusion, and very broad domes and basins may predominate on Mars where the Mohorovicic discontinuity is expected to be quite deep and the lithosphere equivalently thickened. Fourth-order geomorphic features are represented on Earth by single mountains, terraces, shore-line features, lineations, single, volcanic complexes, etc. No 4th-order features have been detected on Venus. On Mars, the gross lineations, fine lineations (canals), and the fine detail of areas like Syrtis Major may represent 4th-order features. Fifth-order features may be used to classify weathered forms, patterned ground, and ground equilibrium slopes. An interesting example is illustrated in figure 22. These are of particular importance to any planned landings on Mars or Venus. Sixth-order features would be microscopic petrological, petrographic, and petrofabric features. Some of these will be observed by the biopac's microscope as it searches for organisms.

The presence and nature of the above listed geomorphic features may be studied by a variety of geophysical methods. Gravitational anomalies measurable by perturbations of a satellite could show orders 1, 2, and 3. Scalar measurements with a surface gravimeter, or vector measurements with an Eotvos balance, should show 4th-order gravimetric features. Magnetic anomalies should be associated with 2nd, 3rd, and some 4th-order features. Study of seismicity should show influence of 2nd, 3rd, 4th, and particularly 5th-order features. Reflection and refraction studies may be necessary before any manned landings are made. Geochemical anomalies should be manifested by all the 1st-order features. Structural geological features will be shown by 2nd- and 3rd-order features, and, in a sense, by the 4th, 5th, and 6th orders.

Concurrent with the many sided approach to understanding and mapping the geomorphic features of the lithospheres of Venus and Mars, geochronological measurements will be attempted. The objective of these measurements will be to eventually detail the historical geology of Mars and Venus. Criteria for geochronological dating on Mars might be (1) superposition of younger beds on older; (2) association of areas of erosion (due perhaps to precession of the equinox, meteorite impacts, crustal tilting, or migration of dunes) with areas of deposition; (3) intrusive sequences; (4) seasonal biological activities; (5) devitrification and seasonal devitrification of natural glasses (obsidian); (6) radioactive features, such as chemical differences, isotopic differences, haloes and metamicted structures, and oldest rocks present.

Figure 22 POLAR STONE RINGS
63-9287

1. Observations and models. Telescopic observations of planetary positions, and their static features yield quantitative knowledge concerning their morphology. The most basic measurements concerning a planet are its mass, radius, mean density, and density distribution. These are approximated as follows:

a. Mass. The mass of a planet is most easily measured if it has a satellite. Geometric and temporal definition of the satellite's orbit makes it possible to compute the mass via Kepler's third law:

$$M = \frac{4\pi^2}{\tau^2 k^2} a^3$$

where

τ = period of the satellite

k^2 = universal gravitational constant

a = semimajor axis of satellites orbit

M = mass of planet.

If a planet does not have a satellite (as would be the case of Mercury, Venus, and possibly Pluto), its mass must be deduced indirectly from its perturbation of orbits of other planets.

b. Radius. All planets except Pluto (which glints) subtend a measurable angle to an observer on Earth. The distance from the planet to Earth is triangulated. The radius of the planet is obtained by multiplying the distance by the angle.

c. Mean density. From the observed radius and mass of a planet, its mean density may be deduced using the formula

$$e = \frac{3M}{4\pi R^3}$$

d. Density distribution. While telescopic measurements cannot yield detailed knowledge of the inner structure of a planet, they may give information concerning the moments of its density distribution. Observations of perturbations of satellite orbits due to deviations of the planet's gravitational field from that of a perfect sphere may be used (see mathematical models) to deduce such quantities as the following:

$$Se\,(2z^2 - x^2 - y^2)\,dv$$

$$Sez\,(2z^2 - 3x^2 - 3y^2)\,dv$$

$$Se\,(x^2 - y^2)\,dv\,.$$

The integration is carried out over the volume occupied by the planet, and x, y, z, denote planet-centered coordinates with y perpendicular to x and both rotating with the planet about z. In principle, an indefinite number of moments may be determined. As yet, only the first has been measured for Mars and Venus. The moment for Venus was measured during the Mariner fly-by. With a Voyager satellite in orbit around Venus, it will be possible to measure additional moments and thus define in more detail the planet's density distribution.

The geomorphology of the Earth is well known to 4th-, and to a degree, 5th-order features through detailed aerial photographs (ref. 99). The historical geology and paleogeology of the Earth is known in considerable detail back to -500, 000, 000 years and in a fragmentary way, back to -3, 500, 000, 000 years (Schuchert and Dunbar, ref. 100).

The geomorphology of Mars is known to the extent of estimating the 1st-order feature, suggesting the dark belt as a 2nd-order feature, suggesting major lineations with concentric (impact?) structures as 3rd-order features, suggesting that "canals" (basalt-filled fissures partially covered with sand?), detail in the dark areas (mountains?), and circumpolar-type mountains may be 4th-order features. Nothing is known concerning the geochronology, but it is suggested that the ochre-, red-, and yellow- (Hellas) type deserts represent different states of oxidation, and may indicate age differences. It is further suggested that the black belt may represent exposure of rocks normally covered with alluvium, and that the black belt may shift from the northern to the southern hemisphere and back approximately every 25, 000 years. This would represent more rapid erosion fluctuating from hemisphere as the northern and southern hemispheres alternated as that with the longer, hotter summer.

The geomorphology of Venus is unknown. No 1st-order feature (oblateness) has yet been measured. The only evidence for 2nd order anomalies is the cold spot detected by Mariner I. The wheel-spoke markings may represent cloud patterns or may somehow be associated with the surface. No positive evidence whatsoever is available indicating the presence of life on Venus as we know it.

e. Model for 1st-order feature of a planet. The 1st-order feature of a planet is the figure which the planet would have if it were in hydrostatic equilibrium. If this were the case, then the surfaces of constant density within the planet would also be surfaces of constant potential energy. Although this is not completely true for the Earth, it seems to be very well satisfied at depths below the crust. The same is probably true for other planets.

The figure of a planet in hydrostatic equilibrium would be a perfect sphere if the planet did not rotate about its axis. Its rotation tends to cause its equator to bulge and the poles to flatten and the planet assumes a spheroidal shape. The amount of flattening (oblateness) and the equilibrium shape of the planet may be computed if the density distribution within the planet is known. (The mathematical method of this computation is outlined in the next section.) The density distribution may be approximately deduced from seismometer recordings if a seismometer is placed on the surface. Preestimates of the shape may be made with judicious use of present information on the mass, radius, mean density, and optical oblateness of the planet's satellites due to departures of the planet's gravitational field from that of a spherically symmetric body.

The acceleration of gravity on the surface of a planet in hydrostatic equilibrium will vary with latitude but not with longitude. The variation with latitude is approximately given by

$$g = g_e \; 1 + \frac{g_p - g_e}{g_e} \sin^2 \theta$$

where g_p and g_e represent the accelerations of gravity at the pole and equator, respectively. The difference $g_p - g_e$ may be approximately expressed by Clairaut's theorem

$$\frac{a_e - a_p}{a} = \frac{s}{Z} \frac{\omega^2 a}{g_e} - \frac{g_p - g_e}{g_e}$$

where a_e, a_p, and a denote the radius at the equator, the radius at the poles, and the mean radius and where ω denotes the angular rate of rotation of the planet about its axis. Deviations from the two above relations will probably be due to departures from hydrostatic equilibrium.

The following is a generalized mathematical model for computing the shape assumed by a planet in a state of equilibrium between gravitational and centrifugal forces. This classical geophysical problem dates back to Isaac Newton. The method we present deviates from those described in standards texts (Heiskanen and Vening Meinesz, ref. 101; Jeffreys, ref. 102, but seems to be more suitable for practical computations.

It is assumed that the planet is composed of N concentric spheroidal layers, each with a constant density, starting from the innermost. These are numbered 1, 2, ..., N. The region outside the solid planet is labeled N + 1. Each layer is assumed to be symmetric about the planetary axis of rotation (θ = 0 in spherical coordinates). It is also assumed that each layer is symmetric about the equator.

The surfaces separating the concentric layers are numbered such that the n-th surface separates the n-th and (n + 1)-th layers. The shape of each surface

is represented mathematically by giving its radius (from the planet's center of gravity) as a function of θ, the polar latitude,

$$r = r_n(\theta) \quad . \tag{95}$$

To start the computation it is assumed that one has the following information:

1. The density ρ_n in each layer
2. The total mass M_n in each layer
3. The angular rotational velocity ω of the planet about its axis.
4. The universal gravitational constant k^2 6.670×10^{-8} (c. g. s. units).

The input sets (1) and (2) must, in addition, be consistent with the relations

$$\sum_{n=1}^{n} M_n = M \ , \tag{96}$$

$$\sum_{n=1}^{n} (M_n/M)(1/n) = 1/\rho \ , \tag{97}$$

where

M = total mass of planet

ρ = mean density of planet.

From the above input data, it is desired to compute the $r_n(\theta)$ which describes the surfaces separating layers of constant density.

The principal assumption on which all these theories rests is that, except for a thin crust (the lithosphere), the planet is in hydrostatic equilibrium. It is assumed that each surface $r_n(\theta)$ is a surface of constant potential (potential energy per unit mass due to gravitational plus rotational energy per unit mass). It is also assumed that the potential and its gradient are continuous from layer to layer, and that the contribution due to gravity is finite at the planet's center of mass, becoming vanishingly small at large distances.

The potential in the n-th layer may be expressed in the form:

$$W_n = (2\pi/3)\, k^2 \rho_n r^2 + (1/r) \sum_{M=D}^{\infty} (A_m^n r^{2m+1} + B_m^n r^{-2m})\, P_{2m}(\cos\theta) + \frac{1}{3}\omega^2 r^2 - \frac{1}{3}\omega^2 r^2 P_2(\cos\theta) \tag{98}$$

where the $P_m(\cos\theta)$ are the well known Legendre polynomials. The fact that the sum in (98) only includes polynomials of even order follows from our assumption that the surface $r_n(\theta)$ is symmetric about the equatorial plane. The constants A_m^n and B_m^n are unknown except for the A_m^{N+1} and B_m^1 which must be zero to satisfy the boundary conditions on the potential at the center of mass and at infinity.

In a similar manner, one expands the $r_n(\theta)$ in the form

$$r_n(\theta) = \sum_{m=0}^{\infty} R_m^n P_{2m}(\cos\theta) . \tag{99}$$

The problem now reduces to that of finding the constants A_m^n, B_m^n, and R_m^n.

Since the potential and its gradient must be continuous at each discontinuity surface, we require

$$W_n(r_n(\theta), \theta) = W_{n+1}(r_n(\theta), \theta) \tag{100}$$

$$|\nabla W_m(r_n(\theta), \theta)| = |\nabla W_{n+1}(r_n(\theta), \theta)| . \tag{101}$$

Also, since the surfaces $r_n(\theta)$ must be surfaces of constant potential, it is required that

$$W_n(r_n(\theta), \theta) = \text{a constant independent of } \theta \tag{102}$$

Equations (100), (101), and (102) hold for $n = 1, \ldots N$ and all values of θ. Each of these equations may be converted into an infinite set of algebraic equations by multiplying both sides by $P_{2m}(\cos\theta)\sin\theta$ and then integrating over θ from 0 to π. Thus, for equation (102), we obtain

$$\int_0^{\pi} W_n(r_n(\theta), \theta) P_{2m}(\cos\theta) \sin\theta \, d\theta = 0 \tag{103}$$

for $m = 1, 2, \ldots$ and for $n = 1, 2, \ldots N$.

The set of equations in (103) together with the sets obtained in (100) and (101) represent a set of simultaneous equations for the A_m^n, B_m^n, and R_m^n. Additional equations result from the fact that density in each layer times the volume of the layer must equal the total mass in the layer.

Hence:

$$M_n = \rho_n \frac{2\pi}{3} \int \left[\left\{ \pi r_n(\theta) \right\}^3 - \left\{ r_{n-1}(\theta) \right\}^3 \right] \sin\theta \, d\theta \text{ for}$$

$$n = 1, 2 \ldots, N \text{ and where } r_0(\theta) \equiv 0 \quad . \tag{104}$$

The solution of the equations for the A_m^n, B_m^n, and R_m^n is accomplished by a perturbation scheme. One considers the A_m^n, B_m^n, and R_m^n as being of the order of ω^{2m}. With this ordering, expand (100), (101), (102) and (104) in a power series in ω. In (100), (101), and (102), this power series is reexpressed as a sum over Legendre polynomials, and corresponding coefficients are equated.

For the zero-th approximation, let all of the A_m^n, B_m^n, and R_m^n for $m > 0$ be zero and let ω^2 be zero. To obtain equations from (100), (101), (102), and (104) for the zero-th order coefficients, terms of greater than zero-th order in ω^2 are discarded. These equations constitute 3N simultaneous linear equations for 3N unknowns and are easily solvable.

In the first approximation, we let the A_m^n, B_m^n, and R_m^n be zero for $m > 1$ and let the $m = 0, 1$ coefficients be split in the form

$$A_m^n = (A_m^n)^{(0)} + (A_m^n)^{(1)} \tag{105}$$

and similarly for the B_m^n and R_m^n. The $(A_m^n)^{(0)}$ are the zero-th approximation solutions. Then these expressions are substituted into (100), (101), (102), and (104), and terms of greater than first order in ω^2 are discarded. Coefficients of corresponding Legendre polynomials are equated to obtain GN simultaneous linear algebraic equations for the $(A_n^0)^{(1)}$, $(A_m^1)^{(1)}$, $(B_n^0)^{(1)}$, etc. In general these will need to be solved on an electronic computer.

The method may be carried to the 3rd, 4th, etc., approximations by similar methods. The only limitation on the convergence of the method is that ω^2 be small compared to $k^2\rho$ where ρ is the planets mean density. For Mars and Venus, this requirement is more than adequately satisfied.

f. Measurement of 1st- and 2nd- order planetary features by pertubation of satellite orbits. The position of a satellite as a function of time depends on the gravitational field in which it moves. If one desires an accurate ephemeris giving the path of the satellite, an accurate knowledge of the gravitational field is needed. If, on the other hand, the gravitational field is not accurately known, then accurate observations of the satellite's position may be used to determine the gravitational field. In the Voyager program, one will initially need a good estimate of the gravitational field in order to predict the position of the orbiter.

The measurement of the deviations of the actual path from the predicted path will enable us to revise the previous estimate of the gravitational field. With this information, a better estimate of the path of future orbiters may be obtained. Furthermore, the information obtained concerning the gravitational field of the primary body is of scientific interest as it will aid in the determination of the distribution of mass within the planet.

In this section, we will briefly discuss the problem of computing a satellite's orbit once the gravitational field is known. This is, of course, the central problem of celestial mechanics, but it shall not be our intent to present a detailed treatise on this subject. Instead, our purpose will be merely to display the fundamental equations and to demonstrate that the problem is completely solvable with the aid of high-speed computers. For a more detailed discussion of the topic, we recommend the text by Brouwer and Clemence (ref. 103). In the latter part of this section, we will show how parametric studies may be carried out to determine the gravitational field of the planet from observations of satellite motions.

Newton's second law for a satellite of mass m in a gravitational field with gravitational potential U may be written in the form

$$m \frac{d^2 \vec{r}}{dt^2} = m \vec{\nabla} U , \tag{106}$$

where $r = (x, y, z)$ describes the position of the satellite with respect to a fixed coordinate system at time t. The gravitation potential U satisfied Poisson's equation,

$$\nabla^2 U = -4 \pi k^2 \rho \tag{107}$$

where k^2 is the universal gravitational constant and ρ is the density of mass in space. The general solution of (107) may be readily written down in the form

$$U(\vec{r}) = k^2 \int \frac{\rho(\vec{r}\,')}{|\vec{r} - \vec{r}\,'|} \, dv' \tag{108}$$

where the integration extends over all space.

Since the mass density is for practical purposes negligible except within massive bodies such as the planets and the sun, we may approximate (108) by

$$U(\vec{r}) = \sum_i U_i(\vec{r}) \tag{109}$$

where $U_i(\vec{r})$ denotes the gravitational potential at point $\vec{r}$ due to the i-th massive body. The individual U_i is also given by an expression of the form (108), the integral extending over the volume of the body and ρ denoting the density within the body. If the body is sufficiently far away from the satellite, it may, for all practical purposes, be regarded as a point mass. In this case, $U_i(\vec{r})$ may be approximated by

$$U_i(\vec{r}) \approx \frac{k^2 M_i}{|\vec{r} - \vec{r}_i|} \tag{110}$$

where M_i denotes the total mass and $\vec{r}_i$ denotes the position of the center of mass of the i-th body.

Generally the approximation (110) is valid for all bodies with the possible exception of the primary body, i. e., the body around which the satellite is moving. It would be valid for the primary body if its density distribution were spherically symmetric about its center of mass. While this is approximately true for all the planets, the deviations of their densities from spherical symmetry should cause observable effects on the motions of artificial satellites in low-altitude orbits or in orbits with large eccentricities. This has been observed and studied in some detail in the case of satellites revolving about the Earth (see, for example, O'Keefe).

The form of the potential of the primary may be put into a convenient form by the use of spherical harmonics. In a coordinate system fixed in the planet, the origin coinciding with the center of mass, and the Z axis extending along the axis of rotation, the potential U_p of the primary is given by

$$U_p(\vec{r}) = \frac{k^2 M_p}{r} + \frac{1}{r} \sum_{l=2}^{\infty} \sum_{h=0}^{l} \frac{A_{lh}}{l} P_l^h(\cos\theta) \cos(h\phi + \delta_l^h \tag{111}$$

where r, θ, ϕ give the position of the satellite in spherical coordinates. The angle θ is measured from the +Z axis. The $P_l^h(\cos\theta)$ are modified Legendre polynomials. A brief table is given by Stratton (ref. 105). The quantities A_{lh} and δ_l^h are constants which are dependent on the density destribution and the shape of the planet. To remove any ambiguity in their definition, it is required that

$$\delta_l^o = 0$$

$$-\pi/2 \leqq \delta_l^h \leqq \pi/2 .$$

With respect to a coordinate system with the same origin and Z-axis, but which is not rotating with the planet, $U_p(r)$ is still given by (111); only ϕ must be replaced by $\phi - \omega_p(t - t_o)$, where ω_p is the angular velocity of the planet and t_o is any time at which the zero meridian intersects the fixed X-axis. With respect to this coordinate system, the positions r_i of the centers of mass of the perturbing bodies will also depend on time. It is assumed that the paths of all such bodies having a nonnegligible effect on the motion of the satellite are accurately known.

An additional complication arises from the fact that the coordinate system having its origin at the primary's center of mass and its Z-axis coinciding with the primary's axis of rotation is not an inertial system. Since the planet is in orbit about the sun, its center of mass is constantly being accelerated towards the sun. Also, the Z-axis is precessing about an axis normal to the plane of the planet's orbit. These effects may be taken into account by adding terms to the right-hand side of (106), i.e. "centrifugal force" and "Coriolis force" terms. It is doubtful, however, that consideration of these terms will be necessary.

We may rewrite (106) in the form

$$\frac{d^2\vec{r}}{dt^2} = k^2 M_p \vec{\nabla}\left(\frac{1}{r}\right) + \vec{g}_{pert} \tag{112}$$

where the first term represents the principal force (per unit mass) on the satellite and the second term represents the perturbing force. The function $\vec{g}_{pert}$ is assumed to be a known function of r and t. With the neglect of Coriolis and centrifugal forces and with the approximations described previously, it is given by

$$\vec{g}_{pert} = \sum_i \vec{\nabla} \left\{ \frac{M_i k^2}{|\vec{r} - \vec{r}_i|} \right\}$$

$$+ \vec{\nabla} \sum_{l=2}^{\infty} \frac{1}{r^{l+1}} \sum_{h=0}^{l} A_{lh} P_l^h (\cos\theta) \cos(\phi - \omega_p [t - t_o] + \delta_l^h) \qquad (113)$$

where the sum over i extends over all other planets, moons, the sun, etc.

g. Gravitational anomalies manifested by 1st-, 2nd-, 3rd- and 4th-order anomalies. The greatest departures of a planet's figure and, consequently, its gravitational field from that of a planet in hydrostatic equilibrium are called 2nd-order anomalies. On Earth, these are the continents and ocean basins. On Mars, the black belt north of the equator may represent a 2nd-order anomaly.

Such deviations may be detected by perturbations in the movement of satellites about the planet in question. More detailed information may be obtained from gravimetric surveys on the surface of the planet. The acceleration of gravity may be measured either by torsion balances or by gravimeters. The former is preferable as it yields the direction of the gravitational field in addition to its magnitude.

The method of analyzing data from gravimetric measurements on Earth is fairly well established:

1) Latitude correction (1st order correction). The first step is to compare the acceleration of gravity at the measured point with the value expected for an oblate spheroidal planet in hydrostatic equilibrium. Since one will desire to compare measurements of gravity made at different latitudes, it will be necessary to correct for the latitude variation expected for a planet in hydrostatic equilibrium.

2) Free air correction (2nd order correction). A point on the surface at which gravity is measured may lie either above or below a point on the 1st-order oblate spheroid. Since the mutual attraction of masses decreases

inversely as the square of the distance between their centers of mass, a point above the oblate spheroid will show a lower value and a point below a higher value than the 1st-order figure named. Correct for this with an altitude or 2nd-order correction. Such deviations are called "free air anomalies."

3) Bouguer correction (2nd-order correction). If a point on a planet's surface is above or below the corresponding point on the 1st-order oblate spheroid, the mass, or deficiency, between the point and the spheroid's surface will contribute to the downward pull of gravity. To compensate for this effect, Bouguer corrections are made. To carry out these corrections, we must know the position of the point measured. Deviations of the corrected gravitation from that of the 1st-order prolate spheroid are called "Bouguer anomalies."

4) Airy corrections (2nd order correction). Measurements on Earth show that in regions of high elevation the gravitational attraction is less than that computed by the Bouguer method, and in regions of low elevation it is greater. The generally accepted explanation for this phenomenon is that proposed by Airy. He states that the Earth's crust is composed of blocks of one density but different thicknesses floating in a heavier substratum. The weight of the part of a block above sea level is held up by the buoyancy of a root extending below the normal depth of the low-density surface layer. To apply Airy's theory to compute gravity corrections, one must have several parameters: H, the normal depth of the low-density layer, the density of the blocks, and the density of the substratum. Values for H and these densities may be approximated from structural geological and seismic evidence.

5) Topographical corrections (3rd-order corrections). Free air, Bouguer, and Airy corrections are essentially related to 2nd-order geomorphic features such as domes, mountain ranges, basins; valleys will cause more localized gravimetric measurements in their immediate vicinity. The correction for their influences is carried out in a manner similar to that for the Bouguer and Airy anomalies.

6) Local deviations (4th-order correction). Local anomalies not compensated by the above series of corrections indicate density variations in the planet's crust. These might be caused by low density granite batholith, high density basic intrusions, etc.

2. Suggested measurements. The first measurements will determine the presence, magnitude, nature, and indicate the origin of 1st-, 2nd-, 3rd-, and, hopefully, 4th-order geomorphic features on Mars. It is hoped that 1st, 2nd, and 3rd features on Venus can be delineated by radar mapping. This initial work can be done from the orbiters. A limited knowledge of 4th-, 5th-, and 6th-order features on Mars can be gained from the landers. Hopefully, it will eventually be possible to place the landers on Venus and gain similar information.

The initial work should be followed by definition of geomorphic provinces on Mars on Venus, as far as this is possible. A manned landing is intended on Mars so considerable emphasis should be placed on determining the percentage and location of ground with features that will prohibit landings by the voyager craft. This might be done by examining the following features:

a. Circumpolar mountains. Percentage of steep slope that would cause Voyager vehicles to roll down into gulleys, and against bluffs which would prohibit opening of the petals.

b. Probable impact features. Determine the percentage of steep mountain slope at crater walls, probability and distribution of fissures, and distribution and nature of coarse rubble which could make landings difficult.

c. Aeolian features. Presence and potential hazards offered by dunes, 4-wind blowouts, bluffs associated with wind pediments, probability of Voyager being covered with dunes.

d. Frost features. Ground patterned by frost action can offer great hazards to manned and unmanned landings.

e. Extrusions. Extrusions should be present and would, under the slow weathering conditions, offer extraordinary broken ground as landing sites. It is suggested that the dark areas, and particularly the dark belt may be sites of such extrusions.

For the sake of terrestrial geology, it would be of prime importance to determine whether or not there have been any manifestations of the Pleistocene, Permo-Carboniferous, early Cambrian, and pre-Cambrian ice ages. If there are manifestations of changes on Mars that can be temproarily correlated with the ice ages on Earth, we will know that this was a system-wide phenomenon which was not restricted to the Earth.

Tables 7 and 8 give planetary morphology and geology for Mars and Venus, respectively.

References 106 through 112 were also consulted in the preperation of this section.

TABLE 7

PLANETARY MORPHOLOGY AND GEOLOGY (MARS)

Information Desired	Comments			Measurements	Value on Scale of 1 to 10
1st order feature (oblateness)	Ellipticity = 0.0052	These features will indicate where lining organisms may be located, what geological-geophysical features dominate in shaping the surface, and where unmanned and manned landings may best be made.		Orbiter kinetics Orbiter T. V. Planispheric map	
2nd order features (continents, belts)	360 deg. "equatorial" dark belt			(orbiter T. V.) Planispheric map	
3rd order features (basins, domes, valleys, ranges)	Fold mountains and valleys not expected Fault features possible Meteor craters likely			Planispheric map (orbiter T. V. lander T. V. balloon, aircraft)	10
4th order features (erosional structure)	Probably terraces and dunes		Mars may be a series of plain and erosion terraces	(lander T. V.) Local maps	
5th order features (weathered detail structure)	Rocks (from extrusion?) and pediments		Will irregularities upset landings?	Pictures (by lander T. V.)	9
6th order features (micro structure)	Fine aeolian grains and hard-pan		Will surface be firm in all geomorphic provinces?	Pictures surface to 1 foot lander microscope	10
Exogenetic/endogenetic character. a) exo-dominant b) balance c) endo-dominant	Exogenetic dominance is expected	Exogenetic dominance on Mars would mean smooth surfaces and dunes	Terraces and benches would be subdued by dune formation and filling	Lander subsoil thermometry with planispheric maps	5
Erosion & Deposition methods of transport a) water b) wind c) gravity rates of movement patterns of movement equilibrium profiles	Minor Major Minor < 1/10 of Earth rates ? Steeper than Earth	Dark rings below fixed clouds may be post rain or mist Low gravity permits steeper slopes Ravines thought unlikely	Polar blue rings may be water moving surface H_2O minor Benches and terraces may appear	Relative humidity a) 4x1 per day b) 50x per day c) 50x per day Surface Eotvos balance Lander T. V. picture	6
Weathering & Diagenesis a) ex/bal/en-dominance b) what part of facies system is present	Greenschist to epidote amphibolite possible		Cosmic and U. V. flux may be important in destruction of rocks and particles	Lander microscope	3
c) destruction: internal forces freeze-thaw thermal-strain abrasion "solifluction" processes	Minor importance Important Important if extrusions present Important 2 cm (extent of actions 1000 m)	Extent of frost features is important; it may be dominant in weathering	Frost polygons & stone rings should be common	Lander T. V. picture Lander T. V. picture Lander T. V. picture Lander T. V. picture Lander T. V. picture	2
Geomorphic Provinces universal coastal plain on Mars?	Only equilibrium slopes, terraces, meteor craters and possibly extrusions are anticipated		Will terraces form or will planet tend toward one vast equilibrium profile		7
Internal Structure Mohorovicic layer lithosphere bottom FeNi core seismicity heat flux out	100 km 600 km 100 km 500 km nearly absent < 1/10 of Earth			Minimum planetary net of 6 sta. Reflection shot Detect with split P waves At pre-set thresholds 4x day for 6 months	(2)
Geochronology yearly varves sun spot cycles precession of Equinox sedimentary cycles disasters (meteors?) oldest exposures	< 1mm ? > 1 cm Occasional sedimentary record >20,000 Earth years <30,000 +100 tons ≥ 1/50,000 Earth years >4,000,000,000 Earth years	Windstorms, weather, and volcanic activity (if any) will show With equinox precession, faults	Indicates summer vs winter rates of sedimentation 11 to 17 year cycles should appear Were there glacial ages No major folds anticipated	Bore as deeply as possible 1 borehole per lander 1 borehole per lander 1 borehole per lander 1 borehole per lander Orbiter + lander T. V.	6
Geochemistry O & H_2O loss H_2O to polar cold traps gravitational difference sedimentary difference diagenetic difference biological concentrations polar cap thickness	To space rate unknown Cold trapping of H_2O Oxygen in exosphere? 1 mm ? 5 meters	H_2O balance between space cold treps & crust is of interest Structures of planets body wanted Light and heavy grains may be separated by wind Water may cause differentials Cold traps may prevent total loss of Mars water	Cold trapping of H_2O may exceed loss to space by many orders of magnitude Water & electrostatic forces may be major consolidating agents	Total H_2O in atmosphere soils, polar caps wanted Seismic, data wanted Analysis at each landing Analysis at each landing Analysis at each landing Measure at polar landing	4

TABLE 8

PLANETARY MORPHOLOGY AND GEOLOGY (VENUS)

Information Desired	Comments			Measurements	Value on Scale of 1 to 10
1st order feature (oblateness)	Ellipticity O.O. From present rate of rotation should be close to zero	If present, this could be frozen in from earlier more rapid rotation	Presence as frozen feature indicative of a very strong lithosphere	(From orbited radar map) Planispheric map	10
2nd order features (continents, belts)	45 deg. in extent As on Earth 180 deg in extent	Plateaus and great basins may be present	Suggest convection in mantle of Venus if present Balance of exo. and endo. forces	(Orbiter radar) Planispheric map	8
3rd order features (basins, domes, valleys, ranges due to folding)	2 deg length to <1/2 deg width Coarser and less frequent than on Earth 360 deg long to 5 deg wide	On planet, the size and mass of Venus there may be a parallel to Earth's geosynclinal cycle	Equivalent of geosynclinal cycle should be weakly redeveloped as oceans seem to be lacking	(Orbiter radar) Planispheric map	7
4th order features (erosional structure)	Height 10 meters Height 30,000 meters	Nature of cliffs, mountains, troughs if present	Sizes of features as compared with those on Earth, nature of erosion caused by exogenetic forces	Planispheric map (Surface T.V. or high atmospheric flyer and orbiter radar	
5th order features (surface structure)	Tafoni weathering?	May represent an extreme case of weathering		(Lander T.V.) Local Maps	
6th order features (micro structure)	Fluo-solids? Sands?			(Lander T.V.) Pictures	
Exogenetic/endogenetic character. a) exo-dominant b) balance c) endo-dominant	It is expected that exogenetic forces will dominate more than on Earth	Geology - geomorphology	If dunes formed by winds are more prominent than fold and fault mountains, exogenetic forces dominate	Lander may measure heat flux from the interior	6
Erosion and deposition methods of transport a) wind b) gravity rates of movement patterns of movement	Endogenetic? Dominant >90% Possible <10% No estimate Hot-pole to cold-pole	Earth comparison Are great dunes main 3rd order features?	Endo-features may dominate as on Earth	From orbiter maps plus surface samples 4x day at 6 stations	5
Weathering and Diagenesis a) ex/bal/en-dominance b) what part of facies system is present c) destruction: internal forces freeze-thaw thermal-strain abrasion	At 800°C only rocks of granulite facies expected. Important Inconsequential Dust only Important, likely major erosional force	Rock facies at higher temperature than terrestrial granulite facies may be present Tafoni-type weathering likely less than on Earth Dust borne aloft	H_2O absent or nearly so near surface Surface varies slightly in temperature	Lander samples Lander T.V. picture Lander T.V. and sampler	3
Geomorphic Provinces Universal Sand dunes on Venus	Plastic accretion of particles Free grains that don't agglomerate	Lack of H_2O in lithosphere may mean that consolidation is slow and poor	Is consolidation taking place at depths far deeper than those on Earth?	Lander microscope	2
Internal structure Mohorovicic layer lithosphere bottom FeNi core seismicity heat flux out	Expected deeper than on Earth Deeper than on Earth Smaller than Earth's >1/2 of Earth <1 of Earth's <1/2 of Earth's <1 of Earth's			Preset thresholds from planetary waves from split P waves average values	4
Geochronology yearly varves sun spot cycles precession of Equinox sedimentary cycles disasters (meteors?) oldest exposures	Likely of short Geological duration <1 Venus year >4 10^9 Earth years	Any cycle would be of great interest		Improbable Presence Presence Presence 1x per landing by absorption mass and chemical spectrograph	1
Geochemistry gravitational difference sedimentary difference diagenetic difference biological concentrations	To upper atmosphere Silicates to surface metals to core ? ?	Nickle-iron core? Calcosphere? Are there any lateral differentiations? Thermal differentiations? Vague possibility of forms in (a, b) upper atmosphere		Every 1000 feet from top of clouds With seismograph Rock analysis at each landing Rock analysis at each landing in upper atmosphere	2

4.8 Geochemistry

It is believed that Venus and Mars are composed of elements identical to those known on Earth. Proportions and thermodynamic states may differ somewhat on these terrestrial-type planets but their geochemistries are expected to be more similar than different. In this section, as in the others, the planets Mars and Venus are regarded as aggregates of matter operated on by internally and externally generated energy, net chemical movements and reactions always being toward an eventual equilibrium.

Geochemically the Earth, and to our best knowledge Venus and Mars, can be divided into atmospheric zones, crustal or lithospheric zones, and interior or mantle plus core zones. The planetary aggregate known as Earth can be divided into geochemical zones as shown below. Similar features are expected on Venus, and rough equivalents should exist on Mars. See also figure 23.

MAGNETOSPHERE
- Magnetosphere
- Protosphere

ATMOSPHERE
- Exosphere
- Mesosphere
- Stratosphere
- Troposphere
- Surface (primary discontinuity)

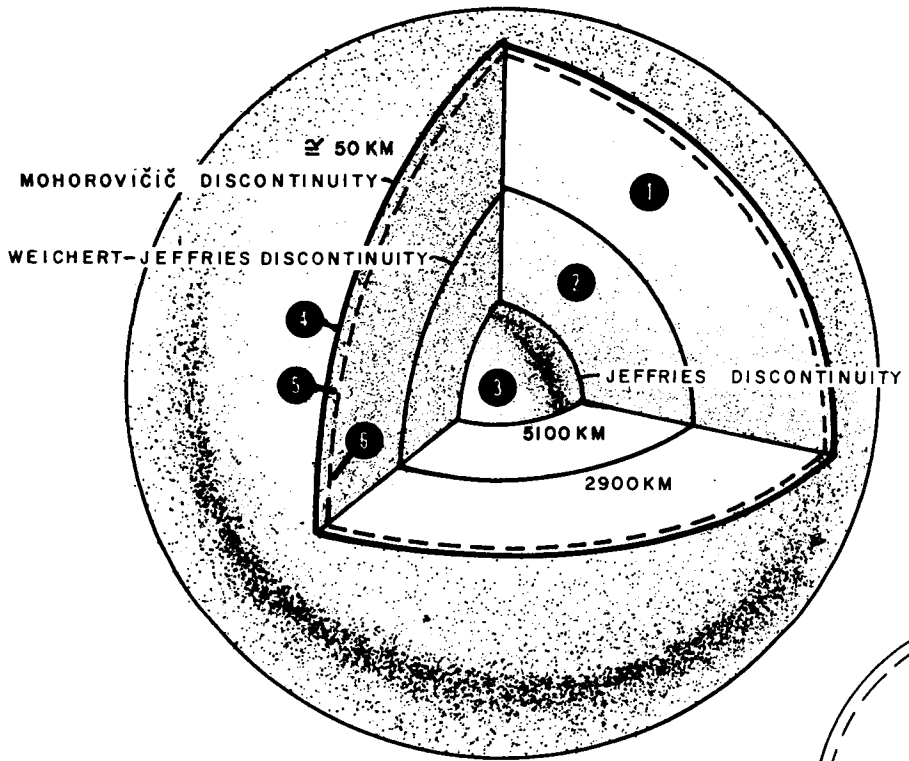
LITHOSPHERE-HYDROSPHERE
- Soils and rocks (decompressed) and water
- Granitic layer
- Basaltic layer
- Peridotite-eclogite layer
- Mohorovičić (primary discontinuity at 30 to 50 km)

MANTLE OF EARTH
- Silicates with interstitial nickel-iron
- A composition like chondrite meteors
- Weichert-Gutenberg (primary discontinuity at 2900 km)

CORE OF EARTH
- Outer core
- Jeffries (secondary discontinuity at 5100 km)
- Inner core

Terrestrial lithospheric and atmospheric chemistry are best understood. However, the interior is only known by indirect seismic evidences and surmises made from studying fragments supposed to have been a planet between Mars and Jupiter. Some generalizations can, however, be made, as illustrated in figure 24.

1. All movement is toward eventual equilibrium, though characterized by temporary, geochemical storage of energy as atmospheric oxygen, biospheric wood, lithospheric coal and oil, and physical-chemical energy gradients stored in gravitational anomalies (2nd-order geomorphic features) of the lithosphere as shaped by forces in the mantle.



EARTH

1 MANTLE (SITE OF SUPPOSED CONVECTION UPDRAFT BELOW OCEANS, DOWN BELOW CONTINENTS) (SILICA; IRON Mn AND Mg OXIDES)

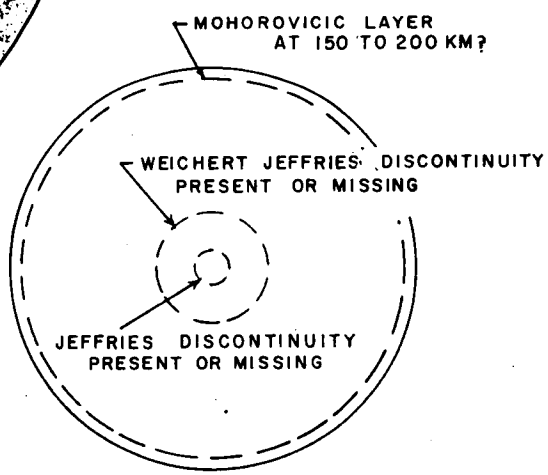
2 OUTER CORE (FREE IRON MINOR SILICATES)

3 NICKEL-IRON

4 (OLIVINE) PERIDOTITE LAYER

5 DENSE OLIVINE DUE TO PHASE CHANGE 150 KM

6 OLIVINE AND NICKEL IRON 300 KM



MARS

Figure 23 INTERIOR STRUCTURE OF EARTH AND MARS
63-8441

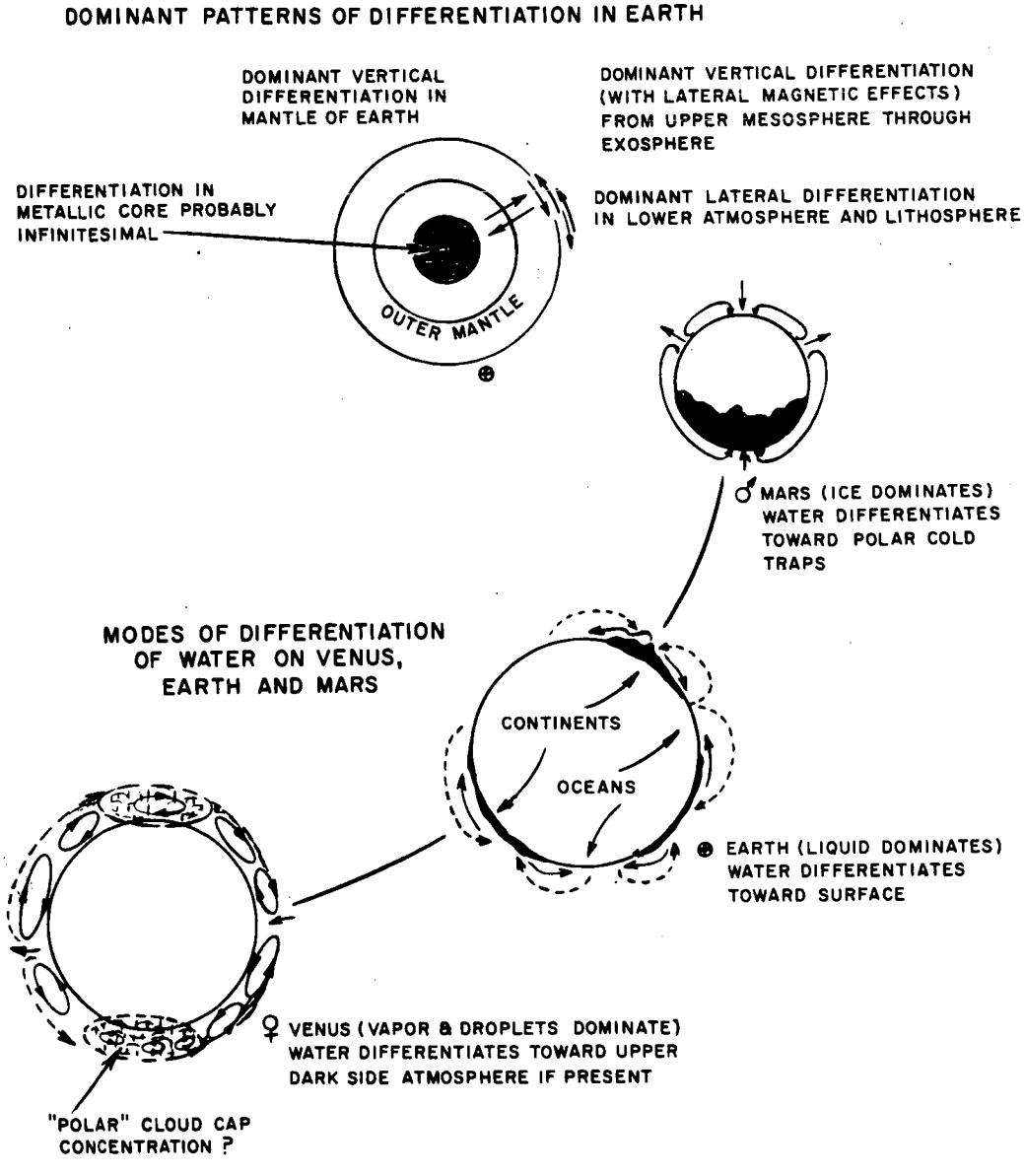


Figure 24 PLANETARY DIFFERENTIATION
63-8442

2. Geochemical differences in all zones arise from differential absorption of energy which causes these local gradients.

3. Vertical differentiation dominates in the upper atmosphere (Paneth, ref. 113). There is significant lateral differentiation, particularly of water, in the troposphere (Humphreys, ref. 114). The lithosphere is markedly dominated by lateral geochemical differentiation (Kay, ref. 115), while the mantle and the core are again thought to be dominated by vertical movements (Jeffries, ref. 116; Gutenberg, ref. 117; and Sahama, ref. 118).

At present only educated guesses, based on telescopic, etc., observations of Venus and Mars, together with knowledge of Earth, can be made. If mankind were able to make observations on Mars and Venus, he would not only enrich his astronomical knowledge, but gain vast insights as to the real nature of geochemical processes associated with the Earth.

1. Observations.

a. Atmospheres. The major constituents of the Earth's atmosphere are nitrogen, oxygen, and minor amounts of water plus carbon dioxide. The major constituents of the Venusian atmosphere seem to be nitrogen (indirect evidence) and minor carbon dioxide with water (indirect evidence). It has been suggested that the oxygen of Earth, and perhaps that of Mars, comes from the photodestruction of water $2H_2O = 2H_2+O_2$. It should be noted that nitrogen, molecular oxygen, and frozen water (ice) do not manifest detectable spectral features at interplanetary distances. The coppery ashen light of Venus may be due to ionic drift with photochemical reactions in the mesosphere of the dark Cytherean side (see broken egg shell model under Atmospheric Statics). Dust in the atmosphere of Venus, rather than liquidus clouds, may account for the high reflectivity of the planet.

b. Water. The geochemical differentiation of water on Venus seems to have been to the upper atmosphere. On Earth it has differentiated to the surface into oceans. On Mars, if the polar caps are water, the differentiation has been into cold traps. This is perhaps fortunate for the water balance of this planet, for water should easily be split into its components H_2 and O_2. The hydrogen could be lost quickly and the oxygen shortly afterwards if splitting into O by photons is frequent. On Earth, major cold traps have formed during the various ice ages; however, these never dominated the oceans as sites of water concentration.

There is some lateral differentiation of water in the troposphere. It may be 4 percent by weight in the lower troposphere of the tropics, less than 0.02 percent by weight near the poles. In the Earth's atmosphere, it is the only common compound that appears as a solid, liquid and vapor in the temperature ranges found over this planet. This unique thermodynamic property causes it to form many localized energy gradients.

The regular association of cloud banks with surface features of Mars, the ground temperatures of these features, the spectral characteristics indicating composition of these features, and an estimate concerning the topographic nature of these supposedly 3rd- and 4th-order geomorphic features makes it possible to predict the movement of water across Mars in more detail.

The major movement of what is supposed to be water is from one polar cold trap to the other. The movement from the northern cold trap is not always complete, as the northern summer is colder. The movement from the southern cold trap has been essentially complete over the years that Mars has been observed. The movement to and from the polar cold traps is in several stages: (1) sublimation, with melting and vaporization of ice and consequent concentration of water in the atmosphere; (2) transport of water with air parcels and by diffusion of water across air parcels to winter hemisphere; (3) condensation of vapor into clouds of water droplets and/or ice, precipitation of water vapor on ground as frost, and/or precipitation of water and snow into winter hemisphere cold trap.

This gross movement should be studied in some detail by terrestrial meteorologists. It is a simplified example of water movements in the Earth's atmosphere which have not been completely analyzed.

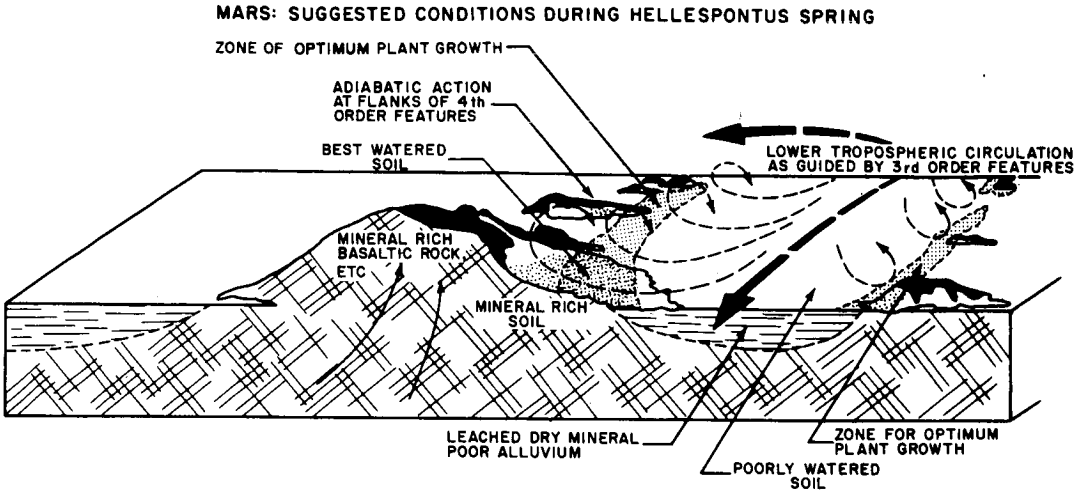
The gross movement of water from its summer hemisphere to the winter hemisphere takes place in its troposphere. The movements of the troposphere are forced by external solar energy, but are modified by the surface features of Mars. In modifying the movement of the tropospheric circulatory regime (see section on atmospheric dynamics), the movement of water vapor is even more markedly modified. Water is thought to be the single constituent in the atmosphere of Mars which is very close to its triple point. This being the case, slight changes in tropospheric pressures, temperatures, and turbulence can cause great changes in the behavior of its water contents. It may be expected that the smoothest, most featureless areas of Mars will show the least changes in the behavior of water. This seems to be the case. The "desert hemisphere", including the areas of Amazonis, Nix Olympica, Memnonia, and Arcadia, seems to display the most regular cloud patterns, and should be the major channel for hemispheric water exchanges.

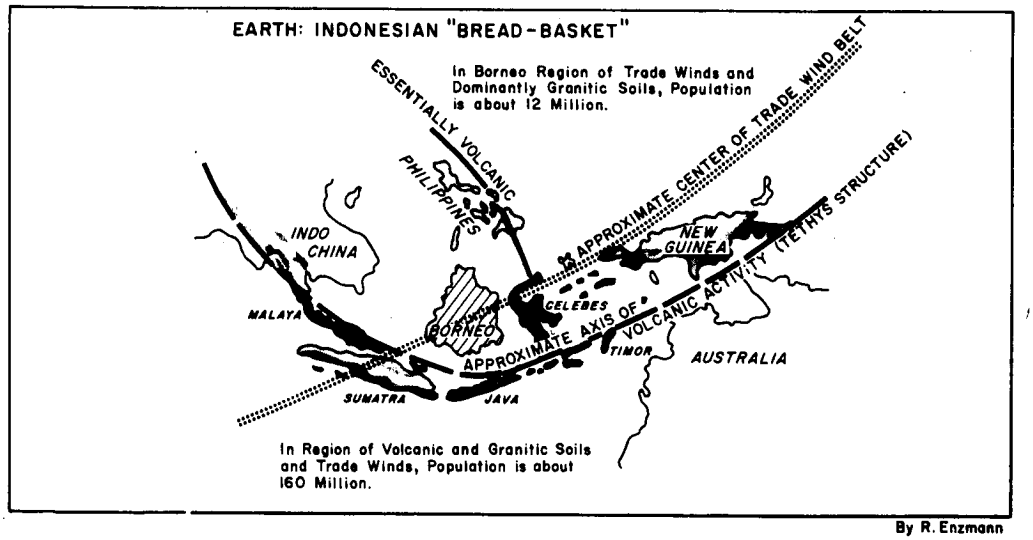
Further details of water movement in the troposphere of Mars are suggested by the rapid darkening of Hellespontus, Nix Olympica, and Protonilus Arabia. These surface features seem to guide and accelerate the movement of seasonal darkenings. It is thought that the darkening is the result of H_2O movement, and this indicates that the permanently dark lineations associated with these tropospheric channels may be higher and darker ground. The movements are suggestive of lower tropospheric vapor movements through channels formed by lines of hills and mountains.

Still finer detail in the weather patterns of Mars is suggested by frequent clear skies associated with Serpentis and Syrtis Major, and cloud banks hovering over Portii, Regio, Ophir, and other markedly dark areas, and fractions of the melting polar caps. Such hovering clouds suggest the generation of a thermal hump by a dark warm area below, high ground below, or a combination resulting from basaltic mountains and hills.

As a final suggestion, a parallel between conditions on Earth and possible conditions on Mars can be drawn. This is to indicate how water and nutrient elements could seasonally be differentiated to concentrate in particular areas. These areas would show seasonal optimums for the growth of living things. In arid regions, atmospheric water is most commonly precipitated on the slopes of mountains. This is because the air forced upward is cooled adiabatically. A similar action may take place in the atmosphere of Mars. It could be controlled by topography or by the greater temperature of the dark areas. It is certainly suggested by the often photographed hovering clouds. If the dark areas represent abundant outcroppings of basaltic or ultrabasic rocks, they would represent a source of nutrient elements which would be scarcer in long reworked sediments. In figure 25, a hillside optimum location for plant growth is suggested. This is the like many of the better watered ranches of the American Southwest. In the same illustration, a geographic sketch of Borneo with its population of approximately 10 million and huge area is shown with Sumatra, Java, and associated islands of small area and population of well over 100 million. The difference is not climatological or topological. It is a matter of soils. The chain of islands is volcanic. Outcrops of volcanic ash, lavas, basalts, and ultrabasics are common. Plants thrive. On Java, for instance, crops are easily raised. This is a striking example of lithospheric-geochemical control of human demography.

Subsurface (or groundwaters) of Mars would behave somewhat differently from those of Earth. Both surface and subsurface flow would be almost entirely absent. Porous ground would tend to be vadose-like with most of the water tending to be held by deliquescent minerals, capillary spaces, water of crystallization, and vapor. Formation of patterned ground by cyclic freeze-thaw actions may be common (figure 22). While runoff as liquid may be entirely absent, there may be considerable "runoff" as vapor. All types of runoff would be minor features associated with the gross seasonal movements of water from cold-trap to cold-trap as modified by 2nd-, 3rd-, 4th-, and 5th-order geomorphic features. Connate water may exist in volumes of aggradation (deposition of sediments) and could take part in metamorphism of such sediments if this happens. It is not thought that regional metamorphisms will be of a degree more marked than the greenschist facies. Contact metamorphism of all facies, from the lowest, which is the greenschist-facies, through the epidote-amphibolite, amphibolite, and extreme premagmatic granulite facies, will be in the presence of enough water to result in rocks similar to those of the Earth. It is thought that contact metamorphism will be more common than regional metamorphism.





By R. Enzmann

Figure 25 GEOCHEMICAL OPTIMIZATION OF SOIL AND ATMOSPHERE FOR PLANT GROWTH
63-9617

Juvenile (new-formed from the depths of the planet) water will only be found associated with primary magma activity. Active burial and metamorphism of volumes of sediments may be associated with hot springs. In general, the flatter and more featureless the topography of Mars, and the quieter and older the crust, the more unlikely it is that springs, fumaroles, and other sources of juvenile and metamorphic waters will be found.

c. Lithospheres. The lithosphere of the Earth is dominated by continental masses and ocean basins. The continental masses (or cratons) are essentially concentric structures with the oldest rocks (intrusive, metasedimentary, and sedimentary) near their cores, and younger rocks at the margins. The continents seem to grow. During this growth process, there seems to be a continuous rise of the center of the mass, accompanied by folding of its edges (and less frequently its interior). The movement of material over the surface from the center to the edge folds (or geosynclinal basins) results in marked geochemical differentiation of all elements and isotopes found in the lithosphere. Once geosynclines are filled, they narrow, fold, seem to be intruded, and solidify into a core. On exposure by erosion, the mass forms a mountain range (or geanticline). Larger, little understood movements dominate the growth of continental masses, or cratons. These larger movements are those that result in the rising and foundering of continental masses. An example is the progression (believed to be continuing) indicated by the foundering of Atlantis, the area between Iceland and Greenland, the North Sea, and it is thought by some geologists that Iceland and parts of Northern Europe are currently sinking toward oceanic depths. These movements are really problems of structural geology not geochemistry. They do, of course, dominate lateral differentiation across the lithosphere and the various cycle elements of the periodic table follow. However, they are only a framework within which geochemical principles operate. The paragraph devoted to the lithosphere might be closed by stating that oxygen tetrahedrally coordinated with silicon is the dominant chemical structure of the lithosphere. The lithosphere is virtually a cloud of oxygen bound by metallic ions in various coordinate patterns. Weathering, metamorphism, formation of magma from sediments, and the habits of primary magmas are dominated by what is called the reaction series, as given below.

On Venus, the lithosphere should be thicker than that on the Earth. If there are major tectonic movements, fault-block mountains rather than fold mountains, as on Earth, should be most frequently formed. This type of movement would allow for much less lateral differentiation. On Mars, the lithosphere is expected to be extraordinarily thick. This should preclude the formation of fold mountains. Vertical movements resulting in block mountains should be more common, and lithospheric petrochemical differentiation may be restricted to faults and a thin surface layer. The black belt close to the equator could represent extrusions, the concentric features, old impact areas, and the darker lineations, more extrusions. The ochre, red, and yellow deserts may just represent impact areas of differing ages.

The cores of Venus and Mars are expected to be similar to those of Earth. Both planets must have Mohorovicic layers. Their positions may be estimated on the basis of equivalent bathymetric pressures. Differentiation in the mantle and core of Venus would be slower than on the Earth and differentiation on Mars vastly slower.

Seismic observations coupled with surface geochemical analyses on Venus and Mars would be of immense geochemical interest. They might serve to answer questions (Goldschmidt, ref. 119) as to whether tremendous pressures could raise phase boundary friction to such values in the mantle and core that vertical gravimetric differentiation might be impossible. According to Kuhn (ref. 120), the mantle and core may be largely undifferentiated solar matter, because at 5000°K under $2(10)^6$ atmospheres 90 percent hydrogen will dissolve in 10 percent iron. In $5(10)^9$ years, only a relatively small percentage of such trapped hydrogen could have escaped.

2. Parametric models. Geochemical models for the Earth when extended to Venus and Mars may yield information that will make them somewhat more exact. Models now used, which should be extended, include:

a. General equations for the thermodynamics of silicates. Essentially behavior of the reaction series under all environmental conditions associated with the Earth

b. Equations for unidirectional movements of elements in planetary aggregates. Essentially: what elements would escape from the planet under ambient exogenetic energy flux; what elements would sink to the core of the planet; and what elements and compounds would remain in the lithosphere?

c. Cyclic movements. On Earth, the oxygen carbon dioxide cycle is typical in the atmosphere/biosphere. The movement of water is cyclic between the atmosphere, surface, and oceans. The movement of iron, aluminum, and phosphorus is cyclic. Still more complex cycles entail the movement of elements in conjunction with each other. It would be most interesting to know what cycles prevail on Venus, and on Mars.

d. Rates of geochemical movement. Rates of geochemical movement are known approximately by study of the oldest rocks, erosion rates, mineral depletion with such fascinating effects as a concentration of a considerable fraction of the planets elemental gold being concentrated in the anthrosphere.

e. The facies concept. This concept is universally applicable. This quite simply states that if a mixture of element is placed under specific thermodynamic environments, the minerals present will always be of a certain composition and relative proportion to each other.

3. Suggested measurements. The first geochemical measurements on both Mars and Venus should be of the atmosphere. This will make it possible to improve the parametric models of section 4. 2. Following atmospheric measurements, lithospheric chemical analyses in conjunction with seismic observations should be made. Following this, the measurements should be continually refined and bettered (see table 9).

The hope is that not only will extraterrestrial geochemistry give us a better understanding of Mars and Venus, but that these researches will make it possible to better understand the Earth. Better understanding might make it possible to improve all the disciplines associated with the finding and utilization of natural resources. References 121, 122, and 123 were also consulted in the preparation of this section.

TABLE 9

GEOCHEMISTRY

Information Desired	Comments	Measurements Advised		Value on Scale of 1 to 10
Mass of planet	Known		Measure with path of orbiter	10
Surface gravitational gradient	Known	Indicates petrographic composition with depth and isostasy	Mean attraction and later local measures for local anomalies	1
Bulk composition of solid planet	Mars and Venus } Feasibility silicates		Chemical sampling at each site landed on, dust analysis	7
Major constituents of atmosphere	Mars and Venus } Nitrogen	Reentry is important for all later missions	Atmospheric analysis every 1000 feet exosphere to surface	9
Layers and zones in body of planet from seismic evidence	Mars and Venus } Mohorovičić Layer, Weicheryt-Guienberg Layer, Jeffries Layer	An excessively thick lithosphere would damp or stop folding processes	Continuous At each landing site threshold seismographs	6
Methods of differentiation in the solid body	Mars and Venus } Vertical below lithosphere with convection in mantles of both planets	Gravitational force and minor chemical differentiation	Indirect follows surface analysis and mapping by orbiter	1
Methods of differentiation in the atmosphere	Mars and Venus } Lateral at base vertical above tropospheres	Gravity and ionization should be major force	Indirect follows atmospheric measures every 1000 feet	2
Bulk composition of the planet lithosphere	Mars and Venus } Feldspars expected	O, Si, Al, Fe should be major elements	Analyze samples at surface and atmospheric dust	10
Lateral differentiation in the planets lithosphere	Lateral movements Marked on Venus, weak on Mars	Net erosion and depositional characteristics will be clarified	Surface analyses at all landing sites	9
Compositions 1st, 2nd, 34d, 4th-order geomorphic features	Clays expected (Al, Si, Fe rich) Fe rich rocks such as basalts and dunites expected	Important to landing, also in understanding geochemical differentiation	Planispheric maps by orbiter pictures by lander T V	5
Types of geomorphic provinces present and relationship to erosion cycle due to exogenetic energies	Venus- 2nd-order features Mars- 34d-order impact features may dominate	Sequence of provinces like those on Earth may be present in part or in whole	Planispheric map by orbiter with lander T. V. photos	4
Equilibrium slopes	Probable on Mars	On both Mars and Venus sand dunes may obscure slopes	T V lander pictures	3
Net exogenetic and net endogenetic energy flux incident on the lithosphere	Venus: Solar electromagnetic energy dominates Mars: Impacts, then solar energy domination		With lander thermometer in borehole 4x/day	1
Dominance of exogenetic and endogenetic energy? balance? or one dominant?	Venus and Mars: Exo-domination		Planispheric map T V orbiter	2
Oldest rocks present on the surface	Mars: 4,000,000,000 years Venus: 50,000,000 years	Indicates minimum age for solar system	Lander 1 to n analyses per landing	3
Erosion/diagenetic (rock forming cycles) and relationship to rock facies present	Mars: essentially a dead planet Venus: 50,000,000 years Lithospheric cycles		One analysis per landing and W analysis in surface borehole	3
Percent of H_2O in atmosphere as ice or droplets or vapor	Venus: atmospheric? Mars: polar cold traps			4
Rain and dew	Venus: upper atmospheric pressure and never reaching the ground Mars: similar to Earth			5
Water of crystallization	Mars: common and abundant Venus: absent in gravimetric rocks at surface possibly present in basaltic rocks			10

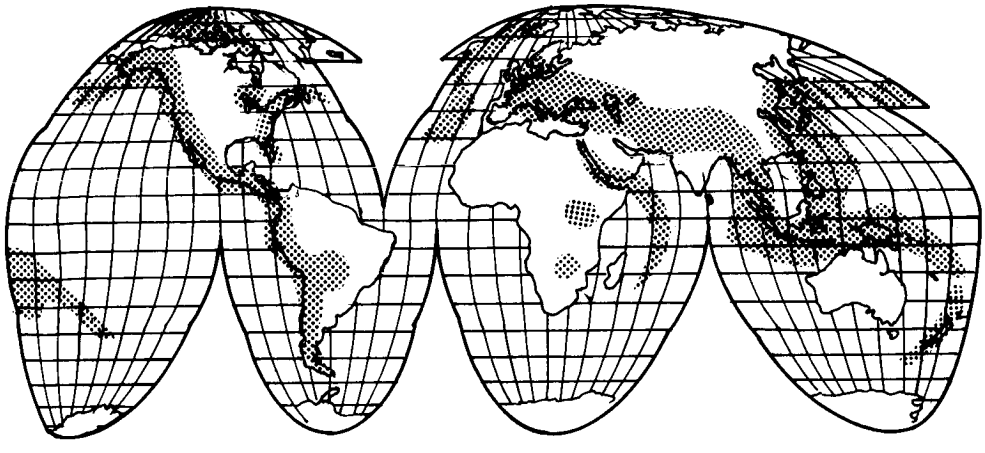
4.9 Seismology

One of the most fascinating and as yet least understood features of the Earth is its internal structure, and the manner by which it generates energy to shape the lithosphere. The vast continental and oceanic regions which dominate the Earth's surface have maintained themselves against erosional forces driven by exogenetic energy. It should be possible to erode a continental mass into the surrounding ocean basins in 25 to 50 million years; yet, geological evidence indicate that continents have been present for at least 3000 million years. The geological record indicates that conditions were not very different from those of the present. Internal forces operating on the lithosphere must be maintaining and constructing continental masses and ocean basins. If this were not true, the Earth would long ago have been covered by a universal ocean. The pattern of the continents and ocean basins guides the activities of all living things by altering the climate and weather, and establishing and changing the topographical environment geochemically, differentiating elements into economic deposits or food-rich/food-poor environments. The very shape of life is molded by the effects of endogenetic and exogenetic energy forcing the lithosphere toward some ultimate equilibrium. Evolution is a result of mutation, selective survival, and adaptation. As mountain ranges rise and erode away, as land bridges form and sink and as lands vary through humid, arid, frigid, temperate, and torrid conditions, creatures from Protozoa to man continually change in response to their environment.

The greater percentage of the information concerning the Earth below the lithosphere is derived from seismic observations. If seismic observations can be made on other terrestrial-type planets (Mercury, Venus, moon, and Mars), the forces which mold the surface of the Earth would be easier to understand, and a more nearly complete understanding of those planets will be accomplished. The most valuable use of these seismic observations will be made possible if related geophysical and geological observations are correlated both in the design of measurements and in the interpretation of the results.

1. Observations and models. Earthquakes and weaker seismic movements tend to originate from boundaries of 2nd-order geomorphic features, continents and oceans, and 3rd-order features, mountain ranges (geanticlines) or basins (geosynclines) (see figure 26). These may be folded by frictional forces from subcrustal convection in the Earth's mantle. Such folds certainly cause isostatic stresses through their evolutions, as is indicated by their movements and associated gravimetric and magnetic anomalies. Minor seismic activity has been deliberately generated by man to study the lithosphere, or resulted as a byproduct of his other activities such as explosions or mining.

Most, though not all, seismic activity is a result of energy being coupled to the bottom of the lithosphere. The most notable exceptions are crustal loading



AREAS OF MAXIMUM SEISMIC ACTIVITY ON EARTH

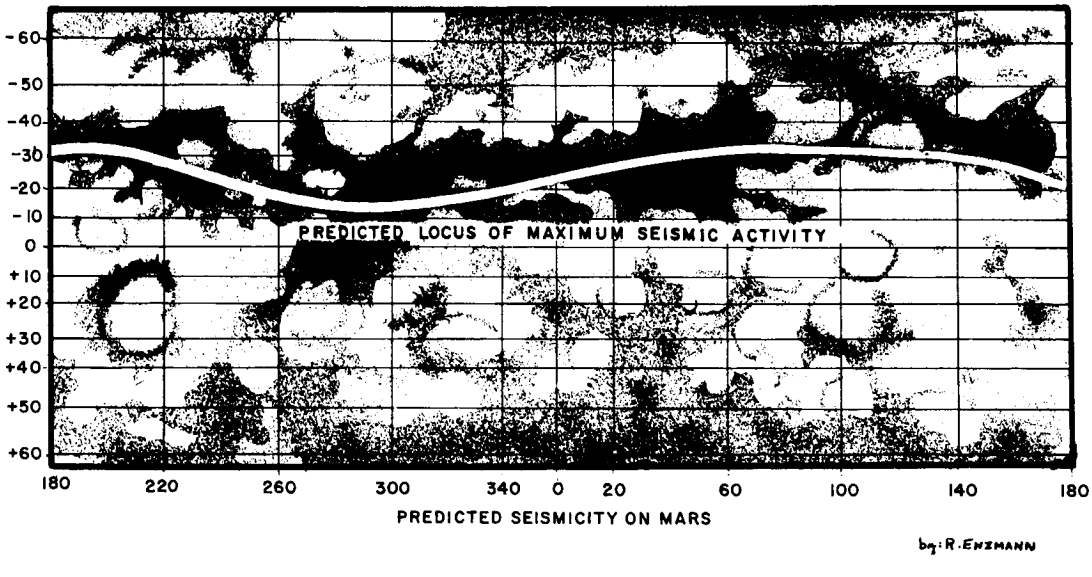


Figure 26 PLANETARY SEISMIC ACTIVITY
63-9193

and unloading by ice or water, low barometric pressure at the eye of hurricanes, tidal kneading by the moon and sun, and crustal tilt due to high and low tides. A typical quake starts at what is called an epicenter. It is as though energy release commenced in a restricted volume. The real nature of earthquake epicenters is unknown; however, most seem to be at depths of about 65 km or 0.01 R_E (Earth radii) with a distribution from 25 to 450-km depths. The epicenters are distributed as shown on the illustration, and at depth they fall on a plane with the deepest tending to be inland. The abundance of quakes on one side of a continent as against the other seems to be associated with the presence of young mountains, and perhaps direction of movement of subcrustal convection currents. There seems to be a strong correlation between distribution of deep focus earthquakes with harmonic components of the rotation of the Earth's pole and with the horizontal component of lunar and solar tidal forces.

To date, no instruments have been mechanically coupled to the lithospheres of the moon, Venus or Mars. The only evidences bearing on seismicity are telescopic, radar, and radio. On the moon, these have made it possible to map 1st, -2nd, -3rd, - and even 4th-order geomorphic features. Computation shows that the moon must have a very thick lithosphere. On Venus, no 1st-order feature (oblateness) can be detected; however, the cold spot detected by Mariner may be a 2nd-order feature of continental dimensions, perhaps a plateau. Its boundaries could well be a region of greater seismic activity. The slow rotation of the planet, resulting in hot-pole to cold-pole circulation with a slowly moving horizontal component of solar tidal forces, should be manifested in the planet's seismicity. The seismicity, as a result of coupling internal energy to its lithosphere, should be less than is the case on Earth, while seismicity resulting from coupling external energy to the lithosphere (particularly solar tidal and differential barometric pressure at the hot-pole yellow spot) should be much more marked. On Mars, it is possible to discern 1st-order oblateness, a 2nd-order dark belt, 3rd-order concentric structures (see section on geomorphology), and 4th-order lineations. The mass of Mars is much less than that of the Earth or Venus; consequently, its lithosphere should be vastly thicker. Its atmosphere is thin, and its distance from the sun together with its lack of significantly large satellites, means that external forces on its lithosphere are relatively small. The seismicity of Mars due to internal and external energy coupling to its lithosphere should be low; furthermore, the lithosphere should be vastly thicker than the Earth's further increasing its resistance to movement.

It is suggested that the following parametric models be constructed:

a. Estimate of endogenetic and exogenetic energy coupled to the lithospheres of Earth, Venus and Mars, and stored therein as potential energy in their gravitational fields

b. Thicknesses of the lithospheres of the moon, Venus and Mars and probable depth of phase change from the solidus to a quasi-plastic state

c. Effect of tidal forces and major barometric anomalies on the lithospheres of Venus and Mars.

Models for the internal structures of Venus and Mars exist. These have been both reviewed and formulated by Kuiper and Middlehurst.

2. Suggested measurements. On Mars, it is suggested that the seismograph be allowed to gather data continually for the first three Martian days. Following this, it might be threshold to accept only energies of a certain magnitude, to remain receptive for a specified period after reception of a desired type of signal, and sequenced to observe microseisms, etc., for certain periods each day (for example, when the subsolar spot is closest). It is conceivable that records showing P (pressure), S (shear), L (longitude), Q (cross), and R (Rayleigh) waves from a single quake will suffice to indicate its direction and distance. This is possible because Rayleigh waves can be interpreted to show the direction from which a wave came; temporal separation of other waves can be interpreted to show the distance and depth of the disturbance; while split P-waves can be interpreted to suggest the nature (liquid?) and geometry of the planet's core.

Following the passive measurements made with the early Voyager planetary landers, active reflection and then refraction measurements are advised. Simple reflection shots could be made by firing grenades weighing a few grams from a Voyager grenade bay. Rudimentary refraction shots could be made by firing grenades to different distances or placing geophones on the surface with a mobile unit. Such reflection and refraction shooting will yield a great amount of detail concerning the subsurface structure of what might be called 4th- and 5th-order geomorphic features. The information would find immediate application in formulating theories as to depth of sediments, rates of sedimentation, compaction, subsurface structure, etc. The foregoing would obviously apply to selection of later unmanned and manned landing sites.

Venus has been called the twin sister of Earth. The masses and the diameters of the two planets are similar. The atmospheres differ greatly. On Venus, the atmosphere is of overwhelming importance. Before any seismic measurements become possible, measurements concerning the aerodynamic drag and turbulance at the surface will have to be made. It may or may not be possible to anchor a lander to the surface long enough and stably enough to make any passive seismic measurements. Passive measurements are greatly desired as data from a planet so similar to the Earth in size and mass, though slightly different, and would be immensely helpful in understanding forces acting on the Earth's lithosphere. Measurements particularly desired include natural seismicity (energies, distributions of epicenters, and relation to 2nd- and 3rd- order

geomorphic features if these are present); seismicity resulting from solar tides; movement of seismicity about Venus as it rotates to slowly move the subsolar spot; seismicity resulting from major barometric anomalies associated with the subsolar yellow spot, antisolar spot, and equator of maximum cooling (if this causes disturbances).

It can be seen that seismic measurements on Venus should not be attemped with the first Voyager explorations. Measurements concerning atmospheric conditions, and radar mapping of 2nd, 3rd-, and possibly 4th- order geomorphic features should precede this, and priorities for measurements can be established as follows:

Mars	Venus
	● Surface aerodynamic drag
	● Surface aerodynamic turbulence
	● Surface roughness
● Position and nature of 3rd- and 4th-order geomorphic features	● Position of 2nd, - 3rd, - and hopefully 4th-order geomorphic features
● Natural seismicity of Mars	● Natural seismicity of Venus
● Geography of seismicity	● Geography of Seismicity
● Depths of epicenters	● Depths of epicenters
● Derived structure of interior of Mars	● Derived structure of interior of Venus
● Derived thickness of lithosphere of Mars	● Derived thickness of lithosphere of Venus
● Active reflection and refraction measurements to show nature of subsurface in typical provinces	● Seismicity associated with subsolar spot

Mars	Venus
● Presence of microseismic activity with subsolar spot or due to local thermal stresses	● Seismicity associated with solar tides in lithosphere and atmosphere of Venus
● Landing of multistation system for refining data gathered during earlier experiments	● Landing of multistation system for refining definition of data gathered during earlier experiments.

Geophysical/geological disciplines would profit immensely by using the early measurements to guide later experiments. Manned landings on Mars would profit from a knowledge of ground characteristics at the proposed or similar landing sites.

If the aerodynamic drag and turbulence at the surface of Venus is so great that landing a seismograph would be impractical with Voyager equipment, it is conceivable that direct measurements could be made through its atmosphere. This could be done by setting off large explosions in the atmosphere. Coupling of air bursts into the ground is a method frequently used terrestrially in prospecting for oil. It would be even more effective in the thick, highly compressed atmosphere of Venus. Such an experiment could serve a double purpose; to examine the solid surface and, concurrently, examine the atmosphere for its "seismic" characteristics.

Table 10 gives the seismology of Venus and Mars.

TABLE 10

SEISMOLOGY (MARS AND VENUS)

Seismic and Related Information Desired	Comments	Measurements Advised	Value Rating 1 to 10
PRESENCE, nature and extent of 1st, - 2nd, - and 3rd-order geomorphic features	Venus - Earth-like Mars - expected impact domination with dunes and pediments	Planispheric map	(5)
Gravity anomalies associated with 1st, - 2nd, - and 3rd, -order features	Venus - anomalies at plateaus Mars - anomalies at dark girdle, at impacts and at lineations (large not "canal-like")	Planispheric map from data available	(5)
Endogenetic thermal anomalies associated with 1st, 2nd, 3rd order geomorphic features	Venus - greater heat flux at low areas Mars - flux greater at lineatious and dark areas	Measure at each landing	(3)
Geomagnetic anomalies associated with 1st, 2nd, 3rd, order geomorphic features	Venus - anomalies with plateaus if present Mars - anomalies with dark areas	Measure at each landing site	(6)
Net exogenetic flux and endogenetic flux incident on the lithosphere	See charts of endo. and exo. energies	Measure from orbiter extrapolate from Earth orbit	(2)
Dominance of endo. or exo. flux as indicated by geomorphology	Venus - exo. - domination? Mars - exo. - domination	Extrapolate from geophysical data	(1)
Presence and nature of areas of net erosion and deposition and areas of rapidly shifting crustal loads as indicated by erosion	Venus - thermal and gravitational gradients Mars - movements from dark to lighter areas	Derived from planispheric maps and lander analyses	(2)
Petrographic provinces as related to rock facies and to geomorphological province diagenesis on Mars is probably limited to Greenschist Facies and contact metamorphism	Venus - essentially granulite facies and basalts Mars - basalts at impacts and aeolian drift	Chemical analyses at each landing extrapolate to provinces	(2)
P-waves (pressure) S-waves (shear) L-waves (longitudinal) Q-waves (cross) R-waves (Rayleigh)	Absent - Present Absent - Present Absent - Present Absent - Present Absent - Present	Continuous but with varying thresholds over period of months	9
Split waves (reflection) plus transmission at phase change such as liquid core internal planetary structures	Split P-waves expected in both Mars and Venus		10
Intervals between arrival of waves		Record as impulses pass preset thresholds	5
Typical energies in quakes acceleration < 20 mm/sec < 1, 200 mm/sec^2			4
Typical periodicities			6
Depths of epicenters	Venus - similar to Earth Mars - much deeper than on Earth		7
Distribution of the epicenters	Venus - at plateau rims Mars - at dark girdle		3
Approximate travel-time graphs	Derived from field data		(2)

4.10 Exobiology

Exobiology is the study of possible life and life forms beyond the Earth and its atmosphere.

Extraterrestrial life might be categorized into these various forms:

1. Prebiotic. The molecular building blocks needed for the synthesis of the complex molecules which might at a later date develop into cellular life forms.

2. Terrestrial. Organisms which would be identical or very similar to the known organisms of the Earth.

3. Exotic. These life forms would be completely different from the forms found on Earth presently or in the past.

4. Postbiotic. Remnants of terrestrial or exotic forms which would have been petrified, fossilized, or preserved in one manner or another.

Let us now examine, in greater detail, the four possible life forms to see how they might have arisen and how they could manifest themselves.

A prebiotic type of life could manifest itself in two ways, the first being the synthesis of a terrestrial-type molecular building block, the second being the synthesis of exotic-type building block molecules. The terrestrial-type molecular building blocks could have been synthesized in a reducing environment.

1. Terrestrial type prebiotic forms. A reducing environment (CH_4, NH_3, CO_2, H_2O, etc.) could have been present, lasting for 1 to 5 million years (Urey, ref. 124; Oparin, ref. 125; Haldane, ref. 126; and Sagan, ref. 127). In this type of environment, it could be possible to synthesize such compounds as amino acid, purines, pyrimidine, sugars (trioses to heptoses), and nucleotides, nucleosides, polynucleotides, etc. (Miller, refs. 128, 129; Calvin, ref. 130; Oro, refs. 131, 132). These later could evolve into terrestrial-type life forms. Such a type environment has been postulated for Earth at one of its developmental stages. The reducing environment could then have escaped due to a heating phenomenon of the sun, or due to the low acceleration of gravity. Thus, the evolution of life forms could have stopped at the prebiotic form.

2. Exotic prebiotic forms. These life forms could have been produced if conditions such as those listed below existed.

a. The structural configuration of carbohydrates, amino acids, etc., developed in a manner different from that on Earth. The carbohydrates were of an L form instead of their D form as on Earth, and the amino acids, a D form instead of the L form.

b. Liquid ammonia was present as a solvent and ionizing medium. The liquid ammonia could have existed in or on hydrolyzate (clay) particles. Using liquid ammonia as a solvent instead of water, the molecular building blocks would be different and behave differently.

c. The use of elements other than carbon as the structural backbone of biologically active compounds; silicon might be one of these elements. If situations or conditions such as these or others existed and then changed, it would be possible to obtain an accumulation of exotic prebiotic life forms. It might also be possible to have these forms develop into exotic, more highly developed cellular forms.

3. Terrestrial-type life forms. It is within the realm of possibility that terrestrial-type life forms exist extraterrestrially. In order to intelligently seek and examine them, one should define life as we know it on Earth. This is not a simple straightforward affair. Life with the exclusion of the viruses, can be said to be cellular in nature, metabolizing (energy conversion and structural synthesis), reproducing (asexually and sexually), and responding to stimuli (physical, chemical, etc.). Other characteristics are added as the organism develops from a unicellular to colonial and then to a multicellular organism.

The earliest life forms have been postulated to be heterotropic anaerobe. They could have made use of the prebiotic compounds (amino acids, sugars, etc.) present as energy sources and structural building blocks. At later dates, chemosynthetic and photosynthetic organisms are said to have arisen.

It should be considered that even though the extraterrestrial organisms could be Earth-like in characteristics, certain differences and modifications could be expected. These would be due to the differences in environment which would influence the process of natural selection. For example, organisms, if present, would undergo modifications to withstand the rigors of environment, e.g., temperature, radiation, pressures, low water content, etc.

4. Exotic life forms. With allusion to the situations set forth in the section on exotic prebiotic life forms, the exotic molecular building blocks could have evolved into life, that is, cells. Thus, we could have a situation in which unicellular, colonial, or multicellular organisms completely different from what we know on Earth exists. The possible life forms under these conditions and their characteristics would be difficult to predict.

Since possible extraterrestrial life forms have been discussed, it is logical to examine and comment upon the different theses for the origin of life in the universe.

In the discussion of the Earth-like prebiotic molecular building blocks and the Earth-like extraterrestrial organisms, the argument for a reducing environment to start life was set forth. This theory appears to be the one most accepted

by the scientific community. Other theories do exist as those of "Pan Spermia" (the pressure of sunlight carrying or moving spores through the solar system), life forms being carried in meteorites, and life forms being carried in comets. Commenting briefly,

a. Radio Pan Spermia Arrhenius (ref. 133) has, for the most part, been rejected.

b. Life forms in meteorites is under investigation at present with strong pros and cons for it. No definite answer at this time is available.

c. Transport of life forms by particulate matter in meteor swarms might occur. It has been suggested that life forms could be moved from Earth to Mars or Mars to Earth in this manner and, by such a device, life could be introduced onto a sterile Earth or Mars.

The following properties or characteristics could be used to detect the four possible forms of extraterrestrial life.

a. Visualization of an entire organism, parts of it, and its cells or fossils on a macro scale by a TV camera and on a micro scale by a microscope.

b. Hearing the noises produced by the fauna by the use of a microphone.

c. Detection of the metabolic activities of the organism. This could be done in a multitude of ways, e.g.; (1) trying to grow the organisms in a labelled substrate (C^{14} label) and monitoring emitted labelled C^{14} gases (CO_2, CH_4, etc.); (2) monitoring the pH and turbidity of a medium into a sample of the possible organism. Most organisms during their metabolic processes will alter the pH of their medium due to the production of organic acids or amines, etc.; (3) monitoring of the redox potential of the growth medium into which the possible organism is placed, because during the metabolic process the redox potential is usually altered; (4) detection of enzyme activity of the possible organisms. All known organisms use enzymes (protein catalysts) in the metabolic process. One of the techniques could be to detect the presence of the ubiquitous phosphatase enzyme.

d. Detection of biologically active and important compounds as proteins (also polypeptides, amino acids), nucleic acids (DNA, RNA, polynucleotides, nucleotides, nucleosides, purines, pyrimidines), lipids, carbohydrates, etc. Techniques as absorption spectroscopy in the ultraviolet and infrared, chromatography (gas and other types), optical rotation, colorimetry, refractive indices, enzymology, etc., could be used.

Ideally a system which could incorporate these determinations would give a highly reliable answer to the question of whether terrestrial-type life exists

extraterrestrially. If one could demonstrate the possible organism, either in its entirety or parts, as organs, tissues, or cells, obtain information as to the chemical makeup of these structures, and finally demonstrate that it metabolized, proof of extraterrestrial life would be conclusive. These criteria should be applied to microscopic life forms as bacteria, algae, fungi, protozoa, etc. A less vigorous proof, but still acceptable, would be the demonstration of the cell and information as to its chemical composition. If only metabolic evidence were obtained, it would be considered significant, but not conclusive evidence. Macroscopic organisms, as the higher plants and animals, if only visualized, could be considered a strong proof of extraterrestrial life.

The preceding criteria could be applied to the possible exotic extraterrestrial life forms, considering both macro- and micro-sized organisms, but the experimental detection presents extremely difficult questions at present unanswered.

For the detection of prebiotic life forms of the terrestrial-type molecular building blocks and the exotic-type molecular building blocks, analytical chemical procedures as previously listed would be required. See also table 11.

TABLE 11

EXOBIOLOGY

Information Desired	Comments	Measurements	Values on Scale of 1 to 10
Physical Values Temperature Unicellular growth Survival Multicellular growth Pressure Radiation Wind Turbulence Gravity Magnetic Soil	Values for Survival of Life as Known on Earth Minimum / Maximum -10°C / 85°C 10°K / 24 Hrs Dry 135°C Heat ? 10°K / 1 Dry 90°C Hour ? (10^{-10}) Torrs / 200,000 lbs/in^2 Background / 50,000°R/total Background Background Zero / 10,000 G ? Zero / 200,000 Gauss ? These are limits for protoplasmic life State of oxidation in soils, nutrients present, structure, ventilation, insulation properties are important to microorganisms	Measure with geophysical quantities or, to an extent, with Earth-based and orbital telescapes	9
Chemical Composition of atmosphere Composition of lithosphere Energy gradient for food availability Metabolites	Aerobic or Anaerobic But not extreme reducing environments e.g., halogens Gradient must be present for life to extract energy for life processes. Depends on need		8
Presence of 2nd, 3rd, 4th, order geomorphic features and rates of change Presence of geomorphic provinces and rates of change	Presence and rates of change of the geomorphic provinces may indicate rates of evaluation on Mars	Combination of orbiter, descent, and surface TV photos	3
Chemical I. R. and Ultraviolet Spectra Bonds and radicals C-H Carbonyl Linkage C=O Aldehyde Linkage CHO Peptides Linkage C=O N-H Esters Linkage -C(=O)-O-R Phosphates Linkage PO_4 Carbocyclic Heterocyclic	from MW ≅ 16 To Cellulose Chains These bond types are found associated with living forms of the Earth. Their presence indicates the possibility of life.	Oribter infrared photos and lander absorption Spectrochemical machine will show their presence	5
Polymeric Silica Bonds	Life might be based on Si rather than C		1

TABLE 11 (Concl'd)

Information Desired	Comments	Measurements	Values on Scale of 1 to 10
Functional Compounds - Protein Amino Acids Peptides Protein Functional Compounds - Nucleic Acids Nucleosides Nucleotides Polynucleotides Nucleic Acids DNA to RNA Carbohydrates Monosaccharides Trioses - heptoses Disaccharides Sucrose, maltose Polysaccharides Glycogen, cellulose Lipids Creatinlipids Phospholipids	MW = 50,000 to MW ≅ 5,000,000 Presence of any of these are to be taken as strong evidence of life being present or having been present	Secure data with lander, mainly with absorption spectrograph	6
Cellular Unicellular Colonial Multicellular Fossiles	sizes of living creatures Minimum 1/2 micron — Maximum 3 cm (Acetadularia) 1 micron — 10 meters 100 microns — 10 meters If fossiles are present micro not macro fossiles will be most common Clays associated with micro-organisms often show unusual concentrations of metals and hydrocarbons in association	Lander microscopic observation and T V picture will show these presences and microphones will relay their sounds if any. Unusual chemical and isotopic concentrations is typical of microorganic and macro-organic metabolism	10
Ecology Presence Effect of Martian environment on Earth organisms Effect on Earth of Mars organisms	Can Earth organisms be safely introduced onto Mars? Could bacteria from Mars cause a plague on Earth?	Lander with sterile zoo--animals born by caeserean-section into compartment.	10+
Man Communication Vision Respiration Homeostasis (Fluid Compartments) Orientation Kinesthetic Ability Dermatology Psychological Sociological	Measurements should be designed to show how closely man can be coupled to the Mars environment. A minimum coupling would be isolation from entire environment except gravitational field.	Secure measures with geophysical geological data external with microscope and sterile zoo.	7

4.11 Physiology

1. Discussion. Physiology is the study of the phenomena and mechanisms of living things. This study is concerned with the biophysical effects of the Martian environment on an "average" man's:

a. Fluid compartments

b. Circulation

c. Respiration

d. Kidneys and epidermis

e. G. I. tract

f. Sense organs and neuromuscular systems

g. Partial and complete coupling of organism to alien environment.

It is obvious that these parameters must be studied before man can land on Mars.

The environmental factors which could affect man are as follows:

a. Atmospheric pressure and composition

b. Radiation - Martian and extra-Martian, both corpuscular and electromagnetic

c. Reduced gravity

d. Presence of toxic substances, inorganic and organic

e. The presence of pathogenic organisms

f. The possible use of native plants and animals (if they do exist) as foodstuffs

g. The location of water for the use of man

h. Composition of the terrain

i. Meteorological information.

It will be noted at this point, no doubt, that much of this will be determined in the exobiological and geological-geophysical studies. This is true up to a point. For broad ranges of information will be obtained by the aforementioned studies, but now the studies will be oriented to man in order to aid his landing and return from Mars.

Let us now examine each of these points to determine how they will be man-oriented.

a. Atmospheric composition and pressure. Extra-Martian studies have been made on the composition and pressure of the Martian atmosphere. The atmosphere is said to consist of nitrogen, argon, carbon dioxide, water, and oxygen in various ranges which have not been exactly fixed. Similarly, the atmospheric pressure has not been accurately determined; a range of approximately 8 to 85 mb has been cited. The atmospheric percentage composition, for example, oxygen content and pressure are of extreme importance. For these facts will determine whether a man can survive with only a simple breathing mask with an oxygen supplement or must have a pressure suit with its own air supply. Also, the percentage of CO_2 and O_2 in the atmosphere would have an effect on plant photosynthesis and respiration.

b. Radiation.

1) Corpuscular radiation, Martian and extra-Martian, could be a hazard to man. It is therefore essential to obtain background radiation levels and its composition on Mars. Radiation might come from radioactive materials on Mars surfaces, or might be extra-Martian. It is postulated that the magnetic field of Mars is lower than that of the Earth and also that Mars' atmosphere is "thinner" than that of Earth. Therefore, Mars' surface might receive a higher level of radiation than Earth due to the lower trapping effect of its magnetic field and lower attenuation from its atmosphere.

2) Electromagnetic radiation could also be Martian, or extra-Martian. The Martian surface might contribute gamma radiation due to deposits of radioactive material, while extra Martian radiation could be gamma radiation, ultraviolet, and visible light. It is of extreme interest to determine the amounts of ultraviolet light received on the Martian surface. For ultraviolet light can be a hazard to the human eye and skin. Thus, the level of ultraviolet would determine whether or not protective devices would be required. Also the spectral distribution of visible light and its intensity would determine how man could see on Mars. If the color distribution of the visible light on Mars is different from that of Earth, man might have problems in distinguishing the different colors and with perception in general. Color visualization and perception, in general, besides being important for reasons of orientation, motion, muscular coordination, and information gathering, could have profound psychological effects. Additionally, light levels and the spectral distribution of light would be important for photosynthesis which, in turn, would control plant growth. Plant growth would be of importance to man as a food source and a means of possible oxygen supply and carbon dioxide removal.

c. Gravity. Gravity on the Martian surface is less than that on Earth. Gravity is of importance to man on Mars for it would affect man's locomotion, proprioception, and general physical activity. All these factors would affect the ability of man to perform physically on Mars and also might engender psychological effects.

d. Toxic substances. The possibility of toxic substances, inorganic and organic, solid or gaseous, being present on Mars is of interest. Keiss (reference 134) suggests that oxides of nitrogen are present, the polar caps being solid nitrogen tetroxide below -40° C, changing to nitrogen dioxide above -40° C. Keiss also suggests that the reddish color of the planet is due to nitrogen peroxide. The aforementioned oxides of nitrogen are highly toxic to man, also to plants and animals as we know them, and are extremely corrosive to metals and organic matter.

e. Pathogenic organisms. If life does exist on Mars, the question arises as to what form it will assume and will it be pathogenic to man. The hazard to the Martian explorer is obvious, but more hazardous is the possibility of man of his vehicle returning to Earth contaminated.

If this did happen, man, animal, and plant epidemics might occur. Equally possible might be the situation of nonpathogenic organisms being brought back from Mars. If it escapes man's control and has no natural enemies on Earth, it could overrun the environment. A case in point would be the problem of rabbit control in Australia. Two possible techniques could be used to prevent these situations, the first being the use of germ-free and normal flora plants and animals as detectors in the premanned flights. The second would be the establishment of a quarantine and disinfection station in space. Here man, his equipment, vehicle, and possible biological specimens could be examined.

f. The possible use of native plants and animals (if they do exist) as foodstuffs. An analytical program would be planned to determine the chemical composition and nutritional values of the organisms and their possible toxicity, if native Martian organisms are found. The benefits of having a Martian food supply would be great from a viewpoint of space and weight savings in the vehicle and from a psychological aspect of dietary variety.

g. The location of water for the use of man. As in the case of possible native food, an available safe water supply would be of great advantage. Therefore, a program to determine its availability and potability is advised.

h. Physical makeup of the terrain. This would affect man, his landings, and ventures on the surface of Mars so that it should be examined carefully. For example, is the surface of Mars dusty? Could man walk on it with ease or difficulty? Would the dust be blown by the wind to obscure his vision, affect his breathing, or injure his skin?

i. Meteorological information. This would consist of studies of wind direction and speed, weather patterns, temperature ranges, storm frequencies and makeups.

1) Öpik (reference 135) and Moore (reference 136) have described storms on Mars which were possibly due to dust. These were of such an intensity that they hid parts of Mars for almost a week. The possible effects of this type of a storm on man would most likely be overwhelming. Visibility could be reduced to almost zero; eyes, skin, and respiratory tract, if unprotected, would be seriously damaged.

2) Low humidity would be an important factor to research. For, if the humidity is as low as predicted, an unprotected man would be dehydrated, and death would follow.

3) Rapid temperature changes on the Martian surface demand examination of their effects on man. Temperature ranges from a high of approximately 26° to -70° C or lower have been reported (Jackson and Moore, reference 137). The drop can occur during the change from Martian day to night. It is therefore most important to have accurate temperature ranges and the rate of temperature rise or drop so as to make provisions for man's protection.

The parameters and/or factors which might affect man during his exploration of Mars should be examined carefully and thoroughly. A base of information can be built up over the Voyager program, with one mission supplementing and reinforcing the information obtained from the previous one. Thus, the necessary information could be obtained with the required degree of assurance and validity.

The end result will tell how closely living men can be coupled to the ambient environment. Presently, it is possible to isolate (decouple) living men from every environmental influence of the Martian environment with the exception of its gravitational field. If the conditions are not too hostile, and if at some future date it is not necessary to isolate the ecology of Mars from that of the Earth, the possibility of introducing useful flora and fauna from Earth to Mars should be given a high priority.

Table 12 gives the physiology and man-machine-environment relationships for Mars.

TABLE 12

PHYSIOLOGY AND MAN-MACHINE-ENVIRONMENT RELATIONSHIPS (MARS)

Physiological and Related Environmental Measurements	Comments		Measurements Advised	Value on scale of 1 to 10
Possibility of pathogenic organisms (plague) man, animal, or plant	?	Both Mars and the Earth must be protected, test with animals in landers	1 test 3 preferred	10
Physical parameters Air pressure Diurnal temperature equator Seasonal temperatures Aerodynamic drag Gravitational gradient on the surface	50 to 120 mb -50° to +70° -100° to +90° ? Low gravity should make work easier	No kinesthetic upsets anticipated	At each site over Martian year	8
Geomorphology as applied to ground movements	0 Deg. ±5 Deg. ±20 Deg	Slopes negotiable by bicycle are greater than those on Earth	Contour maps planispheric	(3)
Possibility of replenishing material stores	H_2O may be recovered for use as fuel	Water might be secured locally Plants could perhaps be eaten Viable flora and fauna could be introduced to Mars	At each site	1
Possibility of local generation of energy, sun, wind, water, etc.	Wind on SNAP reactor		At each site	1
Exogenetic flux and influence on eyes, skin, ability to recognize colors of minerals, etc.	Ultraviolet and meson danger		Frequent eye white and skin examinations	6
Effect of planetary dust on skin of explorers	Effect on skin tolerable	Danger of silicosis	1x/day examination	2
Geomorphology and soil conditions as related to landing and preserving the landing craft during possible storms	Dark areas may be rough		At each site Planispheric maps (1/250,000) Chemical and physical analyses	7
Factors affecting communications on the surface, from surface to spacecraft	Ducting in H_2O vapor may upset radio communications		Detailed under communications	5
Traumatic injuries	Medical and dental provisions must be made		N. A.	1
Water loss from skin if face masks rather than full or partial pressure (space) suits are used	Could be serious problem	If only face masks are used, H_2O loss through skin may be excessive	Continuous	9
Possible use of bicycles for surface transport of balloons, of aircraft, on foot	1/1,000,000 1/250,000 1/50,000			5
Provisions for sleep	"Normal" environment so body can recover			1
Sensory organs Respiration Circulation (EKG) Muscular system Nervous system (ECG) Gastro-intestinal tract and kidneys Thalmic responses		Response of subsystems in human organism to various degrees of coupling to Mars. Minimum coupling would entail response of eyes to filtered light and body to gravity. "Maximum" coupling would be represented by clothed man living on Mars foods, breathing the Mars atmosphere	Continuous records of performance	8
Bodily heat balance under diurnal temperature, wind, and humidity regime, etc.			Continuous	4

5. SCIENTIFIC MEASUREMENTS

Within each of the disciplines, suggested measurements have been proposed which would be of most value to the furtherance of that discipline's understanding of the planets. However, the relative importance of measurements within different disciplines to the broad objectives of Voyager must be evaluated. In this section is outlined a semianalytical method for considering this problem.

The general procedure which has evolved during this mission analysis is as follows:

1. Combine all suggested measurements into a master list, eliminating duplications.

2. Consider, in turn, each broad objective of the Voyager project, including the auxiliary objective of measurements needed to increase the probability of success of future Voyager flights. To each objective, assign a weighting factor to reflect the emphasis applied to that objective by project management.

3. For each of these objectives, in turn, assign a value rating to each suggested measurement to reflect the worth of that measurement to the particular objective. This is of necessity a subjective judgment, but it must attempt to evaluate the relative worth of, say, an ionosphere measurement with a seismic measurement.

4. Determine the net value of each measurement as the sum of the values assigned for each objective, each such value being weighted by the assigned weighting factor.

This general procedure can be illustrated by the following format:

Measurement	Objectives and Weighting Factors				Net Value
	A 1.0	B 0.5	C 0.1	D 0.2	
1	8	6	4	3	12
2	1	1	5	0	2

This general procedure can be applied to each target planet, to each launch opportunity, and individually to each of the orbiter-bus and lander payloads.

For illustrative purposes, it has been applied as shown in table 13 for the first Mars opportunity. It is not proposed that the individual net values obtained in table 13 be considered as firm recommendations. These have been obtained by a small group of scientists after only a very short study.

It is suggested, however, that this procedure can be of value to project management in selecting detailed mission designs. The individual value ratings for each measurement and assigned to each objective can be determined by any one of a number of procedures, and they must be changed as each flight is designed on the basis of constantly increasing knowledge of the planets. The weighting factors, similarly, can be assigned on the basis of NASA's emphasis on the relative importance of the objectives, and will also vary as program objectives evolve.

Finally, of course, it is not suggested that slight differences in net value ratings be taken as a basis for experiment selection. Only the broad groupings of net values are significant. Also, the cost of the measurement in terms of weight, bit rate, power required and similar factors considered in section 6 has not yet been taken into account. A more elaborate systematic analysis might attempt to consider simultaneously, both the value of a measurement, as in this section, and the value and cost of the instrument, as in the next section, but this has not been attempted in this study.

TABLE 13

SCIENTIFIC MEASUREMENTS VALUE MATRIX
1969 MARS OPPORTUNITY

Discipline	Measurement Desired	Orbiter					Lander				
		BIO* 1.0	GEO 0.5	MAN 0.3	VOY 0.8	TOTAL	BIO 1.0	GEO 0.5	MAN 0.3	VOY 0.8	TOTAL
Atmosphere	Pressure	-	-	-	-	-	9	10	10	10	25
	Temperature	8	8	-	-	12	8	8	6	5	18
	Composition	2	2	1	-	3	8	10	10	2	18
	Density	-	-	-	-	-	9	3	5	4	15
	Viscosity	-	-	-	-	-	2	4	5	4	9
	Wind velocity	-	-	-	-	-	8	5	9	9	20
	Turbulente	-	-	-	-	-	3	3	8	7	13
	Cloud composition	4	4	2	7	8	4	4	2	2	8
	Cloud configurations	1	8	5	6	11	2	2	5	2	6
	Precipitation	7	1	4	1	9	7	5	1	1	10
	Solar spectral absorption	-	-	-	-	-	10	6	8	1	18
	Solar spectral albedo	5	7	2	1	10	2	3	3	2	6
	Sky brightness	-	-	-	-	-	-	4	1	4	6
	Luminescence	1	1	1	1	3	1	5	2	1	5
		1	1	1	1	3	-	1	1	-	1
	Ionosphere structure	-	5	4	1	5	1	5	9	5	10
	Dynamo currents	2	-	1	-	2	2	6	5	1	7
	Electro jets	-	1	-	-	1	-	4	5	1	4
	Cosmic rays at surface	-	-	-	-	-	4	5	3	1	8
Planetary Morphology and Geology	Gravity	1	5	1	1	5	1	2	1	1	3
	Seismic activity	-	-	-	-	-	-	8	1	1	5
	1st - order features (oblateness)	-	10	-	-	5	-	-	-	-	-
	2nd - order features (continents)	3	9	5	1	10	3	10	1	4	12
	3rd - order features (mountains)	5	8	8	8	18	4	10	2	10	18
	4th - order features (erosion)	4	-	-	-	4	1	5	8	6	11
	5th - order features (weathering)	-	-	-	-	-	1	4	2	2	5
	6th - order features (microstructure)	-	-	-	-	-	7	9	2	7	18
	Geochemistry	10	2	5	2	14	7	7	8	1	14
	Geochronology	-	-	-	-	-	1	4	-	-	3
Electromagnetics	Refraction	-	2	2	3	4	-	4	1	1	3
	Absorption	2	9	5	3	10	1	5	4	4	8
	Ground wave propagation	-	-	1	1	1	-	2	3	1	3
	Ducting	1	1	1	1	3	-	2	3	1	3
	Ionospheric propagation	-	1	3	2	3	-	1	1	1	2
	Troposcatter	3	-	1	-	3	-	1	-	1	1
	Sferics	2	1	1	1	4	2	5	5	5	10
	Faraday rotation	-	1	1	2	2	-	1	1	2	2
	Ionosphere gyro frequencies	-	5	5	6	8	-	5	9	5	9
	Solar radio spectrum	5	5	-	-	3	3	7	4	2	9
	Biochemical compounds	10	-	1	5	14	10	-	7	3	15
Exobiology	Cellular structures	-	-	-	-	-	10	-	10	10	21
	Colonial aggregates	1	4	4	1	5	10	-	4	5	16
	Multicellular	-	-	-	-	-	10	-	2	1	12
	Artifacts	-	-	-	-	-	10	-	-	-	10

NOTE:

Table entries represent value rating for each measurement towards each objective. Weighting factors listed for each objective reflect NASA emphasis.

*Objectives:
BIO = Search for Extra Terrestrial Life
GEO = Geophysical/Geological Measurements
MAN = Data for Future Manned Landings
VOY = Data to Improve Voyager Future Flights.

6. SCIENTIFIC INSTRUMENTATION

The objective of the scientific instrumentation effort on the study program was to ensure the compatibility of the spacecraft design with the scientific instrumentation it will carry. Although the final selection of instruments could not be made at this stage in the Voyager project, it appeared quite valuable to consider the effect of a representative payload on the conceptual design effort. Therefore, payloads were selected, as described in the following sections, and were included in the Voyager conceptual design. The instrumentation considered for this purpose is described in section 6.1, and the payloads selected from these are described in section 6.2. The criteria used in the selection of instruments and design of the payloads are described in section 6.3.

6.1 Instrumentation Lists

In order that the several Voyager studies which are being conducted by different agencies be on an equal basis, a list of available instrumentation was supplied to Avco. If suitable instrumentation was available on the list, it was to be used in compiling the final scientific payload; if recommended experiments required instruments not included in the list, additional instruments were to be recommended. For lack of better information, it was assumed that all instruments were 100 percent reliable, that they could be properly sterilized, and would be available within the Voyager time schedule. The instruments listed were designated as having been designed for use on either the bus, the orbiter, or the lander vehicles.

Because of its great effect on the compilation of the various scientific instrumentation payloads for Voyager, the instrumentation shopping list is reproduced in table 14.

This instrumentation list, as supplied, had several limitations which made the selection of an optimum payload package somewhat difficult:

1. There was not sufficient information on the operation, form factor, programing, and sample collecting functions of the instruments to allow the design of sample distribution mechanisms and command programing and readout logic.

2. In some cases, the scientific principle of operation of instruments was not known. This made it difficult to evaluate the efficiency of an instrument in performing its required function so that the selection of the best of two competing instruments which measure the same variable was difficult.

TABLE 14

JPL INSTRUMENTATION LIST

Identification Number	Instrument (Capsule)	Instrument Gross Measurement Capabilities	Approximate Weight	Approximate Power	Volume or Dimensions	Bits/Sample and Minimum Total Information	Additional Constraints
	Aerometeorometer					Venus / Mars	
1	Static temperature	Venus: 180-800°K ± 1% of ambient (accuracy of measurement) Mars: 100-300°K; accuracy 1%	5 oz	70 mw	1" dia. x 3" long	9 bits/sample / 7 bits/sample Measure every 500 meters	Sampling mechanism must provide free-stream conditions to the sensor during capsule descent.
2	Static pressure	Venus: 10^2 to 2.5×10^6 newtons/m^2 ±50 for 10^2 to 1.5×10 ±1% above 1.5×10^4 (accuracy of measurement)	5 oz	100 mw	1.6" dia. x 2" long	9 bits/sample / 9 bits/sample 7 bits/sample	
3		Mars: $100-15 \times 10^3$ newtons/m^2 accuracy = ± 50 newtons/m^2				Measure every 500 meters	
4	Density	Venus: 2×10^{-4} to 30 kg/m^3 ±1% of ambient (accuracy of measurement) Mars: 2×10^{-5} to 2×10^{-4}gm/cc; accuracy 1%	12 oz (β ray) 24 oz (γ ray)	250 mw 2.0 watt	15 in.^{3} (γ ray)	17 bits/sample / 8 bits/sample Measure every 500 meters	
5	Velocity of sound	Venus: 250 to 380 m/sec 1% of ambient (accuracy of measurement) Mars: 250 to 380 m/sec; accuracy 1%	10 oz	300 mw	2.3" dia. x 2" long	10 bits/sample / 7 bits/sample Measure every 5000 meters	
6	Mass spectrometer	Determination of the composition of the atmosphere in the mass range of 12 to 50 amu	6 lb	6 watt	10" x 5" x 3"	1100 bits/sample, 5500 bits total	Representative sample of the atmosphere is required.
7	Gas chromatograph	Determination of the composition of the atmosphere	7.0 lb	4.5 watt	5" x 5" x 8"	200 bits/sample, 800 bits total	
8	Simple composition H_2O (vapor)	Venus: (1 atm): dynamic range 190 to 240°K Dew point: 0.1 to 100 ppm Mars: (0.1 atm): dynamic range 1 to 1000 ppm; 190 to 240 °K	1.5 lb	1 watt	3" x 3" x 3"	7 bits/sample, 105 bits total	Representative sample of the atmosphere is required.
9	O_2	Venus: (1 atm): dynamic range 0.01 ppm (3 orders of magnitude per sensor) Mars: (0.1 atm): same as Venus	1.5 lb	1 watt	5" x 3" x 3"	7 bits/sample, 35 bits total	Representative sample of the atmosphere is required.
10	O_3	Venus: (1 atm): dynamic range 10^{-3} to 1 ppm Mars: (0.1 atm): dynamic range 10^{-2} to 10 ppm	1.5 lb	1 watt	3" dia. x 6"	7 bits/sample, 105 bits total	
11	A	Venus: (1 atm): dynamic range 0.1 to 100% Mars: (0.1 atm): dynamic range 3 to 100%	1.5 lb	1 watt	10" x 2" x 2"	7 bits/sample, 35 bits total	
13	N_2	Venus: (1 atm): dynamic range 1 to 100% Mars: (0.1 atm): dynamic range 0.1 to 100%	1 lb 1 lb	1 watt 1 watt	5" x 3" x 3" 4" x 3" x 4"	7 bits/sample, 35 bits total	
14	CO_2	Venus: (1 atm): dynamic range 0.1 to 100% Mars: (0.1 atm): dynamic range 1 to 100%	1 lb	1 watt	4" x 3" x 4"	7 bits/sample, 70 bits total	

TABLE 14 (Cont'd)

Identification Number	Instrument Capsule Biology	Instrument Cross Measurement Capabilities	Weight (pounds)	Power (watts)	Volume or Dimensions	Bits/ Sample	Total Bits	Additional Constraints
15	Radioisotope growth detector	Uses radioisotopic techniques for detection of metabolic and growth process. Carbon 14 included in a liquid media is converted to $C^{14}O_2$ which is detected with a geiger-mueller tube or solid-state detector. Control experiments are performed as a contrast to the actively metabolizing experiment.	6	3	8" x 10" x 6" plus four 1" x 2" x 3"	Sample at 20 bits/30 min.	600 bits for 12 hours	Up-down orientation required Soil sample required.
16	Reduction-oxidation potential experiment	Multiple experiment designed to measure changes in eH (redox potential) in a media which organisms are actively metabolizing and, therefore, changing the redox potential of that media. Large numbers of samples can be run simultaneously.	3	1	8" dia. x 4"	700 bits/ sample with 100 chambers. 2800 bits/ sample with 400 chambers.	2800 bits sampled once every other hour for 8 hours; 3400 bits sampled every hour for 12 hours.	Aerosol or soil sample orientation required.
17	Microscope	Visual observations of morphology and optical characteristics of small organisms. This could be used as a specialized instrument for microcolorimetry, spectrophotometry, and fluorescence.	5	2 watts/10 min, 1 watt (cont.)	3" dia. x 10"	$<10^6$ bits/ picture	To be maximized	Aerosol or soil sample required.
18	Organic gas chromatograph	Detection of organic compounds and possibly organisms by measurement of the volatile organic substances and degradation substances from pyrolysized samples. Characteristic "fingerprints" of microorganisms may be found.	7.0	4-1/2	5" x 5" x 8"	300 bits/scan	900 bits minimum	Soil sample required.
19	Turbidity and pH growth detector	Changes in optical density and other light-scattering phenomenon plus changes in pH are used to detect growing organisms in a transparent liquid culture media.	4	1	6" x 6" x 6"	7 bits/ sample	Sample 2 times per hour continuously	Aerosol sample orientation required.
20	Multiple chamber biochemical experiment	Multiple versatile miniaturized biochemical laboratory capable of performing reactions characteristic of biological life. At present, it is used to measure enzymatic hydrolysis using a sensitive fluorescent technique. Capable of carrying out growth and control experiments.	4	2		100/bits sample	1500 bits 8 hours 2250 bits 12 hours	Vertical orientation. Soil or aerosol sample required.
21	Stain experiment	Stain soil particles selectively to provide a positive identification of organic materials present. The capability may be extended to determining whether or not the organic material is living.	5	5	3" x 10" x 8" plus 2" dia. x 6"	30 bits/ sample	2000 bits 10 hours approx. 7 samples/hour	Soil sample required.
22	X-ray diffractometer	Identification of minerals and determination of relative quantities and precise composition of mineral assemblages.	10	15	10" x 10" x 10"	50000/bits/ sample maximized	to be maximized	Prepared soil sample required.
23	Alpha scattering	Compositional analysis of surface material.	7	2	3" x 3" x 3" sensor 5" x 7" x 7" elec.	1000 bits/ spectra, requires storage	10 spectra	Placement of sensor head slightly above planetary surface
24	Soil mechanics experiment	Measurement of load-bearing strength, shear strength, cohesive modulus, frictional modulus, and bearing stability of surface.	13	3	12" dia. x 24"		10^3 total bits	Axis vertical held 4 inches above surface
25	Seismograph (single-axis)	Study of the internal activity and heterogeneity of the planet.	8	1	5" dia. x 6"	less than 20 cps	continuous, to be maximized	Emplacement on planetary surface several months lifetime required.
26	Seismograph (Three-axis)		34	4	10" dia. x 15"	less than 20 cps	continuous	Emplacement on planetary surface
27	Petrographic microscope	Textural analysis of rock units.	14	7	12" x 12" x 4"	$<10^6$ bits/ picture	to be maximized	Prepared soil sample required.
28	Surface and approach photography							

TABLE 14 (Cont'd)

Identification Number	Instrument (Bus)	Instrument's Gross Measurement Capabilities	Approximate Weight (pounds)	Approximate Power (watts)	Volume or Dimensions	Bits/Sample or Bit/Rate	Total Bits	Additional Constraints
29	Microwave spectrometer	Planetary: Determine the molecular composition of the atmosphere (clouds, below clouds, at surface) by observing the microwave spectrum of the characteristic lines.	30	13	0.6 ft^3	9 bits/sec	Continuous operation	Beam width less than 2 degrees, aligned toward planet vertical
30	Extended microwave spectrometer	Planetary: Will measure quantities stated for the microwave spectrometer and also will give a geographic temperature study of Venusian surface.	35	15	0.7 ft^3	Add 9 bits per temperature sample	Continuous operation	Two meter circular antenna, aligned toward planet vertical
31	Ultraviolet spectrometer	Planetary: Determination of the abundance and height distributions of the principal atmospheric constituents obtained from ultraviolet spectra of the day, night, and twilight portions of Venus with emphasis on lighted side.	22	12	9"x10"x20" optics plus 6"x10"x6" elec.	5000 bits per sample	To be maximized	Sampled appropriately in space and time
32	Infrared spectrometer	Planetary: Determination of those minor constituents of the upper cloud structure whose absorption spectra are in the infrared region. Measurement of the atmospheric profile of temperature and pressure.	29	7	12" dia. x 15"	5000 bits per sample	To be maximized	Aligned toward planet vertical, requires detector cooling
33	Ultraviolet photometer (A)	Planetary: Determination of the presence of particular constituents of the upper atmosphere by means of filter spectroscopy.	1.5	1.5	3" dia. x 5"	4 bits/sec per photometer	Continuous	Aligned toward planet vertical
34	Infrared radiometer	Planetary: Investigation of the structure of the atmosphere by making measurements of the effective radiation temperature of the Venusian cloud tops.	3	3	5" x 7" x 4"	8 bits/sample	Sampled continuously every 10 seconds	Aligned toward planet vertical
35	Microwave radiometer	Planetary: Thermal mapping of the surface (33 mm) and structure of atmosphere (8 mm). Additional data to establish the precise shape of the spectral transition curve from the centimeter value of 600°K to the millimeter value of 400°K. This information is related to surface temperature and kinetic temperature of the atmosphere.	24	4	0.5 ft^3	30 bits/sec	Continuous	Two meter circular antenna, 2-degree beamwidth, aligned toward planet vertical
36	Magnetometer	Planetary: To establish the existance of a planetary field and to determine its characteristics; magnitude, direction, multipolarity, and orientation. To investigate the nature of the interface between planetary and interplanetary magnetic fields.	5	5	4" x 4" x 6"	24	Sampled every minute	Reduction of spacecraft magnetic field required; orientation in planetary coordinates must be known
37	Particle flux	Interplanetary: Used in conjunction with the ion chamber to monitor the energetic particle and photon radiation in interplanetary space. Provides semiquantitative information about the energy and particle types composing the radiation.	2.5	0.35	4" x 5" x 6"	N/A	N/A	Close to ion chamber, spacecraft to subtend minimum solid angle
38	Ion chamber	Interplanetary: To measure the total ionizing radiation (cosmic rays) and the variation with time and position in the solar system.	1.3	0.101	6" sphere	N/A	N/A*	Close to particle flux; spacecraft to subtend minimum solid angle
39	Trapped radiation detectors	Planetary: To search for magnetically trapped charged particles in the vicinity of Venus. If present, to study their intensity, directional and spatial distributions. Also interplanetary cosmic rays.	4	0.7	4" x 5" x 5"	N/A	N/A*	30-degree cone angles, toward and away from the sun

*Total bits for all particle experiments equal approximately 10^9

TABLE 14 (Cont'd)

Identification Number	Instrument (Bus)	Instrument's Gross Measurement Capabilities	Approximate Weight (pounds)	Approximate Power (watts)	Volume or Dimensions	Bits/Sample or Bit/Rate	Total Bits	Additional Constraints
40	Medium-energy proton directional monitor	Interplanetary: Observation on the temporal and spatial variations of cosmic-ray intensity.			4" x 5" x 5"	N/A	N/A*	Not specified
		Planetary: To search for magnetically trapped charged particles in the vicinity of Venus. If such are present, to measure the spatial extent and the anisotropy of the particle fluxes in the low-intensity regions of the trapping regions.	3	1		N/A	N/A*	Not specified
41	High-energy proton directional monitor	Interplanetary: To provide information about the temporal, spatial, and directional variations of galactic cosmic-ray flux.	4	0.5	3" x 4" x 4"	N/A	N/A*	60-degree angle visibility parallel to ecliptic 60-degree cone angle visibility perpendicular to ecliptic 60-degree cone angle toward the Sun
42	Cosmic-ray spectrum analyzer	Interplanetary: To investigate the intensity and the gradient of flux of charged particles in space as functions of nuclear species and time.	18	2	18" x 6" x 6"	N/A	N/A*	Four mutually perpendicular telescopes 30- to 60-degree cone angles
43	Plasma instrument (electrostatic analyzer)	Interplanetary: To measure the flux of positive and negative components of solar plasma traveling outward from the sun with good energy and directional resolution. To correlate these data with the magnetic field and the low energy plasma.	7	1.25	6" x 8" x 8"	N/A	N/A*	Covers seven sections of a solid angle of 4 sterad centered on the Sun.
44	Plasma instrument (Faraday cup)	Interplanetary: To determine the particle number density, the distribution of velocity vector, and the temporal and spatial distributions of the interplanetary plasma. To correlate these data with the magnetic field measurements.	20	4	36" x 10" x 10"	N/A	N/A*	Four 60-degree cone angles, toward, away, and perpendicular to the Sun.
45	Cosmic dust (A)	Interplanetary: To measure the flux of cosmic dust particles as a function of direction, distance from the sun, and momentum with respect to the spacecraft.	2.5	0.2	5" x 5" x 5"	N/A	N/A*	One plate perpendicular to ecliptic.
46	Micrometeoroid detector (A)	Interplanetary: Direct measurement of the velocity and cumulative mass distribution of the cosmic dust of the Zodiacal cloud and in the vicinity of the planets.	8	0.5	10" x 10" x 6"	N/A	N/A*	Three tubes in ecliptic plane, toward, away from and 90 degrees from the Sun One tube perpendicular to ecliptic
47	Bistatic radar	Interplanetary: To obtain information on the absolute electron density in interplanetary space and the fluctuation of this density as a function of time.	6-8	2	4" x 4" x 12" excluding antennas	Cruise: 0.2 bits/sec Encounter: 1.2 bits/sec	Continuous	Occulting of spacecraft by planet required. Antennas to be oriented to Earth Antennas: 40-cm and 300-cm dipoles
		Planetary: Obtain information on the electron-density profile of the ionosphere about Venus by progressive and selective absorptions of the Earth-transmitted signals during the occulting pass.						
48	Infrared television	Planetary: To obtain infrared pictures of cloud structure and surface configuration through possible breaks in the cloud layers.	10-15	6-10	6" dia. x 12"	N/A	Approx. 10^9	Aligned toward planet vertical

*Total bits for all particle experiments equal approximately 10^9

TABLE 14 (Concl'd)

Identification Number	Instrument	Experimental Objectives	Weight (pounds)	Power (watts)	Volume or Dimensions	Bits/Sample Data Rate	Total Data	Additional Constraints
49	Infrared spectrometer	Simultaneous mapping of composition of surface and correct radiation temperature from orbiting vehicle.	12	15	12" dia. x 15"	500 bits/sec	To be maximized	Point to vertical
50	Neutron analysis	Surface compositional studies, major, minor, and trace elements (possibly isotopic ratio determination.)	20	20	4" dia. x 36" detector and generator plus 4" x 4" x 3" analyzer	2000 bits spectra	4 times/min initially every 10 minutes	Prepared soil sample desired. Can be direct surface analysis. RTG shielding required.
51	γ-ray spectrometer	Gross compositional analysis for naturally radioactive materials. Interplanetary γ-radiation analysis.	8	< 2	200 in.^{3}	1000 bits spectra	Sampled every 500 seconds	No radioactive sources on lander.
52	Advanced mass spectrometer	Solid analysis for elemental and isotopic composition.	20	30	14" x 3" x 8"	5000 per sample	5×10^4 bits	Requires surface soil sample.
53	Seismic refractometer	Active seismic experiment to establish time-distance relationships giving the nature of the upper surface layers to a depth of one-third the shot-to-receiver distance.	40	Minimal	300 in.^{3}	N/A	6000 bits	Precise dispersal of explosive charges and geophones to 500 feet.
54	Fluorescent spectrometer	Analysis of surface for elements from sodium through iron.	25	25	5" dia. x 15" 3 boxes 8" cubes	1000 bits per sample	Several samples	Requires a prepared soil sample. This is a surveyor instrument and much adaptation is required.

3. In a few cases, the instrumentation list did not supply a device to measure a desired variable. In these cases, additional instrumentation has been suggested.

4. The legislated 100-percent reliability figure and assumed sterilizability of all instruments prevents accurate assessment of values.

Several instruments not included on the supplied instrumentation lists have been included in the payload packages.

1. Anemometer. Since wind velocity is of importance to several scientific fields as well as to future missions, a simple piezoelectric anemometer has been suggested which will determine wind velocity and direction.

2. Atmospheric spectrometer. To obtain the spectral absorption and scattering properties of the Martian atmosphere, a spectrometer operating in the ultraviolet, visible, and near-infrared is suggested. This instrument would track the sun from horizon to horizon while analyzing the transmitted spectrum. Since the solar spectrum is known, the absorption of the Martian atmosphere could be calculated and this information used to identify the atmospheric compositions. The instrument would then scan the 360-degree horizon and obtain the scattering spectrum of the atmosphere. Since the illuminating source (sun) is known, an estimate of particle size and density in the atmosphere could be made.

3. Microphone. While the scientific value of Martian sounds may be debatable, the concept has great public appeal. Since the weight and power penalty imposed is not great, a microphone was suggested for the instrumentation package. It is realized that some extension of current techniques will be required to produce a satisfactory instrument for operation in the rare Martian atmosphere.

4. Photographic instrumentation. Two television-type photographic systems have been suggested; one on the Martian orbiter for mapping and one on the lander for terrain photography during descent and after landing.

5. BIO package. Because of certain limitations on some of the devices included in the instrumentation list, an analytical system called the BIO package (biological/inorganic/organic package) is suggested. The design of this package is based on absorption and emission spectrographic work and instruments now in process at Avco RAD. This instrument was designed to overcome some of the uncertainties which exist in implementing a Voyager concept. For instance, it will operate completely upside down if the lander fails to erect. It is not a one-shot device; the amount of data it collects is principally limited by available electrical power. Its operation is not based on any preassumed metabolic cycle. There is no long incubation time, as the BIO package starts supplying atmospheric data immediately after parachute opening and soil data immediately after lander deployment.

Throughout this Voyager study, the scientific instrumentation team examined the concepts of other Voyager study teams to prevent the inclusion of equipment which might contaminate the Martian scene with exhaust or waste products which might in turn be sampled by the payload instrumentation and lead to erroneous conclusions. In cases where such equipment or operation could not be eliminated, such as with the creation of entry ablation products, note was made of their existence, and sampling sources were selected to minimize the probability of accepting them.

6.2 Payload Designs

1. Lander dayload designs -- Mars. The initial approach to the problem of selecting instrument payloads was to design packages which were applicable individually to each of the three broad NASA objectives; biology, geophysics/geology and data for manned landing on Mars. For each of the three missions, a list of experiments was prepared by selecting, from those previously outlined above, all those which were applicable to the mission. Each experiment was then assigned a figure of merit which indicated the consensus of the group regarding the importance of the experiment to the particular mission. This mission value, together with the rated ability of a particular instrument to provide the desired measurement, gave the payload value of the instrument. The selection of a payload package for a specific mission and a specific vehicle then consisted of selecting the experiments with the highest payload values and accumulating them until the weight, volume, power supply or bit capacity of the vehicle design was exceeded.

It became evident early in this phase of the study that many experiments were common to all missions and that the variation was in only a few specialized experiments. From this, it began to appear possible to satisfy the major data requirements of all three missions in a realizable vehicle. Accordingly, the attempt to apportion the payload instrumentation according to mission objectives was abandoned in favor of selecting a payload to obtain optimum scientific information for a given vehicle weight and communications capacity. In this optimization, a 24-hour mission time was selected, electrical power and communication battery weights required to supply each instrument over the 24 hours were calculated, and instruments were added in the order of their payload values (determined as described in section 6.3) until the system weight or communication bit rate was exceeded. In this manner, a lightweight instrumentation payload was compiled. This 60-pound payload is given in table 15, as the "Minimum 24-hour Mission Payload," and is composed exclusively of instruments available on the instrumentation list. An "Optional Minimum 24-hour Mission Package" was also selected and is listed in table 16. This package includes instruments not on the JPL list and totals 95 pounds. Since the package was based on a 24-hour mission, all instruments requiring longer than 24 hours to produce data were omitted.

TABLE 15

MINIMUM 24-HOUR-MISSION PAYLOAD

Instrument	(pounds)	Volume (in^3)	Power (watts)	Duty Cycle	Watt-Hours per Cycle	Total Watt-Hours	Bits per Cycle	Total Bits	Number of Samples	Operation Mode	Information Content
Org. plus Bio. Gas Chromatograph (18)	7	200	4.5	4 hours	18	18	1000	0.001×10^6	1 only	After vehicle erection	Identifies molecules but may be extremely difficult to interpret.
Inorganic X-ray diffractometer (22)	10	1000	15.0	6 hours 4 samples	90	360	50,000	0.20×10^6	4 samples 6 hr/ sample	After vehicle erection	Identifies crystal structure. Crystal lattice spacing. Identify compounds.
Television camera (28)	17	384	30.0	45 minutes		22.5	0.787×10^6	4.722×10^6	Start at 30,000 1 picture vertical, 1 each quadrant; 1 vertical, 5 feet	During descent (45 minutes)	Photographs of impact area and vicinity. Topography of impact area. Cloud forms.
			30.0	5 minutes 1 picture every 2 hours		15	0.787×10^6	18.9×10^6	6 pictures in 24 hours	After vehicle erection	Macroscopic terrain structure. Macroscopic lifeforms. Low cloud structure. Dense dust.
Sample collector	15		4.0	0.5 hour per sample; 4 samples	2.0	8.0				After vehicle erection	Abraids small particles from the surface and collects them. Does not drill below the surface.
Atmosphere mass spectrometer (6)	6	150	4.5	Continuous (1 hour for 5 samples)	4.5	4.5	0.0011×10^6	0.0055×10^6	5 samples from Mach 1 to 15 minutes after erection	Decent and 15 minutes after vehicle erection	Mass/charge ratio of atmospheric components. Readings are ambiguous in some cases but can probably be correctly interpreted.
Wind velocity anemometer	1.0	216	0.1	Continuous for 24 hours after landing		2.4	9	0.0026×10^6	Every 5 minutes for 24 hours	After vehicle erection	Surface wind velocity and direction.
Temperature (1)	0.3	3.0	0.07	Every 1000-foot descent, 10 min/hr; 24 hours		1.7	9	0.0026×10^6	54 samples	Descent 30 samples, then every hour for 24 hours	Air temperature after landing. Readings taken during decent will probably be inaccurate due to vehicle heating.
Pressure (2)	0.3	5.1	.1	Every 1000-foot descent; 10 min/hr; 24 hours		2.4	9	0.0026×10^6	54 samples	Descent 30 samples, then every hour for 24 hours	Air pressure after landing. Air pressure during parachute descent.
Cell growth multiple chamber (20)	4		2.0	12 hours		24.0	2250	0.0026×10^6	1 cycle only	After vehicle erection	Existence of living organisms if proper culture medium is selected.
Total Payload	60.6		60			458		0.24×10^8			

( ) denotes instrument number on JPL instrumentation list, table 14.

TABLE 16

OPTIONAL MINIMUM 24-HOUR-MISSION PAYLOAD

Instrument	(pounds)	Volume (in^3)	Power (watts)	Duty Cycle	Watt-hours per Cycle	Total Watt-hours	Bits per Cycle	Total Bits	Number of Samples	Operation Mode	Information Contents
Television pictures (28)	17	384	30	45 minutes		22.5	0.787×10^6	4.722×10^6	Start at 30,000 feet, 1 vertical, 1 each quadrant. At 5 feet, 1 vertical.	Descent (45 minutes)	Photographs of impact area and vicinity. Topography of impact area. Cloud forms.
			30	4 hours (10 minutes each hour for 24 hours)	5	120		18.9×10^6	24 pictures. Close up 12, distant 12.	After erection	Macroscopic surface structure. Macroscopic lifeforms. Low cloud structure. Dense dust.
Pressure (2)	0.3	5.12	0.1	Continuous	2.4	2.4	9	0.001×10^6	Once every 1000 feet, 30 samples	Descent (45 minutes)	Air pressure versus altitude during parachute descent.
			0.1	10 min/hr		0.4	9	0.001×10^6	Once every hour.	After erection	Air pressure after landing over a 24-hour period.
Density (4)	1.5	15	2	Continuous	1.5	1.5	8	0.001×10^6	Once every 1000 feet, 30 samples	Descent (45 minutes)	Air density versus altitude during parachute descent.
				10 min/hr	8	8	8	10	Once per hour; 24 hours.	After erection.	Air density at surface over a 24-hour period.
Temperature (1)	0.3	3	0.07	Continuous		0.05	7	0.001×10^6	Once every 1000 feet, 30 samples.	Descent (45 Minutes)	Air temperature during parachute phase, probably modified by temperature of capsule.
			0.07	10 min/hr		0.28	7		Once every hour; 24 hours.	After erection	Surface air temperature and variations day to night.
Velocity of sound (5)	0.6	10.6	0.3	Continuous		0.23	7	0.001×10^6	Once every 1000 feet, samples.	Descent (45 minutes)	Information for checking density, temperature, and atmospheric composition measurements during parachute phase.
				10 minutes every hour; 24 hours.		1.2			Once every hour; 24 hours.	After erection	Same as above over 24 hours.
H_2O detector (8)	1.5	27	1	Continuous		0.75	7	0.001×10^6	Once every 1000 feet; 30 samples.	Descent (45 minutes)	Water content of atmosphere versus altitude during parachute phase.
				10 minutes every hour; 24 hours		4	7		Once every hour; 24 hours.	After erection	Variation of water content of atmosphere over 24 hour period.

TABLE 16 (Concl'd

Instrument	(pounds)	Volume (in^3)	Power (watts)	Duty Cycle	Watt-hours per Cycle	Total Watt-hours	Bits per Cycle	Total Bits	Number of Samples	Operation Mode	Information Contents
Anemometer	1	216	0.1	10 min/hr; 24 hours	0.01	0.4	7	0.001×10^6	Once every hour; 12 samples.	After erection.	Surface wind velocity.
Microphone	0.6	36	0.5	10 min/hr; 24 hours	0.05	2.0	2,875	0.009×10^6	Once every hour; 12 samples.	After erection	Surface noises. a. Wind b. Seismic c. Biological species d. Airborne derbis
BIO pack; atmosphere	40	7,200	12	Continuous		9	5,000	0.15×10^6	Once every 1000 feet 30 samples	Descent (45 minutes)	Atmospheric composition versus altitude during descent. Both before and after parachute phase. Ablation product identification in Martian atmosphere.
Emission spectroscopy			12	10 min/hr; 24 hours		48	5,000	0.12×10^6	Once per hour; 24 samples.	After erection	Atmospheric composition on surface. Possible dust composition.
Infrared absorption spectroscopy			100	47 minutes every 2 hours	78	936	0.75×10^6	9.0×10^6	Once every 2 hours; 12 samples	After erection	Chemical bonds of specimen. Infrared fingerprints of organic and inorganic compounds. Geometrical shape of samples.
Ultraviolet absorption spectroscopy			30	3 minutes every 2 hours	1.5	18	3.75×10^6	45.0×10^6	Once every 2 hours; 12 samples	After erection	Ultraviolet fingerprint of biological compounds. Photomicrographs of specimens. Crystal structure. Geometrical shapes.
Ultraviolet and Visible emission spectroscopy			900 peak 1 second		0.4	4.8	5,000	0.06×10^6		After erection	Identification of atoms. Identification of certain molecular bonds.
Sun spectrometer	8	360	3	Continuous power, 1 reading	36	36	5,000	0.12×10^6	From sunrise to sunset. Must track sun 12 hours; 24 samples.	After erection	Atmospheric absorption bonds. Atmospheric composition. Light-scattering characteristics of atmosphere. Some information on dust particle size. Some information on dust and cloud density.
Sample acquisition BIO (see note in table 17.)	12	48	100	5 minutes every 2 hours	8	96			1 sample every 2 hours; 12 samples.		Surface abrasion only. Does not drill.
Instrument programer	12	240	10	Continuous		250			Start at 30,000 feet; 25 hours total	Descent and after erection	
During descent	-		45			36		0.047×10^8			
After erection	-		259			1525		0.833×10^8			
Total mission	94.8		259			1561		0.88×10^8			

( ) Denotes instrument number on JPL instrumentation list, table 14.

To augment the "optional minimum" payload, for use on vehicles of yet higher performance, a "Supplement to the Optional 24-hour Mission Payload" was selected, and is given in table 17. This is to be added to the "minimum" package to form a heavier payload totaling 200 pounds. Here, in some cases, redundant instruments are included. This 200-pound payload has been used in the final reference design for the Martian Voyager lander.

The choice of instruments carried aboard the lander will fulfill not only the primary goal of a biological mission but will furnish geophysical and geological information as well. The instrumentation is also complete enough so that further additions to the lander would not achieve significantly more information. If more payload capability is available, it would be best utilized by placing a number of landers on well chosen sites.

The operating requirements of the instruments chosen had considerable influence on the design of the lander; for example,

A number of ports had to be built into the vehicle to allow atmospheric sampling and television coverage during descent as well as soil sample acquisition when the vehicle is on the ground. These ports are exposed when the heat shield is jettisonedafter parachute deployment.

Six petals were also added to the vehicle. These serve a dual purpose: 1) they erect the capsule to an upright position so that certain instruments will function properly; 2) They deploy certain instruments for maximum data achieval: the anemometer, the microphone, the sun spectrometer, and the seismograph. When the petals have erected the capsule, the instruments listed above are deployed as follows: The microphone and the anemometer, which is both a wind-velocity and wind-direction indicator, are attached to a boom vertically mounted on one petal and away from the main body of the vehicle. The sun spectrometer is cradled within another petal so that it can track the sun from sunrise to sunset. The seismograph, which was lifted out of the vehicle by two petals deploying, is deposited on the ground between those two petals and away from the vehicle. Deployment of the petals will also allow the television camera a 360 degree field of vision by means of the rotation of the telemetry antenna on which it is mounted. To achieve maximum scientific return from instruments such as the sun spectrometer and television camera, a requirement for landing during daylight hours has been adopted.

Originally, a 24-hour mission was proposed; the payload has been described above and in the accompanying tables. At present, a very desirable 6-month mission appears to be feasible. For the original 24-hour mission, the power available was a 100 watt RTG. For the 6-month mission, the power consists of a 70-watt RTG supplemented by batteries. After the first 24 hours of operation, the instruments are scheduled to operate at a reduced cycling rate of the following 30 hours, and then at still lower rates over subsequent

TABLE 17

SUPPLEMENT TO OPTIONAL 24-HOUR-MISSION PAYLOAD

Instrument	Weight (pounds)	Volume (in. ^{3})	Power (watts)	Duty Cycle	Watt-hours per Cycle	Total watt hours	Bits per Cycle	Total Bits	Number Samples	Operation Mode	Information Content
Three-axis seismograph (26)	34	1500	4	Continuous	720	720	51.8×10^6	51.8×10^6		After erection must be deployed	Seismic.
Turbidity and pH growth (19)	4	216	1	Continuous operation reading, 2 per hour	504	504	7	0.007×10^6	3 weeks desired for 1 set of samples		Certain lifeforms but information not conclusive.
X-ray diffractometer (22)	10	1000	15	6 hr/sample 4 samples	90	360	50,000	0.2×10^6	4 samples		Identifies crystal structure. Identifies certain compounds.
X-ray spectrometer (51)	8	200	2	48 hours every 10 minutes	96	96	1000			After erection	Radioactivity at surface.
Core drill and mill *	30 (18)	1200	300 (200)	4 hours	1200 (1100)	1200 (1100)			Samples to 10-50 micron size; 1 every inch for 4 inches	After erection	
Petro microscope (27)	14	576	7	0.5 hours	3.5	14	10 x 6	4.0×10^6	1 sample per inch for 4 inches of drilled depth	After erection	Photograph of sample. Geometry of particles. Crystal clevage structure.
Advanced mass spectrometer (52)	20	336	30	1 hr/sample, 12 samples	30	360	5000	0.06×10^6	12 samples	After erection	Mass/charge ratio. Identifies molecules, but may be ambiguous and difficult to interpret in the presence of multiple compounds.
Supplement Totals	108		259			3154		0.56×10^8			
Optimum 24-hour payload	94.8		259			1561		0.88×10^8			
Total payload	202.8		518			4715		1.44×10^8			

( ) Denotes instrument number on JPL instrumentation list, table 14.

* B10 sample acquisition listed on "Optional 24-Hour Mission Payload" not required when core drill is available on this supplemental payload. Weight and power listed in parentheses represent net differences used in computing totals.

weeks and months. Listed in table 18 below is the scheduling of the various instruments for the 30-hour period and the remainder of the 6-month mission:

TABLE 18

SCHEDULE OF INSTRUMENT USE

Instruments	30-Hour Period	Remainder of Mission
Television camera	6 pictures/12 hours of daylight	1 picture/day/week
Pressure, density, temperature, sound velocity and water sensors, anemometer	1 sample/hour	1 sample/hour
Microphone	10 minutes/day	10 minutes/day for the first week, then 10 minutes/2 days
BIO package	1 sample/12 hours	1 sample/12 hours for the first week, then 1 sample/48 hours
Sun spectrometer	sunrise to sunset	From sunrise to sunset, 1 day/month
Sample acquisition system	1 sample/12 hours	1 sample/12 hours for the first week, then 1 sample/48 hours
Cell growth experiment	12 hours	No longer in operation
Gas chromatograph	4 hours	No longer in operation
X-ray diffractometer	1 sample/day	1 sample/day for the first week, then 1 sample every other day
Seismograph	continuously	Continuously
Turbidity and pH growth detector	2 samples/hour	2 samples/hour for the first 3 weeks, then instrument is no longer operational

TABLE 18 (Concl'd)

Instruments	30-Hour Period	Remainder of Mission
X-ray spectrometer	1 sample/12 hours	1 sample/12 hours for the first week, then 1 sample/48 hours
Petrographic microscope		1 sample/week
Advanced mass spectrometer	1 sample/12 hours	1 sample/12 hours for the first week, then 1 sample/48 hours

The schedule above depends on reliable operation of the instruments. Although these instruments were assumed to be 100 percent sterilizable and reliable at the beginning of this program, this assumption is not necessarily realistic. For this reason, we can only recommend that strong emphasis be placed on developing a high degree of reliability for those instruments used in this program.

Since this mission is now extended from 24 hours to 6 months, the original DSIF coverage of 30 days will not suffice. It must be extended according to the above schedule to permit complete data retrieval.

2. Orbiter-bus payload design -- Mars. The orbiter will carry instruments intended to accomplish two goals: a) to obtain interplanetary data during flight to verify and augment that previously obtained by Mariner flights, and b) to obtain planetary data while the vehicle is orbiting. The instruments to accomplish these goals weigh 59.3 pounds and are listed in table 19. The television mapping system and radar altimeter on the orbiter are not included in this list as they are described in detail in a later volume of this study.

The particle flux detector, the ion chamber, and the bistatic radar will operate during both transit and orbit. The bistatic radar will be used to measure the attenuation of the atmosphere. It will also detect sand storms or dust clouds caused by atmospheric disturbances on the planet. The cosmic dust detector will function only during transit and will determine the density of this material throughout the trajectory followed by the vehicle in its flight to Mars.

The magnetometer, the infrared radiometer, and micrometeoroid detector will operate only while the vehicle is in orbit. The magnetometer and infrared radiometer will be used to make maps of the planet. The magnetometer will locate and measure magnetic lines of force, while the infrared radiometer will map the planet surface by utilizing temperature gradients.

TABLE 19

ORBITER-BUS PAYLOAD

Instrument	Weight (pounds)	Volume (in. ^{3})	Power (watts)	Duty Cycle	Bits per Cycle	Total Bits	Operation Mode
Particle flux (37)	2.5	120	0.35	Continuous			In transit and in orbit.
Ion chamber (38)	1.3	216	0.10	Continuous			Same as above and to be located next to it.
Cosmic dust (45)	2.5	125	0.2	Continuous			In transit, one plate perpendicular to ecliptic.
Bistatic radar (47)	8.0	192	2.0	240 in transit	0.2/sec cruise 1.2/sec encounter	4×10^6	In transit and orbit; see list for antenna sizes.
Magnetometer (36)	5	96	5.0	Continuous in orbit	24/min		See list for special constraints.
Infrared spectrometer (32)	29	2100	7.00		5000		In orbit, aligned toward planet vertical.
Micrometeoroid detector (46)	8	600	0.5				Orientation; see list.
Totals	59.3		18				

The presence of gases such as carbon monoxide, carbon dioxide, methane, nitric oxides, or other infrared-detectable components in the atmosphere will be determined by the infrared spectrometer. The micrometeoroid detector will count the number of micrometeorites entering the vicinity of the detector.

All the instruments listed above are unrestricted as to daylight operation. Therefore, complete coverage of the planet will be accomplished in a short time period.

3. Venus payload designs. The payload designs selected for Mars missions are not of course suitable for Venus, even though many of the individual instruments are applicable. For the Venus descent capsule which is quite limited in payload weight, only atmospheric measurements can be carried. Suggested instrumentation for the capsule includes the following:

a. Emission spectrograph. Measures molecular composition of atmosphere and condensed particles during parachute descent. May also be capable of operation during early reentry.

b. Temperature. During parachute descent.

c. Pressure. During parachute descent.

d. Density. This measurement desired as a check on results of first three instruments.

e. Light-scattering photometer. Using an internal light source, this instrument measures backscattered light at 90 and 180 degrees. In combination with measurement of particle composition, this determines particle sizes.

For the heavier Venus lander, the instruments recommended in addition to the above list include the following:

a. Television camera. Operating below the cloud layer in the spectral region such that the 800° F surface is self-illuminated.

b. Mass spectrometer. With sample acquisition system, determines the composition of "soil" samples on surface.

The Venus orbiter-bus payload is identical to the Mars orbiter-bus list given in table 19 except for the addition of the microwave spectrometer (number 30 on the JPL instrumentation list in table 14). This instrument determines spectra of clouds and surface by their microwave spectra during lander descent.

6.3 Instrumentation Evaluation

1. Evaluation procedure in instrument selections. In order to optimize the scientific value of the payload, the general characteristics of the instruments on the list, as well as of other desirable instruments, were studied.

Several criteria were used to establish logical methods of selecting specific instruments for specific measurements. The factors which were involved are outlined below:

a. An effort was made to predict how well an instrument would perform its design goals.

b. An instrument which will start supplying information immediately after deployment was considered preferable to one which required a long setup time or a long incubation period. This is based on mission time reliability.

c. An instrument which will take many samples is considered preferable to an instrument which takes only one or a few samples.

d. Deployment difficulties should be minimal in early missions.

e. Mechanical motions should be kept simple.

f. Self-calibration should be included where possible.

g. The importance of the information supplied should justify the bit content.

h. Weight, volume, and power requirements should also be justified by the information output.

It should be noted that reliability and sterilizability have not been considered in the instrumentation evaluation as outlined above.

A formula was generated to give quantitative comparative indices between several devices which obtained similar information. Although it could not be made completely objective, nor could all factors be applied in most cases, it helped crystallize and point out problems. It is given below in the rough form in which it was used by the Scientific Instrumentation Group. For the collecting of any specific piece of data, the value of the instrument (V_I) to the Voyager payload is defined by

$$V_I = \sum_i \frac{Q_i \, R \, S \, N_i \, T_i \, C}{wf \cdot prf \cdot vf \cdot bf}$$

where Q_i is a number selected by the group which indicates how well the instrument supplies the desired information. A scale of 0-1 was used in assigning a number to this variable. The summation over indicates that the same instrument might be used to measure several variables that would be used more than once, but the quality of its information might not be the same for each of the variables. For example, a mass spectrometer might be used to measure "atmospheric composition," "inorganic soil composition," and "organic matter," but because of the nature of its operation the information on organic matter would not be of high quality because the various organic molecules might be broken down to other products in the instrument, so that Q_{AC} and Q_{ISC} would be greater than Q_{OM}.

R is the reliability factor, taken in this study as always being unity.

S is the sterilizability factor, also always taken as unity in this study.

N_i is a number based on both the ability of the instrument to handle numerous samples and on the scientific and reliability values enhanced by several samples.

T_i is a number based on the time required by the instrument to start supplying information on its subject.

C is the factor which takes into consideration the complication of the lander system imposed by including the instrument. This considers deployment difficulties, sample loading, and programing.

wf is a weight factor

prf is a power requirement factor

vf is a volume factor

bf is a bit requirement factor.

There are other parameters which might be considered, but even the relatively simple formula given for V_I becomes difficult to apply without computer programing, and since much is based on the judgment of the group assigning the values, it is doubtful that a more refined formula would produce a nearer optimum payload package.

With the instrument list in hand, the cataloguing of Martian possible lander experiments began by listing all the types of data which could be supplied by those instruments. To this was added other scientific questions which should be answered on early flights. It was seen that these questions fell into several general classes so that the individual experiments were grouped into these broader classes. The final groupings bore the following titles, which are self-explanatory.

For Mars

a. Radiation Belt Experiments

b. Mapping

c. Cloud Structure

d. Atmosphere Composition

e. Physical Properties of the Atmosphere

f. Demonstration of Biological Structures or Cells

g. Biological Cell Growth

h. Inorganic Soil and Dust Analyses

i. Organic or Biological Compound Detection

j. Surface Topography

k. Seismographic Experiments

l. Soil Mechanics Experiments.

For Venus

a. Radiation Belt Experiments

b. Cloud Mapping

c. Atmospheric Composition (by layers)

d. Physical Properties of the Atmosphere (by layers)

e. Atmospheric Particle Size Examination (by layers)

f. Atmospheric Biological Search (by layers)

g. Inorganic Soil and Dust Analysis

h. Surface Topography

i. Seismographic Experiments

j. Surface Physical Properties.

For Mars, all applicable instruments from the list and all suggested additional instruments were evaluated for their performance in collecting the data for each category tabulated above. Except for mapping, which is covered elsewhere, the evaluations are outlined in tables 20 through 30.

Due to the different environmental conditions on Venus, it does not follow that the evaluations used on the work sheets for Mars would hold for a Venus-bound Voyager. Many of the instruments listed would be useless on Venus, while some could be used with modification. Some desirable experiments for a Venus lander call for the development of new instrumentation. For example, an atmospheric particle size examination could be conducted from an entering lander with a yet-to-be-developed backscattering instrument.

It will be noted in the selected scientific payload instrumentation packages that some of the instruments in the shopping list were not selected even though there was no substitute included which would perform the same measurement. (An example of this is the seismic refractometers.) In these cases, it was considered that the complications or techniques involved in using or placing the instruments exceeded the capability of early Voyager vehicles, and that such experiments should be performed on later probes after improved techniques had been worked out from experience gained on the early shots.

2. Operational analysis of instrumentation selection. An operations research technique to aid in the selection of an optimal scientific payload for Voyager missions is reviewed. At the outset, it was recognized that the complete development of this technique, because of its exploratory nature, would lag somewhat behind the study timetable. In spite of this difficulty, the technique has contributed in two ways: first, to pace the actual selection of various experimental packages by establishing a framework of objective selection criteria for instrumentation and second, to corroborate the choice of the several packages which had been selected earlier. Some refinements in the selection models are still necessary; however, the existing models are valid for a first-order selection. Moreover, it is believed that if value judgments of scientific experts from several disciplines are obtained by NASA to fill in open matrices related to the scientific merit of various experiments and instruments, then a scientific payload, determined on the basis of these judgments and the technique, would result in nearly the identical list of instruments being selected. Finally, it is recommended that this technique be improved and extended in later studies, for use not only in the simultaneous determination of optimum scientific payloads, telemetry capacities, and power packages related to evolution of missions throughout the Voyager program, but in other space programs as well.

a. Discussion. The purpose of this section is to review a technique for choosing among candidate instruments such that the total scientific yield of those instruments chosen is maximum. This review describes the methods used: (1) to explore the meaning and quantification of scientific merit, (2) to evaluate the factors relevant and significant in the acquisition of Voyager

TABLE 20

RADIATION BELTS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
37 and 38 Particle flux and ion chamber		3.8	0.45	4" x 5" x 6" 6-inch sphere			Spacecraft to subtend minimum solid angle	For interplanetary use only
39 Trapped radiation detector		4.0	0.7	4" x 5" x 5"	N/A	30-degree cone angle away and toward sun		For use Mars and Venus interplanetary
40 Medium-energy proton directional monitor		3.0	1.0	4" x 5" x 5"		Not specified		
41 High-energy proton directional monitor		4.0	0.5	3" x 4" x 4"		60-degree cone angle visibility		

TABLE 21

CLOUD STRUCTURE

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
28 Surface and approach photography from lander	0.2	20	480	4" x 8" x 12"	1.9×10^7	Requires movement focusing and orientation	None	Due to high bit rate, limited number of pictures. Can only look about entry trajectory.
48 IR television from orbiter	0.4	15	10	6" diam. by 12"	10^9	Aligned toward planet vertical	None	Resolution poor, limited to near IR.
Avco mapping stereo camera	1.0						None	Will cover a large portion of the Martian surface.

TABLE 22

ATMOSPHERIC COMPOSITION

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
6 Mass spectrometer	0.9	6	6	10" x 5" x 3"	13,200	Access to outside atmosphere	Atmosphere	Must have vacuum system. Can probably sample during descent.
7 Gas chromatography	0.5	7	4.5	5" x 5" x 8"	2,400	Access to outside atmosphere	Atmosphere	Provisions must be made for carrier gas. Slow; cannot sample during descent. Spectrum obtained from any given column is too narrow to cover all ranges of unknown gases
8 Water Vapor	0.3	1.5	1	3" x 3" x 3"	1260	Access to outside atmosphere	Atmosphere	Temperature limitations, upper limit too low as listed. Detects only H_2O vapor
9 Oxygen	0.3	1.5	1	5" x 3" x 3"	420	Access to outside atmosphere	Atmosphere	Dynamic range too small Detects only O_2
10 Ozone	0.3	1.5	1	3" diam. x 6" long	260	Access to outside atmosphere	Atmosphere	Detects only ozone
11 Argon	0.3	1.5	1	10" x 2" x 2"	420	Access to outside atmosphere	Atmosphere	Power limit may not be adequate Detects only argon
13 Nitrogen	0.3	1	1	4" x 3" x 4"	420	Access to outside atmosphere	Atmosphere	Detects only nitrogen
14 CO_2 Carbon dioxide	0.3	1	1	4" x 3" x 4"	840	Access to outside atmosphere	Atmosphere	Detects only CO_2
29 microwave spectrometer on orbiter	?	30	13	0.6 ft^3	216	Beam width less than 2% aligned toward planet vertical	Looks through atmosphere	?
32 IR spectrometer on orbiter	0.1	29	7	12" diam. x 15"	60,000	Aligned toward planet vertical	Looks through atmosphere	Has planet as a background. Requires cryogenic cooling Limited to infrared region
33 UV Photometer on orbiter	0.1	1.5	1.5	3" diam. x 5"	?	?	Looks through atmosphere	Requires an individual photometer for each element to be detected. Cannot anticipate unknown components of the atmosphere
Avco Biopackage	1.0	60	100	3" x 20" x 12"	30,000	None	Atmosphere	Can sample during descent both before and after parachute opening Can take one sample every 5 seconds
Avco sun scanning spectrometer	0.9	8	11	4" x 6" x 8"	8,640		Atmosphere	Must be deployed on ground Reasonably fast but requires the sun as a light source

TABLE 23

PHYSICAL PROPERTIES OF THE ATMOSPHERE

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
1 Static temperature	0.9	5 oz	70 mw	1" diam. x 3" long	168	Access to outside free atmosphere	---	Upper range of 300 °K might be too low for surface temperature of Mars. Sensor range less than sterilization temperature.
2 Static pressure	0.9	5 oz	100 mw	1.6" diam. x 2" long	216	Free-stream conditions	---	
4 Static density	0.9	24 oz	2	15 in.^{3}	192	Free-stream conditions	---	Radioactive source must be shielded, or will interfere with other experiments as growth detector using C^{14} label.
5 Velocity of sound	0.2	10 oz	300 mw	2.3" diam. x 2" long	168	Free-stream conditions	---	
Avco anemometer	0.7	1	100 mw	6" x 6" x 6"	168	Exterior of vehicle and free stream after landing	---	Require calibration for Martian air density.

TABLE 24

BIOLOGICAL STRUCTURE OF CELLS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
17 Microscope	0.6	5	2 minimum, 1 continuous	3" diam. x 10"	1.2×10^7	None	Aerosol or soil	Cannot visualize macroscopic organisms. Cannot determine composition.
21 Staining experiment	0.2	5	5	3" x 10" x 8" plus 2" diam. x 6"	48 oz	Must be near vertical	Soil	In soil samples using fluorescent techniques from the soil itself, and response of microorganisms can present difficulties.
Avco biopackage	1.0	60	100	30" x 20" x 12"	0.9×10^8	Operates in any position, no deployment	Soil or aerosol	Cannot visualize macroscopic organisms. Can see cell or crystal structure. Can determine composition.
28 Surface and approach photograph	1.0	20	480	4" x 8" x 12"	1.9×10^7	Requires movement and orientation and focusing	None	Cannot visualize microscopic organisms. Can operate during descent.

TABLE 25

CELL GROWTH PROCESS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
15 Radio isotopes growth detector	0.6	6	3	8" x 10" x 6" plus 4" x 1" x 2" x 3"	2,400	Up-down orientation required	Soil sample needed	Organisms must grow in the media provided. Organisms sampled must be viable and in large enough numbers to start growth. Growth of exotic life forms and certain of the autotrophic organisms is questionable. Requires up to 20 days incubation time.
16 Redox Potential experiments	0.5	3	1	8" diam. x 4"	6,800	Near vertical orientation required	Aerosal or soil sample	Organisms must grow in the media provided. Organisms sampled must be viable and in large enough numbers to start growth. Growth of exotic life forms and certain of the autotrophic organisms is questionable. Change in Redox potential can be brought about by conditions other than microbiological growth, i.e., certain possible compounds in soil. Requires long incubation time.
19 Turbidity and PH growth detector	0.6	4	1	6" x 6" x 6"	336	Near-vertical orientation required	Aerosal	Same as 1 to 3 in instrument 16. Dust particles introduced with aerosal might give turbidity and pH reaction (e.g., as particles of an acid soil or an alkaline soil). Long incubation time required.
20 Multiple chamber biochemical experiment	0.7	4	2		4,500	Verticle orientation	Soil or aerosal	Same as 1 to 3 in instrument 16. Enzynes used must in a native state. It is questioned whether surface soil samples will have enzymes in the native state due to harsh environmental conditions. In soil samples using fluorescent technique, there are problems with background fluorescence from soil itself. Enzyme of possible exotic forms might not react with substance provided.
21 Stain experiment	0.5	5	5	3" x 10" x 8" plus 2" diam. x 6"	4,800	None	Soil	In soil samples using fluorescent technique, there are problems with background fluorescence from soil itself.

TABLE 26

INORGANIC SOIL AND DUST ANALYSIS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
22 X-ray diffractometer	0.8	10	15	10" x 10" x 10"	600,000		Must have prepared soil sample	Problems with soil sample preparation. Lack of information from list concerning spectral range. What is source of X-rays, if radioactive material used; question of shielding also if X-ray tube used.
23 Alpha scattering	0.4	7	2	3" x 3" x 3" 5" x 7" x 7"	10,000	Head must be slightly above planetary surface	None	
50 Neutron analysis	0.4	20	20	4" diam. x 36"; 4" x 4" x 3"	2.8×10^5	Point to planet surface	Prepared soil sample	Preparation of soil samples required. Shielding of neutron generator required
51 Gamma ray spectrometer	0.2	8	less than 2	200 in.^{3}	14,400	Pointed to planet surface	Prepared soil sample	No radioactive sources on vehicle, or heavy shielding would be required for the radioactive sources.
52 Advanced mass spectrometer	0.8	20	30	14" x 3" x 8"	6×10^4		Prepared soil sample	
54 Fluorescent spectrometer	0.2	25	25	5" diam. x 15" plus 3 boxes 8 in.^{3}	12,000	None	Prepared soil sample	Requires adaptation for Mars landing. Limited number of channels; therefore, number of elements determined.
Avco Biopackage	1.0	60	100	30" x 20" x 12"	0.9×10^8	Operates in any position	Soil samples	Identifies compounds and elements Operates immediately after landing Takes many samples Particle shapes and structure shown.

TABLE 27

ORGANIC OR BIOLOGICAL COMPOUNDS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
18 Organic gas chromatograph	0.4	7	4.5	5" x 5" x 8"	10,800		Soil	Indirect measurements, a number of different compounds can yield the same pyrolysis products, thus causing misinterpretation. No technique for interpreting an unknown organic material for which no prior spectrum (gas chromatography) is available. Provisions must be made for carrier gas. Number of samples limited to number of packed calories carried.
20 Multiple chamber biochomical experiment	0.2	4	2		45 oz	Vertical orientation	Soil	Limited use for this purpose, could be used to detect cellulose, SO_4, and compounds which could be acted upon by enzymes, etc.
21 Stain Experiment	0.1	5	5	3" x 10" x 8" plus 2" diam. x 6".	48	None	Soil	Limited value due to restrictions of the stain and staining produce.

TABLE 27 (Concl'd)

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type.	Remarks
55 UV spectrometer	0.5						Soil	Information limited to proteins, peptide, nucleic acids
56	0.5	5	1	6" x 6" x 4"			Soil dissolved in a liquid	If a solution technique is used, then you obtain subtractive or additive intensity components, due to mixtures of compounds dissolved in the solvent.
Avco Biopackage	1.0	60	100	30" x 20" x 12"	0.9×10^8	None	Soil, aerosol, or dust	Identifies compounds and linkages. Supplies picture of geometrical shape of sample components.

TABLE 28

SURFACE TOPOGRAPHY

Instrument Numbers	Performance Value Number	Weight (pounds)	Power 24 hrs.	Volume	Bits 24 hrs.	Deployment	Sample Preparation and Type	Remarks
28 Surface and approach photography	0.8	20	480	4" x 8" x 12	1.9×10^7	Requires movement and orientation and focusing.	None	Due to high bit rate, limited number of pictures. Good resolution near landing site.
48 IR television on orbiter	0.5	15	10	6" diam. x 12" long	10^9	Aligned toward planet vertical	None	Resolution poor Limited to near-infrared.
Avco stereo mapping from orbiter	1.0						None	Poor resolution. Covers most of the Planet.

TABLE 29

SEISMOLOGY

Instrument Number	Performance Value Number	Weight	Power 24 hrs.	Volume	Bits 24 hrs.	Deployment	Sample prep. & type	Remarks
25 Single axis seismo-graph	0.5	8	1	5" diam. x 6"	172,800	Must be placed on planet with known orientation	None	Must operate for several months. Emplacement of seismo-graph so as to preclude any weather effects.
26 Three-axis seismo-graph	0.8	34	4	10" diam. 15"	172,800	Must be placed on planet	None	Same as above.
53 Seismic-refracto-meter	0.5	40		300 in.^{3}	6,000	Must be placed on Planet	None	Must have precise dispersal of explosive charges and geophones.

TABLE 30

SOIL MECHANICS

Instrument and Number	Performance Value Number	Weight (pounds)	Power 24 hours (watts)	Volume	Bits 24 hours	Deployment	Sample Preparation and Type	Remarks
24 Soil mechanics ex-periment	1.0	13	3	12" diam. by 24"	10^3	Vertical axis 4 inches above surface		Not enough information given for proper evaluation.

scientific yield, (3) to formulate objective selection criteria based on a mathematical model relating the scientific merit of an instrument and the cost of acquiring information with it as a figure of merit, and (4) to choose, from the candidate instrument list, on the basis of an optimization those instruments which would yield the maximum scientific return within the constraints of the available payload. Essentially, this technique is performed in two steps, first the construction of an instrument scientific-merit rating index, and second by the payload selection with the use of an optimization algorithm.

Certain evolutionary aspects of this analysis are worthy of mention. As initially envisioned, the figure of instrument merit to be used as the basis of selection would be a comprehensive model of all factors related to the scientific value and use burden of all instruments. In the interest of simplifying unnecessary complexity, those factors which are relevant, yet insignificant to the outcome, were deleted providing an abbreviated, more workable model. The techniques under consideration for optimal selection were linear programing, dynamic programing, and the so-called exhaustive search. As a brief comparison, the linear programing selection would provide an optimal allocation of payload constraints on the basis of their marginal tradeoff (substitution) coefficients such that the sum of their scientific yield would be maximized. Dynamic programing would maximize the scientific yield for increasing values of payload until constrained; thus, each size payload would have an optimum package of instruments. Exhaustive search is a trial-and-error process using the differential figure of merit as the steepest ascent criterion until payload constraints were reached. In practice, exhaustive search became quite attractive as the number of potential instruments rapidly decreased on the basis of figure of merit alone, thereby relieving the necessity for mathematical programing. Exhaustive search is valid as a first-order analysis; however, it becomes inefficient (hence, its name) in examining boundary conditions. For this study, the results were used only to corroborate the already prepared lists so that no boundary conditions were examined. In view of the latitude possible in making value judgments, examination of boundary conditions is considered not meaningful.

In the process of devising the optimization technique to select the best scientific package within the available payload constraints, a very useful byproduct was discovered. Namely, that in the determination of the best scientific package, a simultaneous outcome is the determination of the communication bit rate and the power generating capacity, not only required for the instruments but also feasible within the payload. Because the scientific instruments, the power systems, and the telemetry communications systems are all competing for the same payload weight and volume, a spacecraft designed on the basis of these simultaneous outcomes will result in greater scientific yield potentiality.

b. Scientific merit. The objective of the Voyager program is to obtain scientific information about the planets Mars and Venus. More specifically, one objective is to obtain biological information to answer the questions "does (or did) life exist on these planets?; if yes, "is this life as we know it?; if not, "could it support life?" There are numerous alternative means of answering these questions; some means are not feasible within our technology; other means are quite efficient. In choosing one means over another, who is to say, for example, whether a television camera of macroevents is more valuable that a C_{14} cell growth measurement? The role of the analyst is to structure the objectives in such a way that expert opinion can provide value judgments as to their relative worth. The approach taken was to treat the objectives comprehensively and then to simplify. This was done in the following way: For the first program mission(s), the dominant objective is to detect the existence of life. As the program matures, other objectives, such as hospitality/hostility to man, geophysical measurement, etc., would probably be introduced. Therefore, the first element of scientific merit is the mix of scientific objectives which each probe undertakes to fulfill. Value judgments of experts are solicited to quantify the relative emphasis of the entire set of objectives for each mission.

For each objective, all alternative means of fulfillment, partial and complete, are identified. For example, as a direct means of detecting the existence of life, the major available scientific phenomena are motion, metabolic, metamorphosis, reproduction, pH changes, redox, response to stimuli, respiration, and large protein chemistry. Some of these techniques are conclusive, others probabilistic. Furthermore, other means exist for the indirect, general and specific, measurement of the basis of life, organic and exotic. Again value judgments of experts are solicited to quantify the relative ability of each phenomenon to satisfy each member in the set of mission objectives.

For each observable phenomenon, all alternative instruments which are capable of detecting and measuring the phenomenon are identified. As in the previous steps, value judgments of experts are solicited to quantify the suitability of all candidate instruments to measure the several sets of phenomena and mission objectives.

In the interest of limiting the scope of this analysis, the above procedure was simplified. Since the objective of a mission may be to obtain biological intelligence, the scientific topics of relevant interest (to the Mars lander) could be identified as follows:

1) Organic or Biological Compounds

2) Cell Growth

3) Biological Demonstration on Cells

4) Surface Topography

5) Physical Properties of the Atmosphere

6) Atmospheric Composition

7) Inorganic Compounds

8) Soil Mechanics

9) Seismic.

Each of these was examined for its contribution to the biological objectives, and quantitative value judgments were given by a group of scientists. The value judgments were restricted from 1 to 10, but no total quantities were imposed.

The same group of scientists made quantitative value judgments for each of the 56 instruments in the NASA catalogue, plus 4 Avco-proposed instruments. These instruments were examined for suitability, in detection capability and quality of measurement, for each of the scientific topics of interest noted above. As before, the value judgments were restricted from 1 to 10, but total quantities were not imposed.

The scientific merit of any one instrument as a payload candidate would then be a function of the suitability of the instrument (detection capability and measurement quality) and the relative value of the phenomenon being measured, summed over all experiments in which that instrument could be used. In practice, the joint distribution of the two sets of value judgments has been normalized and linearized to facilitate manipulations in using the selection technique.

The conversion of the two sets of value judgments into linear, normalized distributions was made with the following models:

$$V_i = \frac{\log_{10}^{-1} X_i}{\sum_{i=1}^{n} \log_{10}^{-1} X_i}, \quad V_{.} = \sum_{i=1}^{n} V_i \equiv 1.0$$

$$V_{ij} = \frac{\log_{10}^{-1} X_i \cdot \log_{10}^{-1} Y_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{m} \log_{10}^{-1} X_i \cdot \log_{10}^{-1} Y_{ij}}, \quad V_{..} = \sum_{i=1}^{n} \sum_{j=1}^{m} V_{ij} \equiv 1.0$$

$$V_{.j} = \sum_{i=1}^{n} V_{ij} \equiv 1.0 \quad ,$$

where

X_i = $[x_i]$ = experiment value judgments

Y_{ij} = $[y_{ij}]$ = instrument value judgments for each experiment

V_i = matrix of fractional values of experiment i to mission

V_{ij} = matrix of fractional values of instrument j used in experiment i to mission

$V_{.j}$ = matrix of fractional values of instrument j to mission.

To the extent that the linearization is a forced distribution, interaction in the selection of instruments in the instrument mix would require special treatment. That is, when two instruments perform duplicate measurement their joint scientific merit would not be the sum of their individual merits but an adjusted value. It is recognized that the models used have restriction with respect to linear additivity, and the examination of other approaches is recommended for future use.

c. Evaluation of factors. In addition to the scientific value of an instrument, there are a number of other factors which contribute to the relative merit of one instrument as compared with other instruments. In this section, these factors are examined, and those factors deemed significant are identified for later use in the instrument scientific-merit rating index. Relevant factors are now evaluated.

1) Instrument value. This factor was determined in the preceding section on the basis of the experiments to be performed and the instrument suitability in terms of detection capability and quality of measurements. In the process of converting the value judgments into a single instrument value, the model included a summation over all experiments. This summation is an incorporation of another factor, instrument versatility -- the ability of an instrument to fulfill several experimental objectives.

2) Instrument useful life. This factor is a measure of the ability of an instrument to take repeated measurements, that is, a one-shot device versus continuous. To some extent, this can be treated by dividing the instrument value by the number of instrument readings (hence the number of one-shot instruments) necessary to acquire the threshold quantity of value. Other facets in the evaluation of useful life relate to the dynamics of value

acquisition, or the time profile of value attainment. For each instrument, the value density function is different; some typical value-generating functions are described below.

Measurements M of equal value (1 required): $V_{ij} = M_{ij}$

(x required): $V_{ij} = x \cdot M_{ij}$

Measurements M of increasing value: $V_{ij} = M_{ij} \cdot (1 - e^{-x})$ or $M_{ij} \cdot e^{x}$

Measurements M of uniformally decreasing value: $V_{ij} = M_{ij} (1 - M_{ij})^{x}$

Measurements M of cyclically decreasing value: $V_{ij} = M_{ij} \cdot e^{-x} \cdot \cos x$

Measurements M of cyclically increasing value: $V_{ij} = M_{ij} \cdot e^{x} \cdot \sin x$.

Implied in the statement of these functions are expressions of duty cycle, mission duration, and other considerations beyond the scope of this discussion; but, in some cases, these items show up as considerations in other factors as well. It is important to point out that the value associated with time phasing of instrument readings interacts with the mission reliability profile. Although this is not significant over short periods of time, the effect can be quite important when considering alternative instrument measurements for descent after impact and after several days or months.

3) Instrument reliability. This is the probability that the instrument will perform its intended function. This has been set at 1.0 for all instruments and therefore is not significant in instrument selection.

4) Instrument sterilization capability. The factor is the ability of the instrument to perform its intended function after sterilization. This has been set at 1.0 for all instruments and therefore is not significant in instrument selection. Alternatively, if not sterilizable, this may be considered the probability of carrying a viable organism.

5) Instrument interaction coefficient. This is a factor to adjust an instrument value because of such circumstances as (a) generation of a disadvantageous byproduct which may contaminate, obscure, or otherwise devalue other instruments, (b) state-of-the-art complications, (c) deployment or orientation design difficulties, and other special technical problems. This factor may contribute positively as well; for example, the use of a television camera for site selection.

All factors discussed above influence the value of the instruments in the mission, and as such their product is considered to be the instrument worth. Associated with the worth is an instrument "cost," that is, the cost of acquisition in terms of using up the available payload resources. The relation of instrument

worth divided by instrument cost becomes the instrument scientific-merit rating index. The cost factors are now discussed.

For each launch window, there is what may be called a total reference payload; that is, in the case of the lander, an amount of residual weight and volume after structure, propulsion system and propellant, guidance system, descent system, heat shield, and other vehicle systems are accommodated. Determination of the operating power systems, the communications system, and the scientific payload must be made within the constraints of this residual weight and volume. Of necessity, some of the weight required by the communications system and power system is fixed. However, the weight of the power-generating equipment, associated with instrument operating power and associated with telemetry operating power, and the weight of the communications system associated with bit-rate capacity, are functions of the instrument package. Payload constraints include not only weight but also volume as well. It is possible to treat the weight/volume relationship as a reference density (cost); thus, instruments with deviations from the reference are added to the payload in terms of density associated with their greater capacity requirement while at the same time generating slack capacity in the other requirement. Volume limitations were expected to be of sufficiently lesser importance than weight limitations; thus, in the interest of simplicity, volume considerations were dropped. "Cost," $W_{.j}$, is the total weight attributed to the instruments to be selected. We shall now examine the manifestation of weight associated with instrumentation.

1) Basic weight. Simply the weight of the instrument, that is, its housing, sensing mechanisms, analytical mechanisms, internal motors, etc.

2) Ancillary weight. The weight of all devices uniquely required for an instrument, such as special mounts, thermal control, booms, optics, deployment, location, explosives, etc., and a proportional share of weight for similar accommodations which are shared.

3) Operating power weight. The equivalent weight of the planned energy source which is required to operate the basic instrument plus its ancillary devices over the planned duty periods. More explicitly, if an RTG yields 3 w/lb then an instrument which had an average power consumption of 6 watts would have an equivalent operating power weight of 2 pounds.

4) Telemetry power weight. The equivalent weight of the planned energy source which is required to drive the communications system in telemetering all data generated by the instruments.

In summary, these weights are penalties on the instruments for such reasons as their heaviness, special handling, excessive need for operating power, or an excessively high bit rate.

d. Merit rating index. As previously discussed, the merit rating index, a figure of scientific-merit for comparing instruments, is simply the adjusted value of an instrument divided by its relevant total "cost." Two models for calculating this index are presented. The first is presented in the interest of comprehensive discussion but was not actually carried out in the analysis. The second, an abbreviated version, is described as it was [illegible]

The comprehensive model is

$$I_{..j.} = \sum_h \sum_i \sum_k \frac{A_h \cdot B_{hi} \cdot C_{hij} \cdot D_{hijk} \cdot E_{hijk} \cdot F_j \cdot G_{hijk}}{P_j + Q_{hijk} + R_{hijk} + S_{hijk}}$$

and

$$I_{....} = \sum I_{..j.} = 1.0 \quad ,$$

where

Term	Description	Value Range
I	Merit Index	0 to 1.0
A	$[a_h]$, values of mission objectives emphasis	normalized to 1.0
B	$[b_{hi}]$, values of observable phenomena	normalized to 1.0
C	$[c_{hij}]$, values of instrument suitability	normalized to 1.0
D	$[d_{hijk}]$, incremental measurement value	approaches 1.0 as limit
E	$[e_{hijk}]$, incremental mission reliability	decays to 0 as limit
F	$[f_j]$, sterilization capability	0 or 1.0
G	$[g_{hijk}]$, adjustment coefficient	favorable > 1.0, unfavorable <1.0, otherwise 1.0
P	$[p_j]$, basic instrument weight	> 0
Q	$[q_{hijk}]$, ancillary weight	≥ 0
R	$[r_{hijk}]$, equivalent operating power weight	> 0
S	$[s_{hijk}]$, equivalent telemetry power weight	> 0

Term	Description	Value Range
h	mission of interest	
i	observable scientific phenomena of interest	
j	instrument of interest	
k	measurement (operating cycles) of interest.	

The abbreviated model is

$$I_{.j.} = \sum_i \sum_k \frac{V_{ij}}{P_j + Q_{ijk} + R_{ijk} + S_{ijk}} ,$$

and

$$I_{...} = \sum_j I_{.j.} = 1.0 ,$$

where

Term	Description	Value Range
V	$[v_{ij}]$, fraction values of instruments as described previously	normalized 1.0
R	$[r_{ijk}]$, calculated from (cycles). (watt-hours/ operating cycle). (pounds/watt-hour) for storage devices; and (cycle) (watt-hours/ operating cycle). (pounds/watts x average operating time) for generating devices.	
S	$[s_{ijk}]$, calculated from (cycles). (bits/operating cycle). (watt-hours/bit).(pounds/watt-hour) for storage devices; and (cycles). (bits/operating cycle) (watt-hours/bit). (pounds/watts x average operating time) for generating devices.	

All other terms are sufficiently described above or elsewhere.

P and Q are readily available or identifiable. When several measurements from a one-shot instrument are required, then kP_j should be used. Total

relevant weight for instrument $jW_{.j}$ is the sum of $P_{.j}$, $Q_{.j}$, $R_{.j}$, and $S_{.j}$. Table 31 is a tabular solution for the matrix $I_{...}$ where each row tabulation is associated with the solution for given $I_{.j.}$.

Since there are many design options associated with the power and communications systems, this model, as well as that about to be introduced provide means for the parametric evaluation of these alternatives.

e. Instrument selection model. The second major part of this analysis is the process of instrument selection. As discussed earlier, three techniques were considered. The detailed algorithm of the technique which was used is described. A brief statement on the approach to be used with the other techniques is also included as an aid to the extension of this study.

The selection technique chosen starts with the ranking of instruments according to their merit-rating index. The selection criterion is to choose instruments sequentially on the basis of largest merit index value first, and so on. The instruments are selected on the basis of merit index ($I_{.j.}$) and are added to the experimentation package in quanta of weight and value ($V_{.j}$), until the residual payload weight capacity is too small for the next instrument candidate. Then the next best instrument on the basis of index value is added, and so on, until the residual payload weight is completely consumed, at which point the combined value $\sum_{j'}^{j} V_{.j}$ is a first-order maximum. The boundary conditions are examined by grouping two (or more) instruments not yet added to the payload such that their combined (total value/total weight) merit exceed that of one or more instruments already included, in which case a substitution would be made.

Table 32 is a tabular model to assist in the selection process. Note that in the summation of total bits, total power, and average power, design parameters are supplied for the communication and power systems. Since the best communication system would be designed around the mission bit-rate requirement, an iteration can be carried out starting out with some bit-rate capacity related to a target total number of bits and improving sequentially on the basis of better estimates after the payload has been initially sized. In practice, the thermal-control limitations dictated the maximum power-generator size, therefore resulting in some additional battery weight and slightly different payload.

The payload instrumentation as selected by this technique corresponded to the recommended list with the exception of three minor instruments. The lack of correlation in these cases was considered to be due to boundary conditions, interactions in the form of nonlinear value additivity, and the limitation imposed on power-generator size by the thermal-control system.

TABLE 31

INSTRUMENT MERIT RATING INDEX TABULATION MODEL

Explanation	Instrument No. in Catalogue (1)	Instrument Value Matrix (2)	Basic Instrument Weight (3)	Ancillary Instrument Weight (4)	Operating Power Requirement (5)	Bit Generation Rate (6)	Planned Operation (7)	Total Instrument Operating Power (8)	Total Instrument Bits Generated (9)	Telemetry System: Power Requirement (10)	Total Instrument Telemetry Power (11)	Planned Power Source: Weight/Power (12)	Equivalent Weight: Operating Power (13)	Equivalent Weight: Telemetry Power (14)	Instrument "Cost" (Total Weight) (15)	Instrument Merit Rating Index (Sum = 1.0) (16)	Ranking No. on Basis of Rating (17)
Code	j	$V_{.j}$	P_j	$Q_{.j}$			k						$R_{.j.}$	$S_{.j.}$	$W_{.j.}$	$I_{.j.}$	j
Units			(pounds)	(pounds)	WH/ cycle	B/ cycle	cycle	WH	B	B/ WH	WH	lb/ WH*	(pounds)	(pounds)	(pounds)		
Steps	1 2 3 4 5 . . . . etc. . . . 60							(5)· (7)	(6)· (7)		(9)+ (10)		(8)· (12)	(11)· (12)	(3)+ (4)+ (13)+ (14)	(2)+ (15)	$I_{.j_1}>$ $I_{.j_2}>$ $I_{.j_3}$

*(lb/W) x (average operating time), corresponding to storage or generating devices

TABLE 32

INSTRUMENTATION SELECTION MODEL

Explanation	Instrument Rank by Index Value (1)	Instrument No. (2)	Index Rating (3)	Value (4)	Cumulative Payload Value (5)	Total Instrument Weight (6)	Cumulative Payload Weight (7)	Total Instrument Power (8)	Cumulative Payload Power (9)	Average Payload Power (10)	Peak Power (11)	Total Instrument Bits (12)	Total Payload Bits (13)	Payload Bits Rate (14)
Code	j'	$.j.$	$I_{.j.}$	$V_{.j}$	$\sum_j V_{.j}$	$W_{.j.}$	$\Sigma W_{.j.}$							
Units						(pounds)	(pounds)	WH	WH	W	W	B	B	B
Steps (table 31 reference)	(17)	(1)	(16)	(2)	Σ(4)	(15)	Σ(6)	(8)+ (11)	Σ(8)	(9)+ T**		(9)	Σ(12)	(13)+ T

Use Table As Follows:

1. Descend column (7) until total weight is just equal to or less than allowable payload for instruments, ancillary devices, and equivalent (operating power and telemetry power) weight.

2. Payload will consist of

   a. Instruments column (2) located above line of descent in step 1.
   b. Power generator capable of at least* average power on descent line in column (10)
   c. Total mission bits, line of descent column (13)
   d. Batteries sufficient for max. peak power column (11)
   e. Communications system with bit rate capacity equal to line of descent column (14)

*If rechargeable batteries are required, then generator size must increase capacity.
** T = mission-duration planned.

The approach which had been planned for the linear programing method was to use the merit rating index as a basis for substitution (tradeoff) coefficients, the instrument values for the value parameters, and total weight for cost constraints, and to solve for an allocation of weight to maximize the payload value, $\sum_{j'} V_{.j}$. The line of thinking for the dynamic programing method was to use the weight and value functions and the merit index selection criterion and to solve for optimal packages $\left(\sum_{j'}^{max} V_{.j}\right)$ for payloads of increasing weights.

In all three methods, an assumption of linear additivity is required, although this was not strictly the case.

f. Conclusions. A valuable technique has been developed to perform the selection of instrument payloads. Although some difficulties and limitations must be resolved, the technique is already developed to a point where it can assist in the selection in terms of objective selection criteria and as a corroboration to independent payload choices. It is recommended that further efforts be made to improve and extend this technique.

7. PLANETARY EXPLORATION PROGRAM

Several considerations enter into laying out a specific exploration program for Voyager. The capability of the individual spacecraft and its scientific payload has been considered in other volumes of this report and earlier in this volume. The interaction of the instrumentation capabilities and requirements has been combined with the total spacecraft (and booster) capabilities to establish an optimum payload design. A second consideration to be examined is the capability of the system to place and operate this payload in the most desirable locations on and around the planet. This capability can be expressed in terms of the constraints limiting such placement and operation. These limitations are considered in detail for the Mars mission in section 7.1.

A third consideration is the probability of success of the spacecraft system and its effect on the exploration schedule. Stated briefly, this means that the number of launch attempts is expected to be greater than the number of successes. Therefore, predictions are necessary in order to establish the total program scope so that the desired objectives are achieved. This analysis is presented in section 7.2.

Finally, when the capabilities and constraints are established, and the necessary number of attempts is estimated, then specific exploration schedules can be recommended. In sections 7.3 and 7.4, specific landing sites for each lander attempt for Mars and Venus are selected, and the rationale for each is given in the light of the measurements desired.

7.1 Martian Lander Footprints

There exists a wealth of observational data concerning the topographical aspects of Mars. Since the Voyager lander will be able to be placed on the planet with a dispersion smaller than many of the observable permanent features, this capability should be utilized to select specific landing sites in order to maximize the range of information gathered. However, several constraints limit the portion of the Martian sphere which is accessible to the lander. When these constraints are examined in detail, as outlined in the following paragraphs, it develops that the net effect is to limit the latitudes and the seasonal dates of landing. We use the word "footprint" to denote these spatial and temporal limits to the Voyager lander.

1. Seasonal dates of arrival. Consider first the Martian seasonal time of arrival. For each conjunction of Mars and Earth, a minimum exists in the amount of propulsion energy needed to effect a transfer orbit. When trajectories are calculated such that the total weight injected into the transfer orbit and the

orbiter weight placed in Martian orbit are both maximized, then 30-day launch windows are determined. If now the interplanetary transfer time (which varies throughout this launch window) is considered, then the arrival window can be determined. These transfer times are shown graphically in figures 27 through 30 as functions of the launch date for each opportunity from 1969 through 1975. From these curves, the dates of arrival can be calculated, and it can be seen that the arrival windows will vary from a minimum of 20 days in 1971 to 50 days in 1975. For these arrival dates, Mars will be located at certain positions in its solar orbit, also given in figures 27 through 30 in terms of heliocentric longitude relative to the Martian vernal equinox. (Add approximately 87 degrees to these longitude values to obtain heliocentric longitude relative to Aries.)

2. Determination of geometrical footprint. When the times of launch and transfer orbits have been selected as discussed above, certain geometrical and operational constraints determine the portion of the Martian surface within which landings can be accomplished. These considerations are as follows:

a. Approach asymptote orientation and relative velocity vector

b. Angle of entry of lander into Martian atmosphere

c. Orbiter-lander communications during landing

d. Sunlight illumination of landing area

e. Direct lander-Earth backup communications.

In order to best visualize the interaction among these constraints, consider a sphere centered at Mars but not rotating with the planet. Latitude can be defined for this inertially fixed sphere in a manner identical to true Martian latitude. Longitude can be conveniently measured as a positive rotation about the North Pole of Mars (i.e., an angle measured in the Martian equatorial plane) with zero longitude being the projection on the equatorial plane of the vector from Mars to Earth, the latitude and longitude of the asymptotic approach velocity vector (velocity of the vehicle with respect to the planet when the vehicle is crossing the sphere of influence), and the latitude of the vector to the sun can now be defined in this system for each date in the various launch opportunities.

The possible landing areas for a given asymptotic approach velocity vector are limited by constraints on the acceptable entry angle. The shallow angles, $\gamma_E < -20$ degrees, produce long times of passage through the atmosphere and unacceptable impact point dispersions due to atmospheric perturbations and entry condition uncertainties. Very steep entry angles, $\gamma_E \sim -90$ degrees, may produce unacceptable heating limitations for the higher values of approach velocity. In addition to the degree of freedom provided by the choice of entry angle, a vehicle on an impact course with the planet has an azimuthal degree of freedom

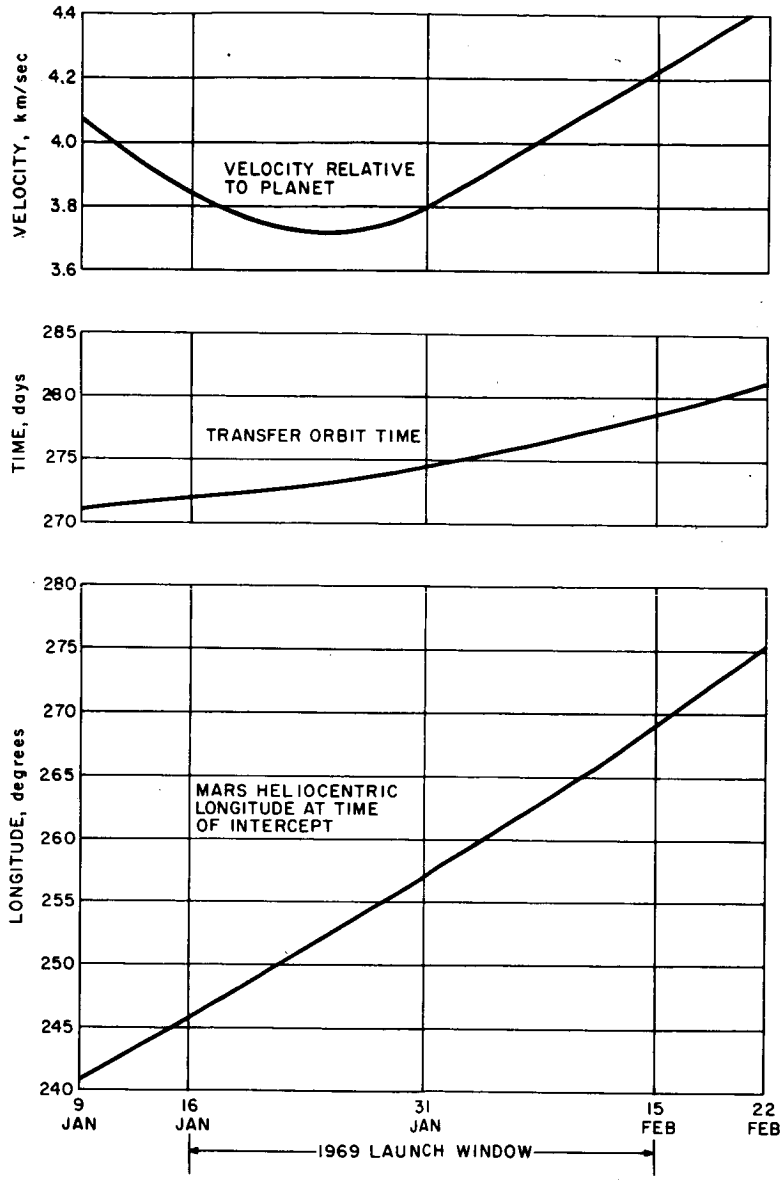


Figure 27 TRANSFER ORBIT PARAMETERS - 1969
63-8712

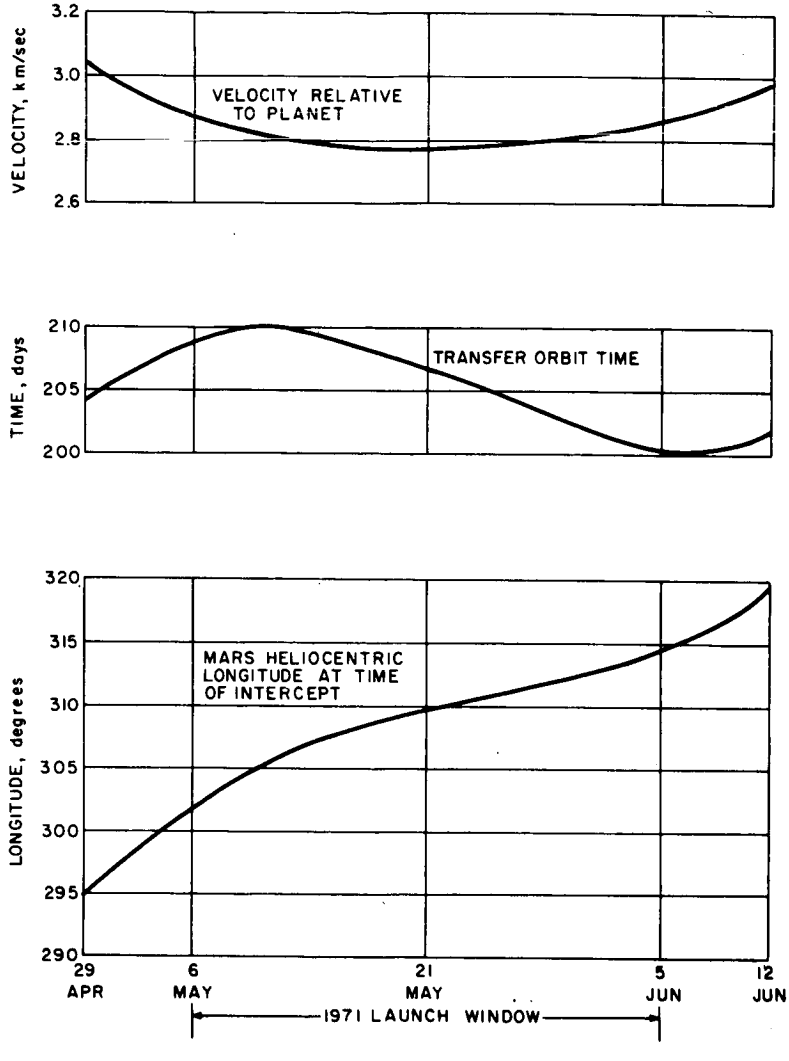


Figure 28 TRANSFER ORBIT PARAMETERS - 1971
63-8713

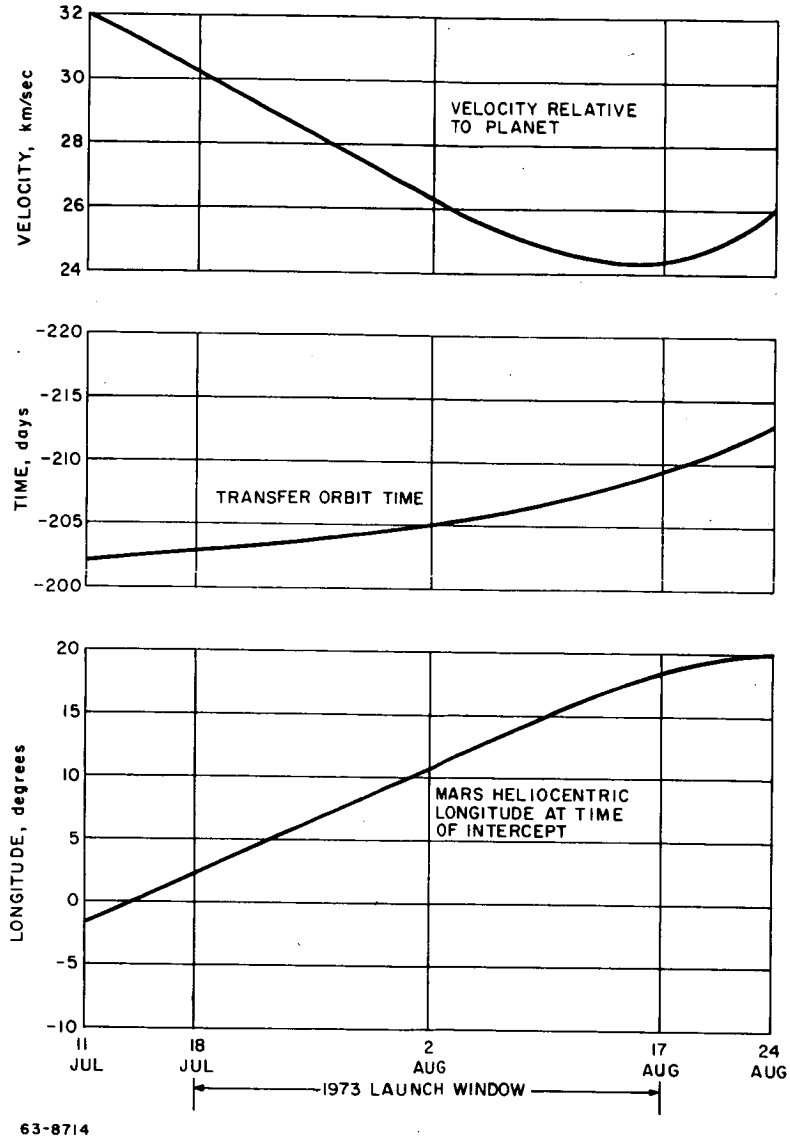


Figure 29 TRANSFER ORBIT PARAMETERS - 1973
63-8714

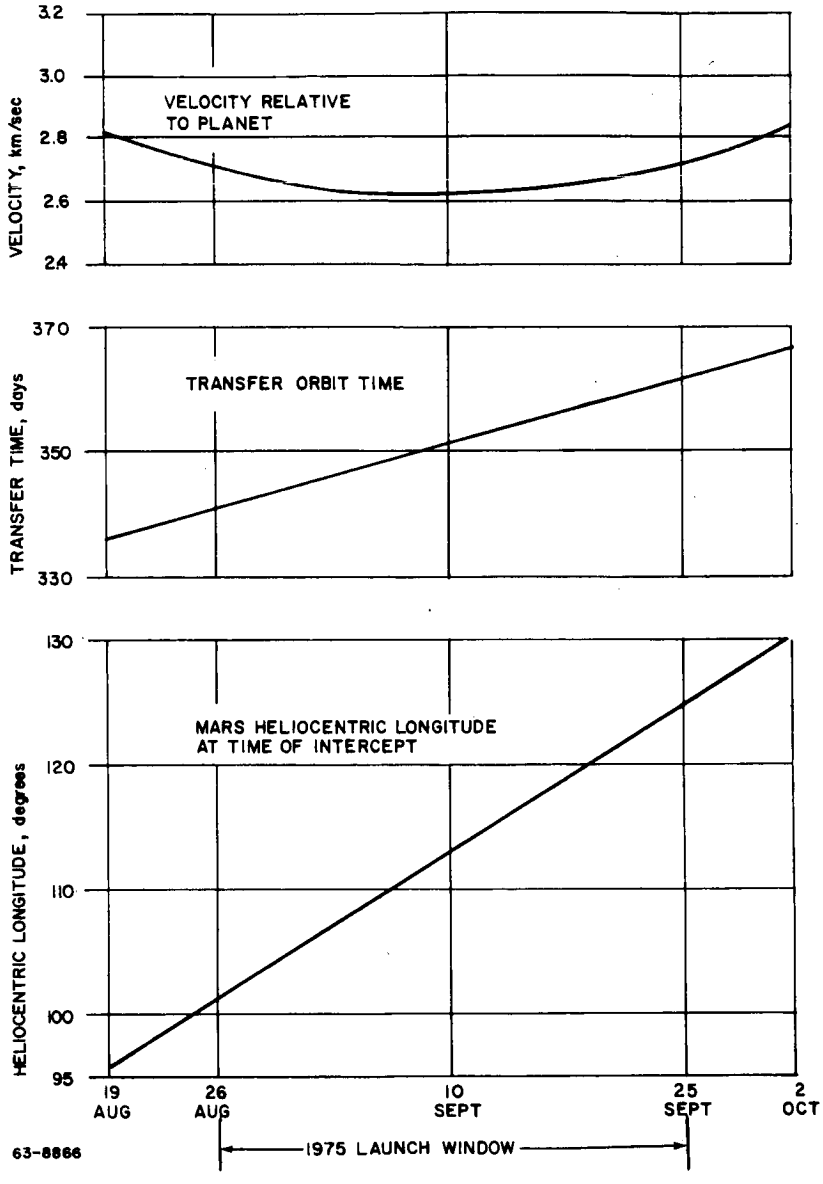


Figure 30 TRANSFER ORBIT PARAMETERS - 1975
63-8866

about the approach velocity vector. Since the approach velocity vector at large distances from the planet is pointed essentially at the planet, small changes in the direction of the velocity vector by means of small incremental velocity adjustments can produce large changes in the orientation of the approach trajectory plane of the lander. In essence, then, at large distances from the planet 2 degrees of freedom are available for the choice of the lander approach trajectory: 1) the choice of any plane that contains the asymptotic approach velocity vector, and 2) the choice of entry angle within the constraints of heating and landing accuracy.

Thus, the locus of impact points for a given approach velocity and entry angle consists of a circle centered on the -90 degree γ_E impact point on the inertial sphere of reference. The planetocentric half angles, β_I, of these circles are shown in figure 31 for several entry angles as functions of the approach velocity. The latitude and longitude coordinates of the asymptotic approach velocity for each of the launch windows are shown in figures 32 through 35, and the magnitudes of these velocities are shown in figures 27 through 30. Note that if the longitude and latitude coordinates of the approach velocity vector are (ϕ, θ), then the coordinates of the 90 degree entry angle impact point are $(\pi + \phi, -\theta)$.

The choice of trajectories for the orbiter is considerably more restrictive. In order to provide adequate mapping coverage and daily lander-orbiter communication capability, a polar orbit is required. A nominal periapsis altitude of 1700 km was chosen to provide high resolution mapping while still maintaining sufficient lifetime in orbit (50 years) in the presence of approach and injection guidance errors. Thus the nominal approach hyperbola for any given date is specified since the magnitude and direction of the asymptotic approach velocity vector are known for the given date, and the polar orbital plane and periapsis altitude are system requirements.

Communication between the lander and the orbiter is constrained by a limitation on maximum range (14,600 km) and a geometric limitation requiring the orbiter to be at least 30 degrees above the lander's local horizon to avoid serious atmospheric attenuation. In order to transmit engineering and scientific data gathered immediately upon landing, it is also necessary for the lander to be in communication with the orbiter for a minimum of 5 minutes after lander deployment. The landing sites which meet these requirements are contained in a corridor of complex shape on the inertially fixed sphere which is symmetrical about the polar orbital plane and about the -90 degree γ_E impact point.

The next specification requires that the landing site be in sunlight during descent so that pictures of the area can be taken during descent without the requirement of artificial lighting. The sunlit area can, therefore, be defined for a given date of arrival in terms of the latitude of the sunline with the longitude of the sunline chosen as zero on the reference sphere. These sunline latitudes for each of the launch opportunities are shown in figures 32 through 35. The sunlit hemisphere is of course centered on the inertial sphere at this point.

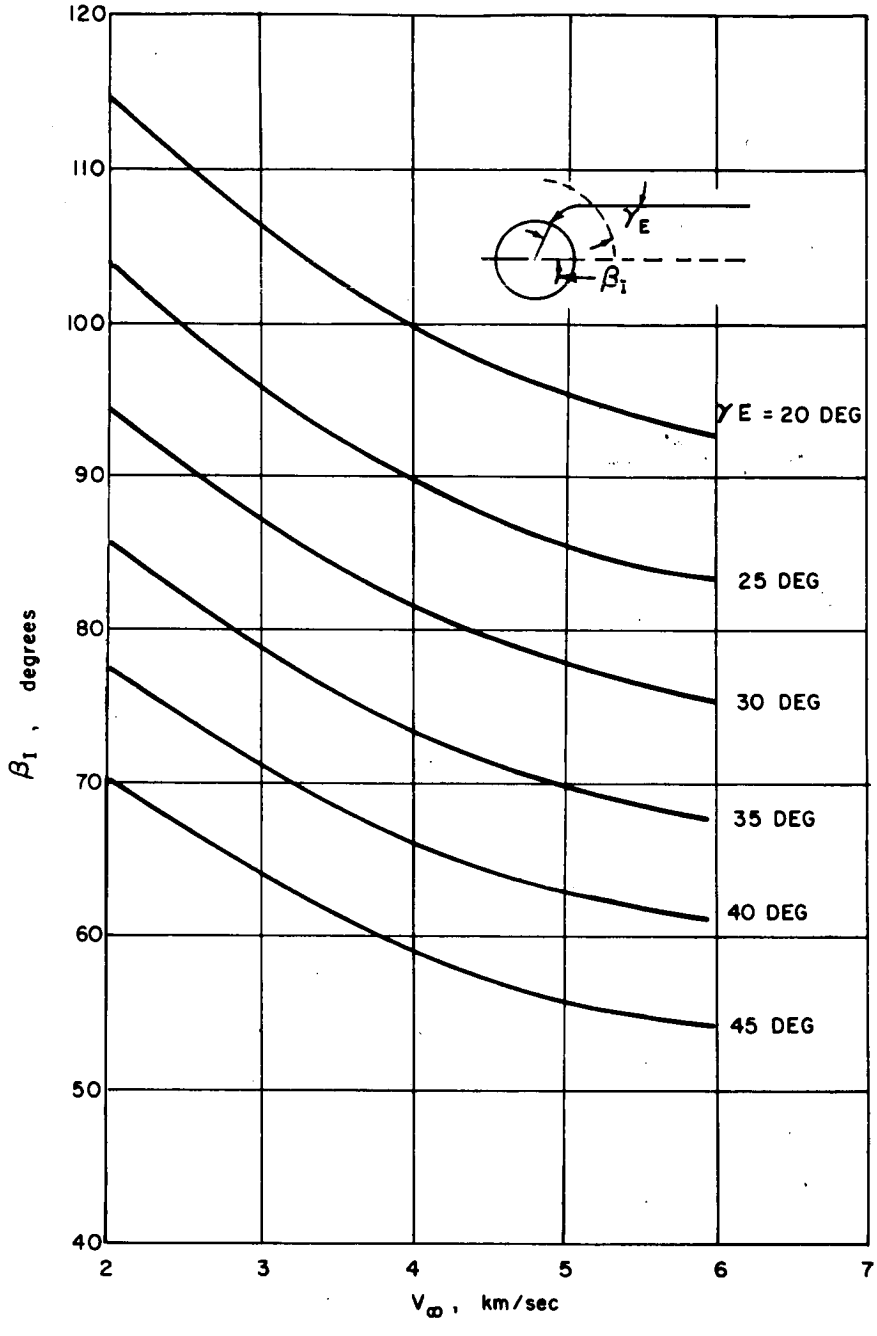


Figure 31 CENTRAL ANGLE OF IMPACT ON MARS
63-9293

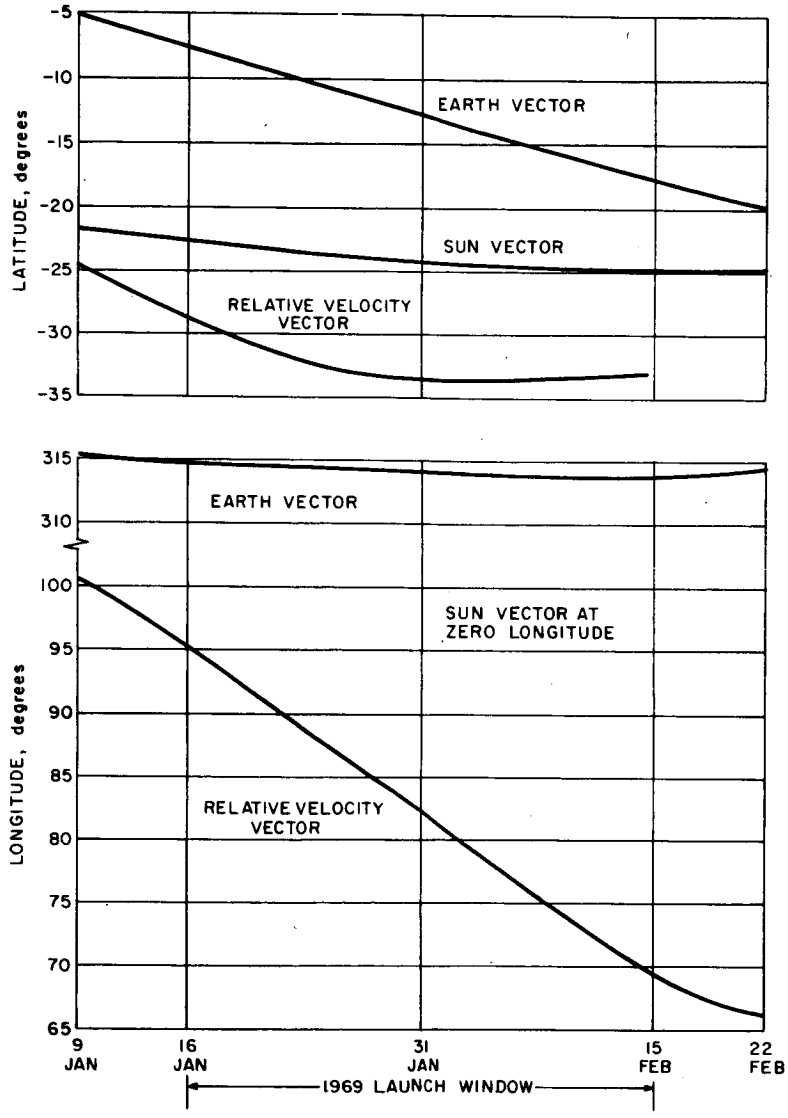


Figure 32 GEOMETRY AT PLANETARY INTERCEPT -- 1969
63-8708

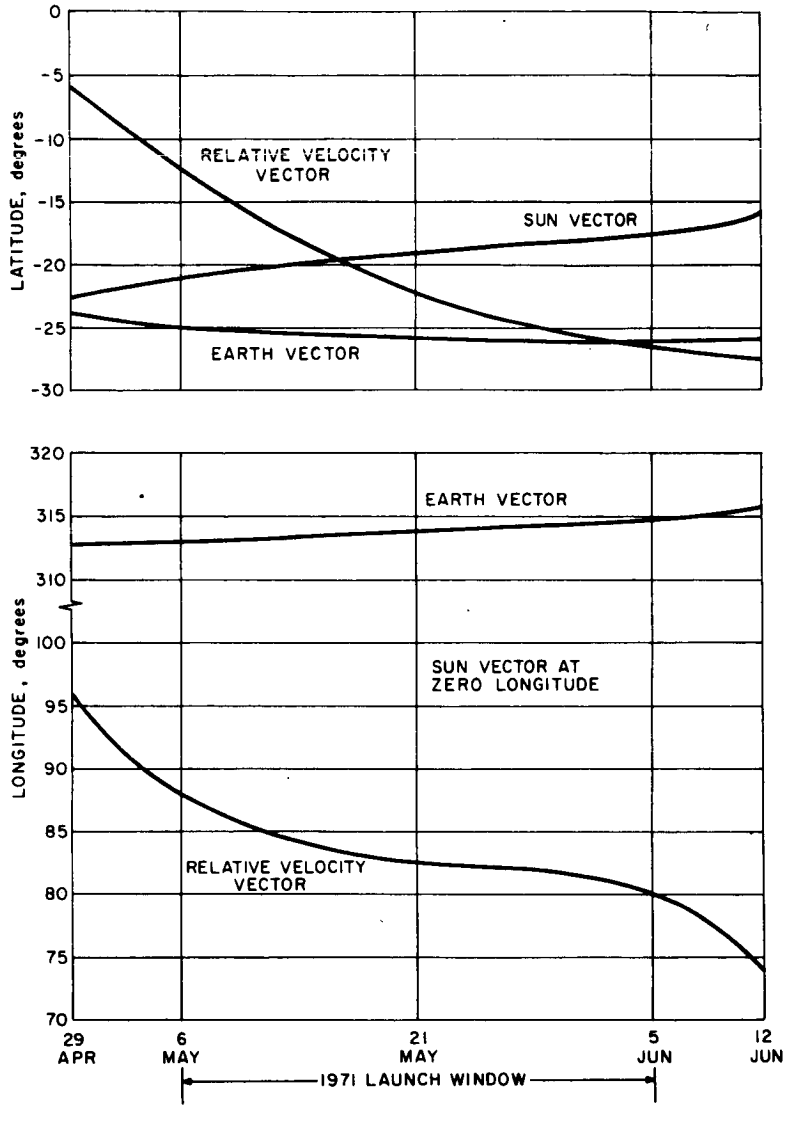


Figure 33 GEOMETRY AT PLANETARY INTERCEPT -- 1971
63-8709

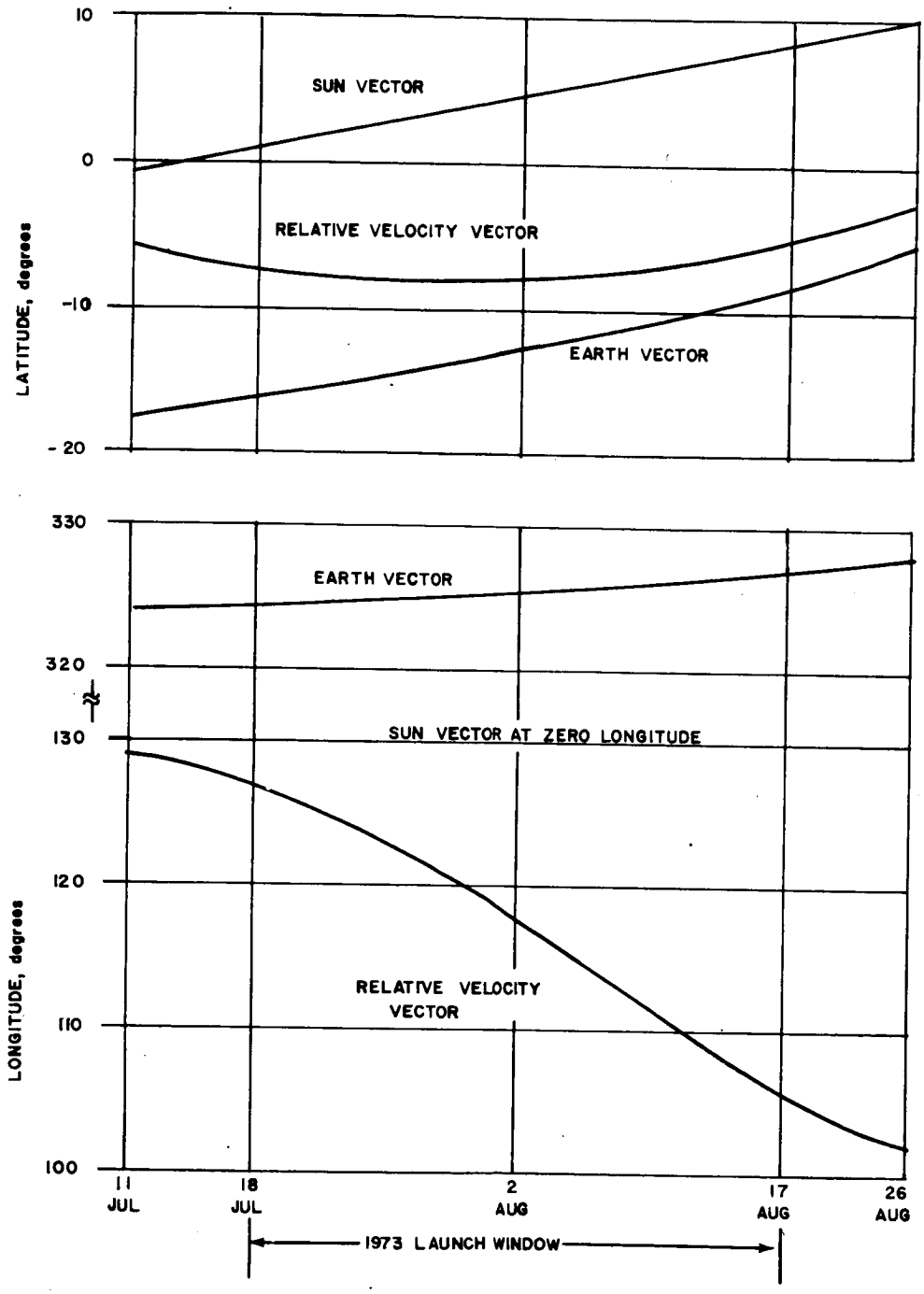


Figure 34 GEOMETRY AT PLANETARY INTERCEPT -- 1973
63-8748

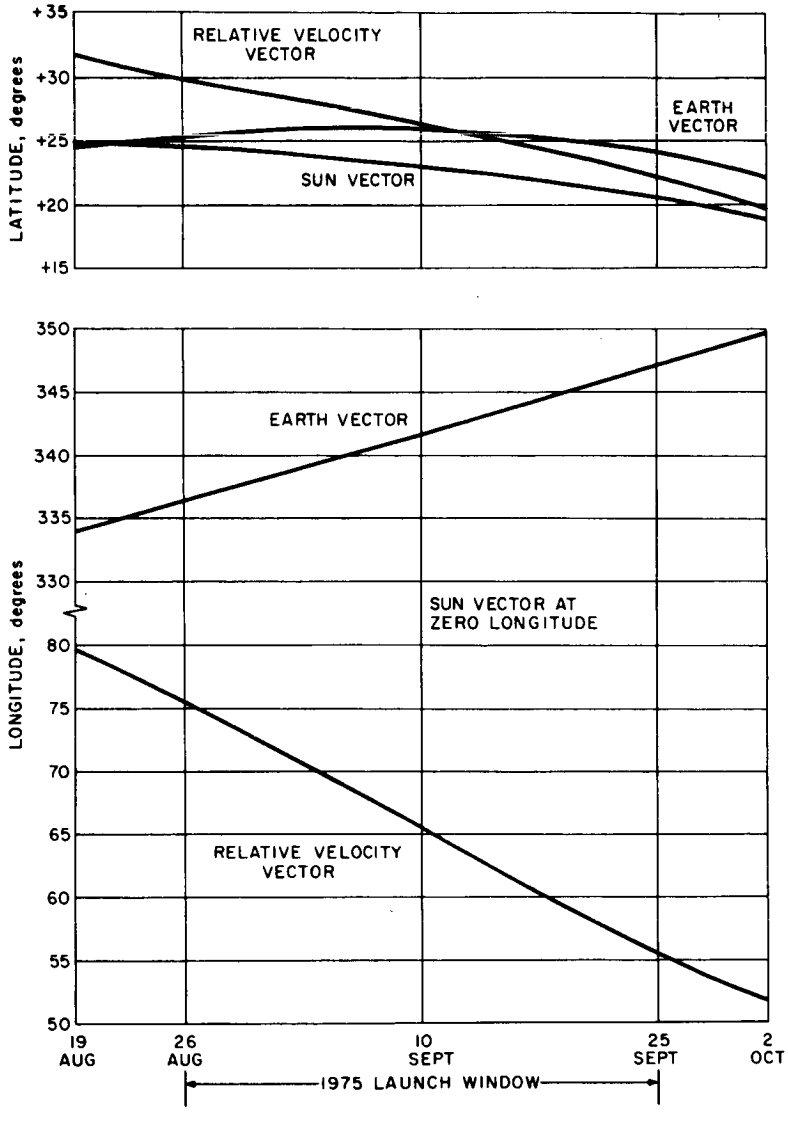


Figure 35 GEOMETRY AT PLANETARY INTERCEPT -- 1975
63-8711

Communication between the lander and Earth can be examined in a similar manner. Assuming a communication capability to within 10 degrees of the horizon, and requirement of backup communication directly with Earth, during at least some portion of each Martian day, it is only necessary to land within maximum latitude bounds since the planet's rotation will cause the landing site to move through the acceptable region. It is worth noting, however, that the greater the separation in latitude between the earthline and the landing site, the smaller will be the percentage of time available for direct communication with Earth. The latitude of the Earth vector on the inertially fixed reference sphere is shown in figures 32 through 35, and the limit on landing sites is then 80 planetocentric degrees above or below that latitude.

The net effect of the simultaneous application of these constraints is to define a small portion of the reference sphere which is available to the lander. This is illustrated in figure 36, where the various boundary curves have been plotted on a Mercator projection of the reference sphere for a launch date of 31 January 1969, and the net footprint has been heavily outlined.

The constraints discussed up to this point have been dependent upon vectors (i.e., the sunline, the earthline, and the approach asymptote) that vary only slowly with time. The position vector of a particular landing site, however, rotates with the planet relative to this inertially fixed frame of reference and therefore with respect to the three vectors of interest. If the latitude of a particular landing site falls within the latitude limits of the constraints previously discussed, that landing site can be attained by adjusting the time of arrival so that the desired site is in fact within the acceptable inertially fixed area at the time of arrival. This time of arrival can be predetermined by transfer orbit adjustments at injection and at each midcourse correction. This effect of the planet rotation is illustrated in figure 37 where the net footprint of figure 36 has been superimposed on Sliphers map of Mars. The longitudinal position of the footprint has been chosen arbitrarily for the illustration, but any area between the horizontal dotted lines will obviously appear within the footprint boundaries as the Martian globe rotates approximately once each Earth day.

When figure 36 is plotted for each day of each launch window, it becomes evident that the limiting latitudes are defined by single restrictions such as -20-degrees γ_E entry angle, direct Earth communication, or sunline. These vary slowly throughout each launch window, but are easily calculated from the data in figures 27 through 35. For example, the -20-degree γ_E maximum latitude line in 1975 is β_I degrees (figure 31) above or below the asymptotic approach velocity vector latitude (figure 35), where β_I is determined by the approach velocity (figure 30). These resulting latitude limits are shown in figures 38 and 39 plotted against launch data for each launch opportunity. These same limits appear in figure 40, later in this report, plotted against Martian seasonal dates at the time of arrival at the planet. Note that in 1969 the trend of the earthline is toward a more restrictive position, so that landing sites in the northern hemisphere which are acceptable during the arrival window may not be suitable for direct lander-Earth communications later in the lander lifetime.

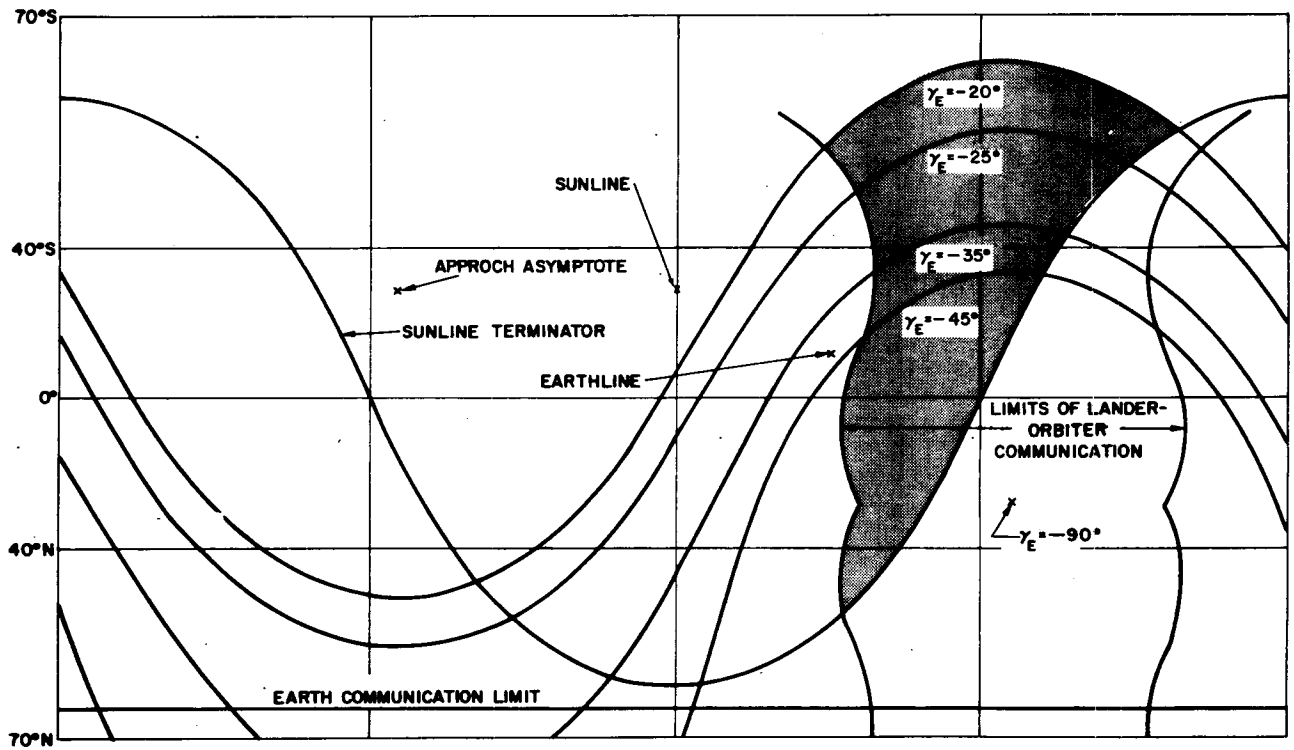


Figure 36 DERIVATION OF MARS LANDING FOOTPRINT
63-9592

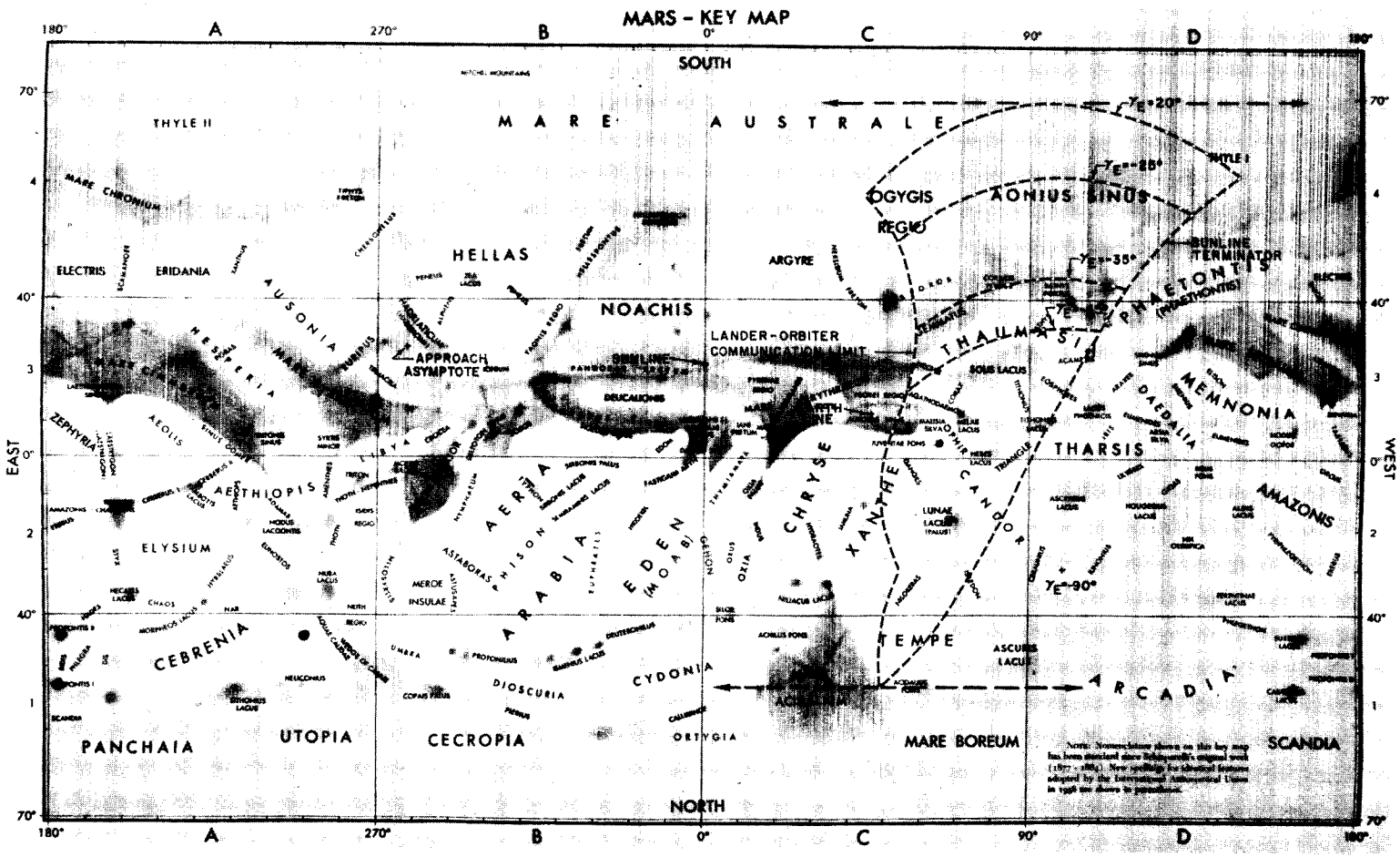
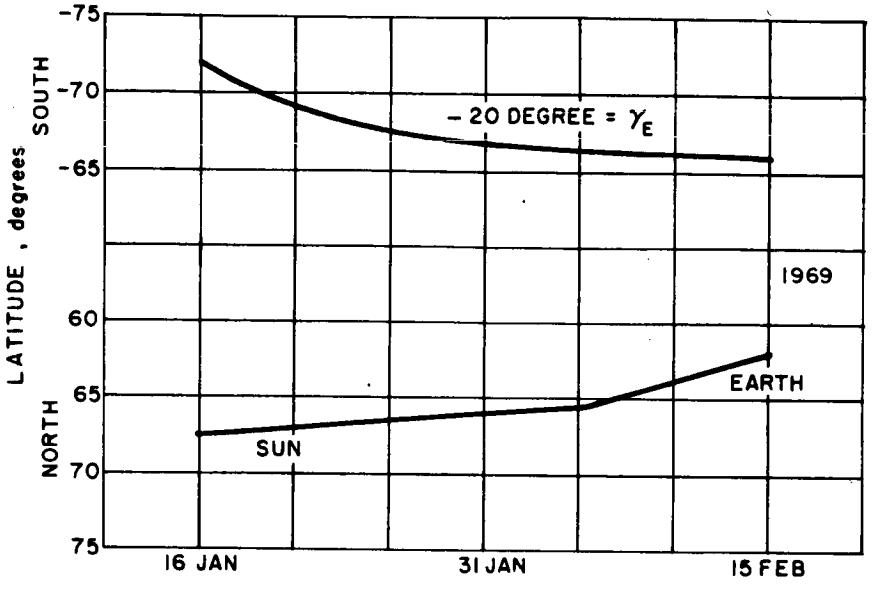


Figure 37 MARS LANDING FOOTPRINT



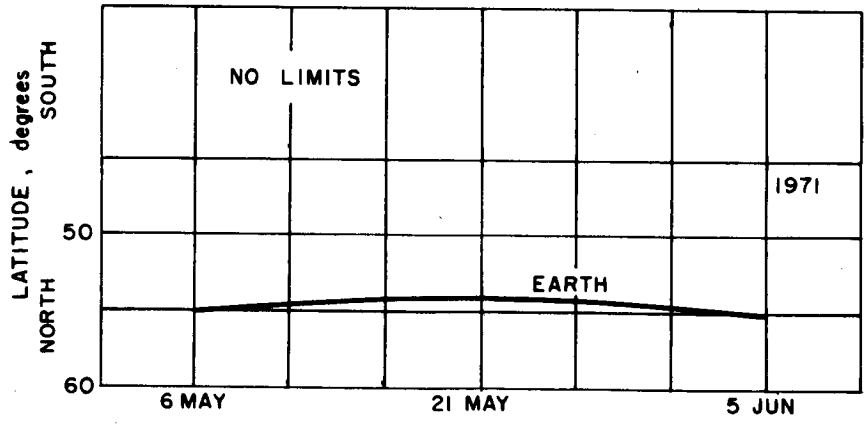
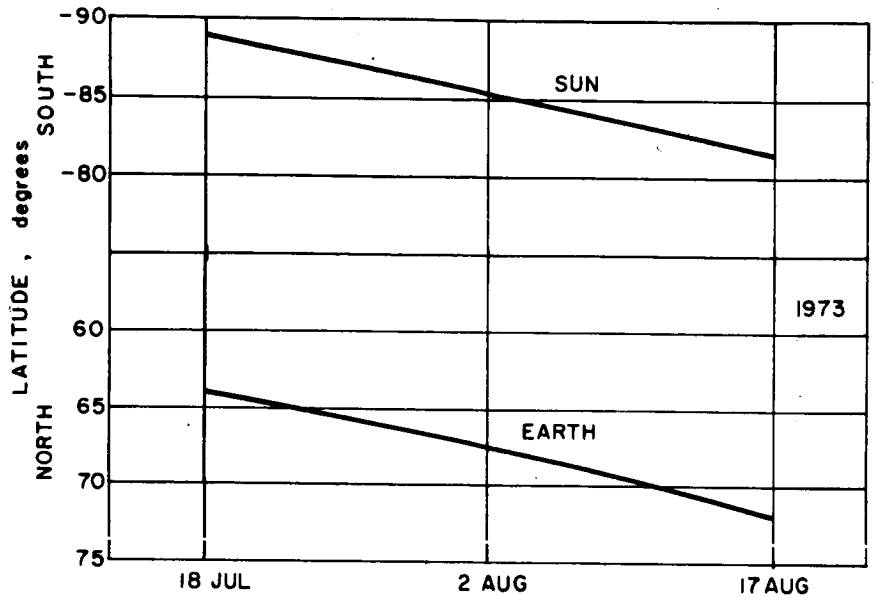


Figure 38 LATITUDE LIMITS ON MARS LANDERS -- 1969 AND 1971
63-9291



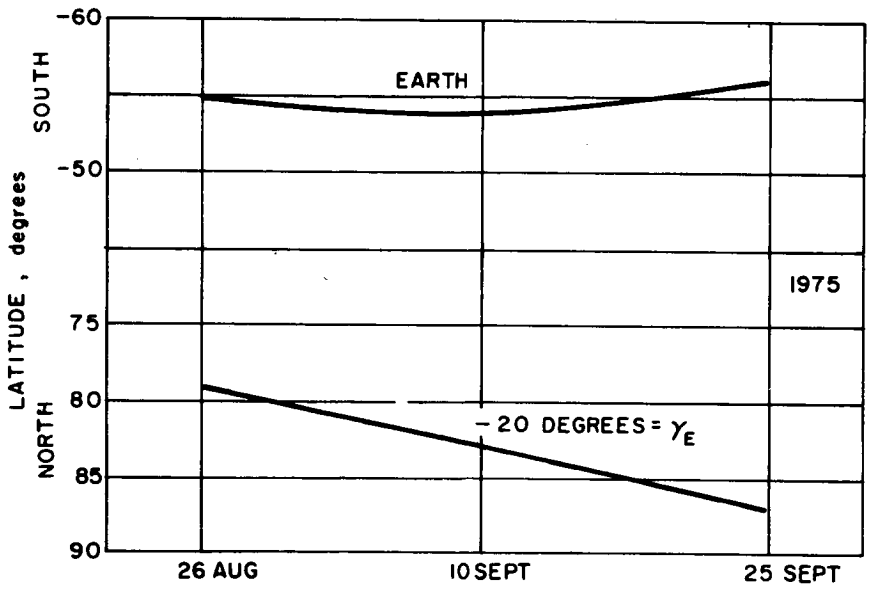


Figure 39 LATITUDE LIMITS ON MARS LANDERS -- 1973 AND 1975
63-9292

This has been shown by the dotted line on the northern boundary of the footprint in figure 40, which extends to 54 degrees north latitude about 60 days after the arrival window. A similar effect could occur for the sunline, such that the polar continuous night might envelop the landing site sometime after arrival. This possibility has been examined and found not to occur within 180 days after any of the arrival windows through the 1975 opportunity.

7.2 Mission Evolution

1. Introduction. The configuration of the Voyager spacecraft to be employed for each launch opportunity within the Voyager time span is, of course, dependent upon several factors which vary in importance, such as time, technology, and knowledge about the planetary targets. In the absence of specific definition of the planetary environments, detailed development of the exploratory program for Mars and Venus in each of the launch opportunities within the Voyager program can only be preliminary in nature and must be modified as our knowledge of the planets increases through Earth-based observation, Mariner flights, and early Voyager flights. For planning purposes, a mission analysis was performed for the Voyager program based upon our present state of understanding of the target planets and the scientific goals which have been outlined in the preceding sections. In order to achieve the scientific objectives for the Voyager program, the following minimum program of successful orbiters, capsules, and landers has been adopted:

	Mars	Venus
Orbiters	2	2
Landers	5	2
Capsules	--	4

The two Mars orbiters will permit observation of the planet during different and changing seasons of the year. For Venus, at least two orbiters must be employed to accommodate the slow rotation (or lack of rotation) of the planet and still achieve wide area mapping of the surface. The five Mars landers will be employed to observe different surface areas of the planet: the dark maria before and after the wave of darkening, the polar caps, the dark bend at the edge of the polar cap, and the desert areas. The Venus capsules will be employed to gather information concerning the atmosphere and cloud layer about Venus to better enable the development of direct entry Venus lander. The Venus landers would be directed to investigate the hot pole of Venus (the subsolar point), and the cold spot detected by the Mariner II flight.

The Voyager program through 1975 has been limited to relatively simple payloads and excludes such things as mobile surface or atmospheric craft and complex experiments such as deep drilling to obtain samples well below the planet surface. A study of the payload capabilities of the Voyager spacecraft for each of the launch opportunities allows potential mars spacecraft configurations as indicated in table 33. A similar though less thorough approach was employed for Venus. The NASA-imposed constraint that both vehicles within a given launch opportunity be of the same configuration, and a study of the potential reliability of the spacecraft and booster, have resulted in the selection of the spacecraft configurations listed in table 34. A preliminary review of the spacecraft and booster reliability indicates that more than one attempt per launch window is necessary if a reasonable probability of achieving the stated program goals is to be achieved.

2. Discussion. To establish the reliability capability of the Saturn launch vehicle, a literature search was made to ascertain the reliability of several presently available boosters. The search revealed a prime source of data pertinent to the relative complexity and reliability growth of several boosters. This document (ref. 138), supported by the data obtained from other sources, indicated a level of reasonably attainable Saturn booster reliability that could be assumed for the program.

Predictions of the orbiter-lander expected mission success was based on the premise that partial success would occur on some orbiter and lander missions. Each Mars/Venus mission segment was weighted in terms of its contribution to the success of the total mission considered and a fractional value assigned to that segment. The reliability of the orbiter and lander was then estimated for the various segments of the Mars/Venus orbiter and lander missions. The expected fractional success, or fractional expectation, of an orbiter-lander mission during a given launch window was calculated as the sum of the product of the reliability of each mission segment and the contribution (value) of that segment to the total mission considered.

$$E_{jkl.} = \sum_{m}^{n} [(R_{jklm})(V_{jklm})]$$

where

m = the mission segment

n = the number of mission segments

j = an orbiter-lander mission

k = a Mars/Venus mission

R = the reliability of a mission segment

V = the value of a mission segment

E = the expected fractional success or fractional expectation

l = the launch window.

For each launch opportunity, the expected mission success was determined on the basic of projected, sequential reliability growth, assuming a full-scale reliability effort. Tables 35 and 36 show the value of each mission segment to the type of mission considered and the expected fractional success of the Mars/Venus orbiter and lander missions by launch window (calendar year).

The probabilities of fulfilling the Mars/Venus program objectives were then determined from cumulative binomial tables. Table 37 gives Mars/Venus program objectives, reference launch configurations, assumed booster reliability values, cumulative numbers of expected (fractional) mission successes, and binomial probabilities.

In summary, the reference Mars/Venus launch configurations were examined to determine the possible fulfillment of Voyager program objectives. Furthermore, should launch attempts be bypassed, the resulting penalty in achieving these objectives was also evaluated. With two launch attempts per opportunity and the maximum reference launch configurations, the binomial probability associated with Mars lander missions and Venus orbiter missions are 0.72 and 0.97, respectively. It should be noted that the primary emphasis in the Voyager program is on the success of these missions. Considering the primary emphasis, the magnitude and scope of the Voyager program, and the unique engineering and scientific tasks required of the orbiters/landers, the probabilities of fulfilling these objectives are concluded to be reasonably satisfactory.

3. The extended voyager program. It is contemplated that the Voyager program will be extended to allow collection of all data required to prepare for manned Martian exploration. The growth potential of the Voyager program, even within the constraint of the Saturn 1B booster capability, is extensive and, with the additional capability available from the Saturn 5 booster, would present almost unlimited possibilities for planetary exploration even beyond the inner planets. Development of an aerodynamic orbiting vehicle to replace the present retrothrust design could vastly increase the payload capability. This increase makes possible higher resolution mapping from low-altitude circular orbits even though the large weight penalty associated with orbiter sterilization must be sustained.

TABLE 33

MARS OPTIONS

1969	1971	1973	1975
Orbiter - 1500 pounds 1700 x 4000 km Lander - 1880 pounds	Orbiter - 1500 pounds plus 1800 km circular Lander - 1880 pounds	Orbiter - 1500 pounds 1700 x 12,000 km Lander - 1880 pounds	Orbiter - 1500 pounds 1700 x 10,000 km Lander - 700 pounds
Orbiter - heavier 1700 x 10,000 km Lander - 1880 pounds	Orbiter - heavier 1700 x 10,000 km Lander - heavier	Orbiter - none Lander - two 1880-pound	Orbiter - none Lander - two 1880-pound
Orbiter - 1500 pounds 1700 x 10,000 km Lander - heavier	Orbiter - 1500 pounds 1700 x 10,000 km Lander - two 1880-pound	Orbiter - 1500 pounds lower apoapsis Lander - smaller	
	Orbiter - none Lander - three 1880-pound		
	Orbiter - Earth return Lander - none		

TABLE 34

RECOMMENDED LAUNCH CONFIGURATION

Launch Opportunity	First Launch	Second Launch
Mars		
1969	O-L *	O-L
1971	O-LL	O-LL
1973	O-L	O-L
1975	B-LL	B-LL
Venus		
1970	O-CCC	O-CCC
1972**	O-CCC	O-CCC
1973	O-L	O-L
1975**	O-L	O-L

*O = Orbiter
L = Lander (direct entry)
C = Capsule (orbital entry)
B = Fly-by bus

**These opportunities can be omitted with subsequent reduction in the mission success probability.

TABLE 35

DEFINITION OF PARTIAL MISSION SUCCESS

Mars Mission

1. Orbiter Mapping

Days from Separation	Value of Mission Segment
1	0.250
2 - 70	(1 - 0.25) (69/180) = 0.292
71 - 180	(1 - 0.25) (109/180) = 0.458

2. Lander Experiments

Days after Landing	Value of Mission Segment
1	0.75
2 - 30	0.20
31 - 180	0.05

Venus Mission

1. Orbiter Mapping

Days from Separation	Value of Mission Segment
1	0.250
2 - 21	(1 - 0.25) (20/60) = 0.262
22 - 60	(1 - 0.25) (38/60) = 0.488

2. Lander Experiments

a. Capsule. Total mission success is required.

b. Lander -- Direct Entry. Because of the uncertainty of the environmental hazard, there is no firm basis for reliability estimation. As an alternative, the fractional mission success expectation for the first Mars lander is assumed because of the similarity, but uncertainty, of the Venus lander engineering/scientific tasks.

TABLE 36

EXPECTED FRACTIONAL MISSION SUCCESS*

Mars Missions				
	1969	1971	1973	1975
Orbiter mapping	0.55	0.74	0.86	0.93
Lander experiments	0.61	0.78	0.88	0.94
Venus Missions				
	1970	1972	1973	1975
Orbiter mapping	0.62	0.79	0.84	0.91
Capsule experiments	0.62	0.79	--	--
Lander experiments	--	--	0.76	0.88

*Excludes reliability of booster.

TABLE 37

PROBABILITIES OF FULFILLING MARS/VENUS

PROGRAM OBJECTIVES

I. Reference Launch Configurations

A. Mars Missions

	1969	1971	1973	1975
Launch vehicle 1	O-L	O-LL	O-L	O-L
Launch vehicle 2	O-L	O-LL	O-L	O-L

B. Venus Missions

	1970	1972	1973	1975
Launch vehicle 1	O-CCC	O-CCC	O-L	O-L
Launch vehicle 2	O-CCC	O-CCC	O-L	O-L

II. Predicted Booster Reliability

	1969	1970	1971	1972	1973	1975
Booster reliability	0.60	0.62	0.65	0.67	0.70	0.75

III. Cumulative Total Number of Expected (Fractional) Mission Successes*

A. Mars Missions

	1969	1971	1973	1975
1. Orbiter mapping	0.66	1.62	2.83	4.22
2. Lander experiments	0.73	2.76	4.00	5.40

B. Venus Missions

	1970	1972	1973	1975
1. Orbiter mapping	0.77	1.83	3.00	4.37
2. Lander experiments				
a. Capsule	2.32	5.48	--	--
b. Lander--direct entry			1.06	2.27

*Includes reliability of booster

TABLE 37 (Concl'd)

IV. Program Objective and Probabilities of Fulfillment

A. Mars Missions

Program Objective:

At least	Probability of Fulfilling Objective
1. One orbiter success -- 1969 and 1971 missions	0.87
2. One orbiter success -- 1973 and 1975 missions	0.98
3. Two orbiter successes in program	0.97
4. Five lander successes in program	0.72

B. Venus Missions

Program Objective:

At least

1. Six capsule successes -- 1970 and 1972 missions	0.49
2. Two lander successes -- 1973 and 1975 missions	0.78
3. Three capsule successes -- 1970 mission**	0.43
4. One lander success -- 1973 mission**	0.79
5. Two orbiter successes -- 1970 and 1973 missions**	0.67
6. Two orbiter successes in program	0.97

**Program objectives should the 1972 and 1975 launches be canceled

Before attempting manned flight to the moon, detailed maps of the landing area to a resolution of approximately 1 foot are required. To obtain these maps, orbital altitudes as low as 8 miles above the surface are under consideration. Unlike the moon, Mars and Venus have substantial atmospheres which preclude any possibility of orbiting at such low altitudes. In order to obtain a high resolution survey of the Martian surface, mobile surface vehicles or mobile atmospheric vehicles, such as gliders, propelled aircraft, or some form of VTOL (vertical takeoff and landing) vehicle, will be necessary. At present, it appears that such a vehicle is well within the capability of an all-lander mission to Mars.

The best payload capability occurring within the presently envisioned Voyager program occurs in 1971. The next occurrence of such a favorable launch opportunity occurs in the mid 1980's. It appears reasonable that manned exploration of Mars will be attempted during these favorable opportunities, since this is also a period of light solar-flare activity, reducing this type of hazard to the astronauts. In order to prepare for such manned exploration of Mars, an intensive extension of the Voyager program must be conducted with the primary mission of collecting the data necessary to prepare for the first manned planetary landing.

7.3 Landing Sites -- Mars

On the basis of observation and measurements of the planets, and of analyses and predictions within each of the disciplines, various desirable landing sites on each of the planets can be specified. Combining this body of knowledge with the broad objectives of the Voyager project, priorities can be assigned to indicate the more promising sites. For Mars, the lander footprints (in time and space) indicate which of the sites are accessible at each opposition. In this section, the landing sites for Mars are thus specified for each launch vehicle, with reasons given for each.

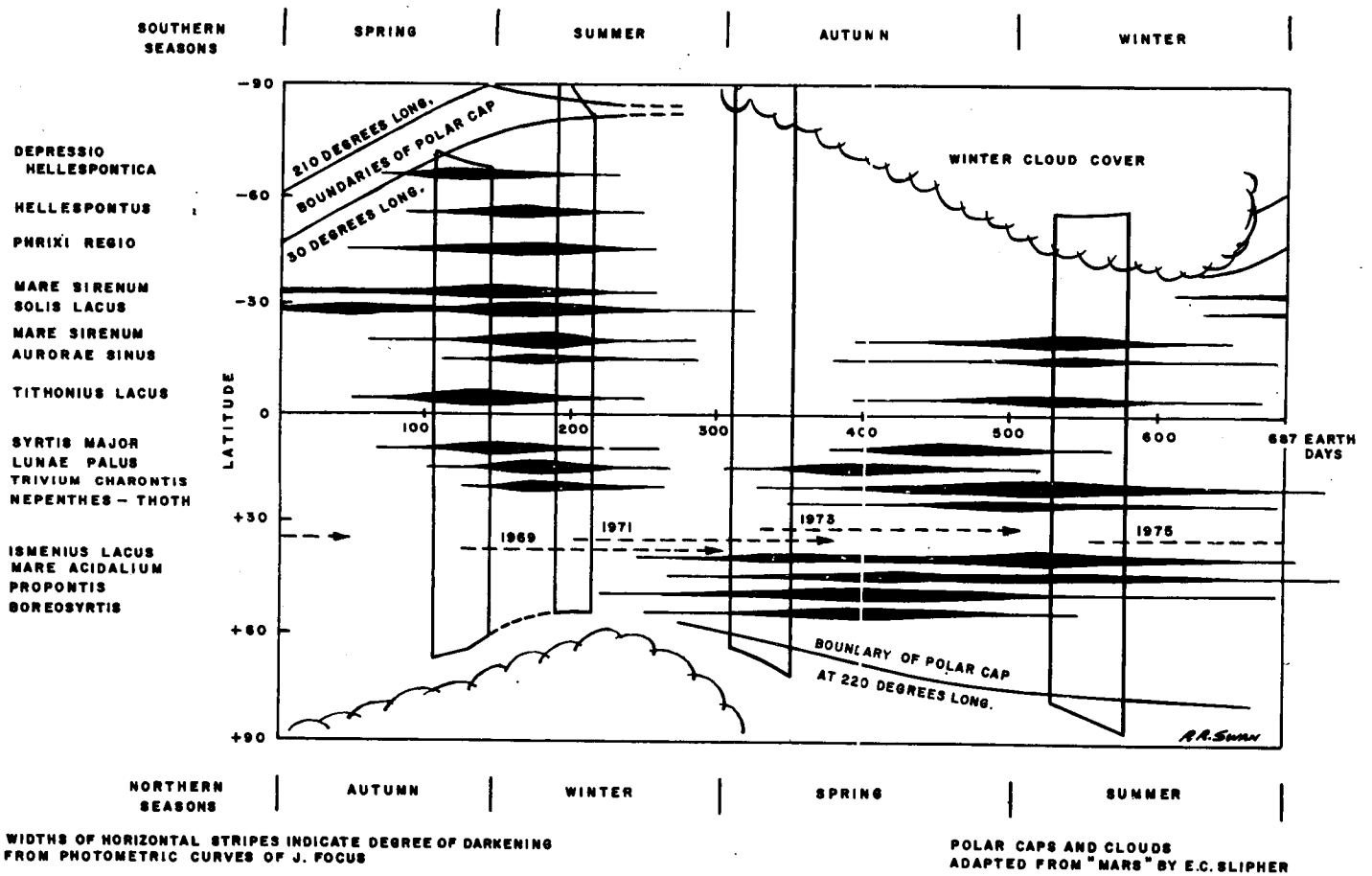
1. Martian observations. Two aspects of the topological observations of Mars are of interest in the problem of specifiying landing sites for Voyager landers. These are the permanent, unchanging features and the temporal events taking place against this constant background. For completeness, this discussion should include both long, slow variations in the more permanent features, as well as abrupt but noncyclic changes which have been recorded, but we will treat these individually when specific sites are discussed. The permanent features are of course the primary concern of the geologist and geomorphologist, the temporal or seasonal variations primarily of interest to the meteorologist. However, the most powerful interpretations of the planet phenomenology arise from the interaction of all of these interests in a single study which mirrors the actual physical interactions on the planet itself.

To briefly review the more obvious geomorphological features of Mars, we note that the planet appears to be basically composed of bright ochre-colored material on which appear dark, temporally variable areas. The bright areas display different hues, presumably due to differing oxidation states due to different ages of exposure. The most striking features of the deserts themselves are the many circular areas, as for example Hellas and Elysium, and many of the boundaries between light and dark, as in Syrtis Major. The most tenable explanation seems to be that of very large meteoritic craters such as are found on Earth. The dark areas amid these ochre deserts often appear in linear patterns, especially south of Solis Lacus. This lineation is presumably due to rifting of the comparatively thick lithosphere of the small planet. The dark areas in general can be interpreted as due to vertical differentiation and extrusion of interior planetary material to the surface, and should be regions of strongest seismic activity. In the polar regions there are indications of mountains, and permafrost phenomena will be strongest in these areas.

The seasonal topographical changes on Mars can, to first order, be described as varying in latitude as each season progresses in time. This is of course not true in detail, since the events vary from longitude to longitude both in scope and in time. Bur for illustrative purposes, it suffices to consider these initially as latitude-dependent phenomena. In figure 40, an attempt has been made to illustrate Martian seasonal events on a plot of latitude versus time throughout a Martian year. Thus at the autumnal equinox, clouds begin to form in the polar region, and grow steadily in extent until by midwinter they form a continuous cover over middle and high latitudes. Shortly before the vernal equinox, this cloud cover lifts and exposes the surface polar cap which then begins to recede toward the pole. As this recession takes place, various areas begin to turn darker, this darkening effect progressing as a wave towards and across the equator. This darkening is shown in figure 40 for the sites listed at the left of the illustration by means of a dark stripe the width of which is a measure of the darkening observed photometrically by J. Focas (Ref. 139).

Superimposed on this seasonal chart are shown the footprints of the Voyager landers, taken from figures 27 through 30 and 38. These are bounded in time by the length of the arrival window, and in latitude by one or more of the constraints discussed previously. The dashed lines indicate the planned 180-day lander life, but of course the probability of reliable operation will inevitably decrease over that period of time. Note that it becomes immediately apparent that certain seasonal phenomena are accessible only for certain launch opportunities. The wave of darkening, for instance, represents the most likely phenomenon to study in a search for Martian life. If this darkening, which waxes and wanes with time for any one spot, is indeed indicative of some life process, then it is highly desirable to study the phenomenon throughout its cycle.

2. Landing sites and schedules. By inspection of figure 40, it is obvious that the best opportunity for a study of the wave of darkening exists in 1969. Here a lander can be placed at one of several locations on the planet just prior



WIDTHS OF HORIZONTAL STRIPES INDICATE DEGREE OF DARKENING FROM PHOTOMETRIC CURVES OF J. FOCUS

POLAR CAPS AND CLOUDS ADAPTED FROM "MARS" BY E.C. SLIPHER

Figure 40 MARTIAN SEASONS AND LANDER FOOTPRINTS
63-9288

to the peak of the darkening effect, and can observe the darkening through its peak and the subsequent lightening within a time span of no more than 50 days. In 1973, the next and less desirable opportunity for such a study, well over 100 days of observations would be necessary, and the observed phenomena are much less striking than in the sourthern hemisphere.

In 1971, the southern cap is accessible, but due to relative sizes of the cap and the lander dispersion circle, it is improbable that the lander would be able to observe the dark collar hugging the cap as it recedes past a lander position. Nevertheless, this is the best opportunity to measure the properties of the southern cap itself, and should receive high priority that year. Note that all of the dark areas have passed their peaks of darkening when the 1971 launch vehicle arrives at Mars.

In 1973, the desert areas and so-called canal features should be studied, since the seasonal changes are not particularly pronounced at the time of arrival for that opportunity. In 1975, the north polar cap and its dark collar will be accessible to the lander. At the time of arrival at the planet, the edge of the polar cap at 220° longitude will be at about 78° north latitude, and should be receding at approximately 1 km/day. It is recommended that special consideration be given in the 1975 launch to reducing the lander dispersion (perhaps by late separation from the bus) so that the probability of measuring the dark collar can be increased.

A list of suggested landing sites has been prepared with rationale for each. Their selection has taken into account the opportunities for studying various phenomena discussed above, as well as specific reasons for each particular site. These sites have been specified for each launch attempt, rather than for the number of probable success, and the schedule of sites to be investigated assumes the success of each previous launch attempt. The necessity for alternate plans in the event of failures within the series is of course obvious, but the possible permutations are too great in number to lay out such a schedule this far in advance. The locations of these landing sites are shown in figure 41, where the circles indicate the size of the 3-σ lander dispersions.

1969. Primary Objective: Wave of Darkening Two Landers.

Priority	Name	Longitude	Latitude	Comments
1.	Solis Lacus	90°	+25°	History of striking secular changes occurring at optimum time. Region of strong cross lineation.

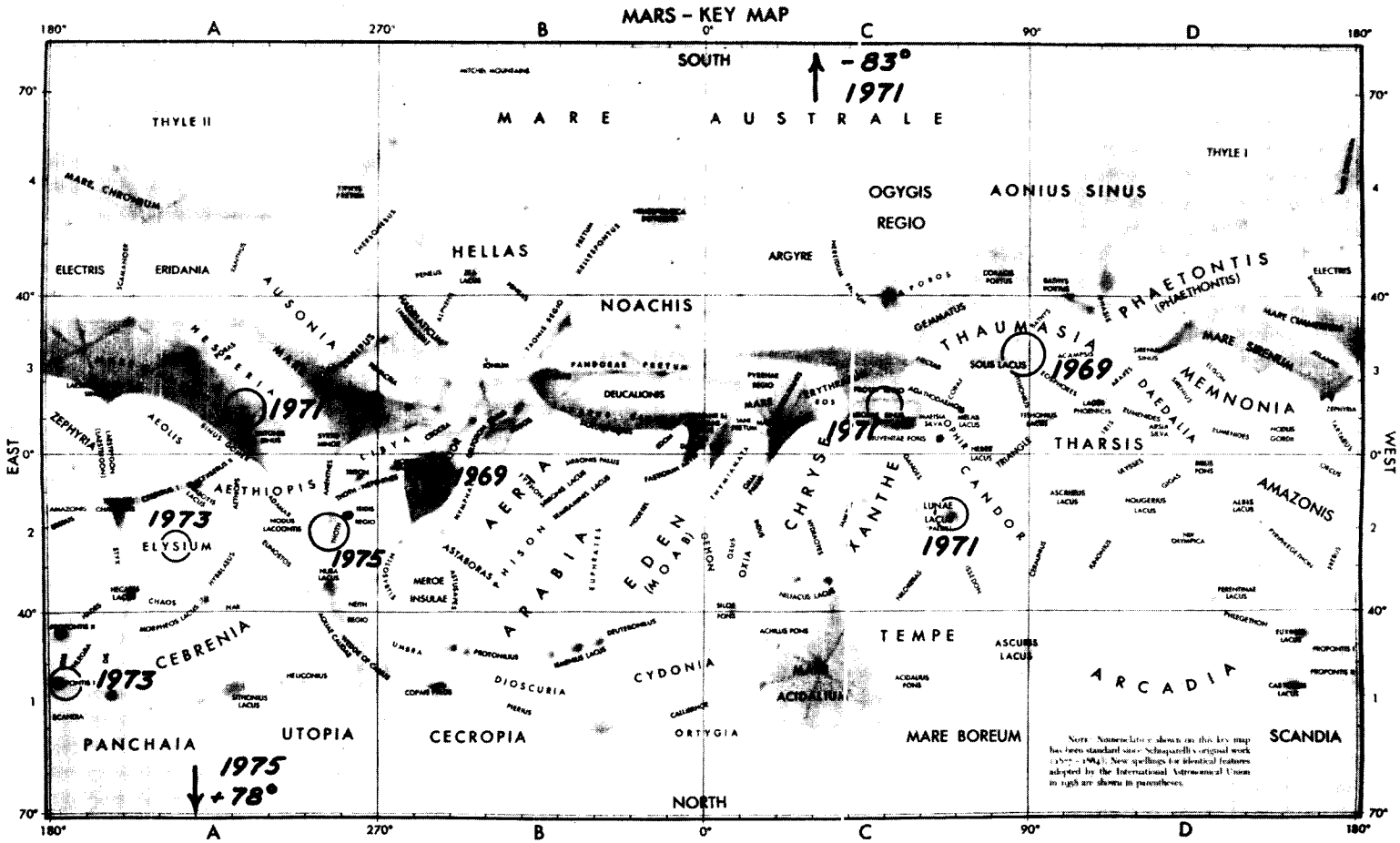


Figure 41 VOYAGER LANDING SITES -- MARS
63-9976

1969. Primary Objective: Wave of Darkening Two Landers

Priority	Name	Longitude	Latitude	Comments
2.	Syrtis Major	286°	+15°	Darkest of Martian dark areas; reports of characteristic color changes. Biological implications, by both infrared spectroscopy and by polarimetry. Boundary with Isidis Regio very sharp and strikingly circular in shape.
Alternate Sites:				
3.	Mare Sirenum	140°	-30°	Reports of marked seasonal color changes at optimum time. Adjacent to anomalously colored Memnonia desert.
4.	Lunae Palus	65°	+15°	Dark area with greatest change in photometric contrast in recent years. Marked double cycle of seasonal changes most easily studied in both 1969 and 1973.
5.	Trivium Charontis	200°	+20°	Reports of striking anomalous color changes. Lineation feature at edge of circular, "pink" Elysium desert.

1971. Primary Objectives: Polar Cap and Dark Areas. Four Landers.

Priority	Name	Longitude	Latitude	Comments
1.	Polar Cap	40°	-82°	Only opportunity for southern polar cap. Second lander on second launch vehicle should be directed here unless first launch vehicle lander is known to have landed sucessfully. Moisture measurements of prime importance. Permafrost features most likely here.
2.	Mare Cimmerium	235°	-18°	Reports of characteristic seasonal color changes. Second wave of darkening from north can be observed in 1975.
3.	Lunae Palus	65°	+15°	Dark wave still present although waning. See comments in 1969.
4.	Aurorue Sinus	50°	-15°	Reports of marked seasonal color changes. Cross lineation.
Alternate Sites				
5.	Solis Lacus	90°	-20°	See 1969. Changes still occurring at season of 1971 arrival. Likely candidate if successive landings at one location desired.
6.	Mare Serpentis	315°	-30°	Characteristic seasonal changes. Dark wave fed by major channel through Hellespontus.

1973. Primary Objectives: Deserts and Canals. Two Landers.

Priority	Name	Longitude	Latitude	Comments
1.	Propontis	185°	+45°	Region of typical Martian "canal" of early literature. Striking secular topographical changes. Undergoing greatest photometric contrast at time of arrival. Boundary of desert hemisphere.
2.	Elysium	210°	+25°	Near circular bright region of "pinkish" color. Assigned first priority since it is assumed that the more standard bright areas will have been studied previously to some extent in conjunction with complete dark areas. Prominent circular feature, landing off center of circle recommended for possible panoramic view.
Alternate Sites:				
3.	Hellas	290°	-40°	Bright area of anomalous "yellowish" coloration and anomalous albedo of surface.
4.	Nix Olympica	130°	+20°	Typical bright area of standard color. Center of dry hemisphere, major atmospheric channel.
5.	Ismenius	330°	+40°	Reports of striking anomalous color changes during this season.

1975. Primary Objective: Polar Cap. Two Landers.

Priority	Name	Longitude	Latitude	Comments
1.	Polar Caps	220°	+78°	Exact location dependent on detailed study of recession of cap, extent of dark collar, and dispersion of lander. Attempt should be made to land on cap at position such that dark collar passes lander during lifetime; other longitudes may be preferable. Probable winds shadow mountains and permafrost features.
2.	Nepenthes-Thoth	255°	+25°	Site of unusual secular changes in 1940's. Former location of "canal" system. This lander should be considered "in reserve" to investigate any unexpected features which might be discovered by earlier orbiter mapping.
Alternate Sites:				
3.	Mare Cimmerium	235°	-18°	Best location for observing wave from northern hemisphere. See 1971.
4.	Mare Acidalium	40°	+40°	Biological evidence by infrared spectroscopy and polarimetry.

7.4 Landing Sites -- Venus

Observations of Venus have given results which are almost entirely restricted to its atmosphere. It is acknowledged that even the supposed surface markings, called wheel-spoke patterns and illustrated in figure 42, may be features associated with an atmospheric circulatory regime below the uppermost cloud layers. It is known that atmospheric temperatures increase to perhaps 800°F at the surface.

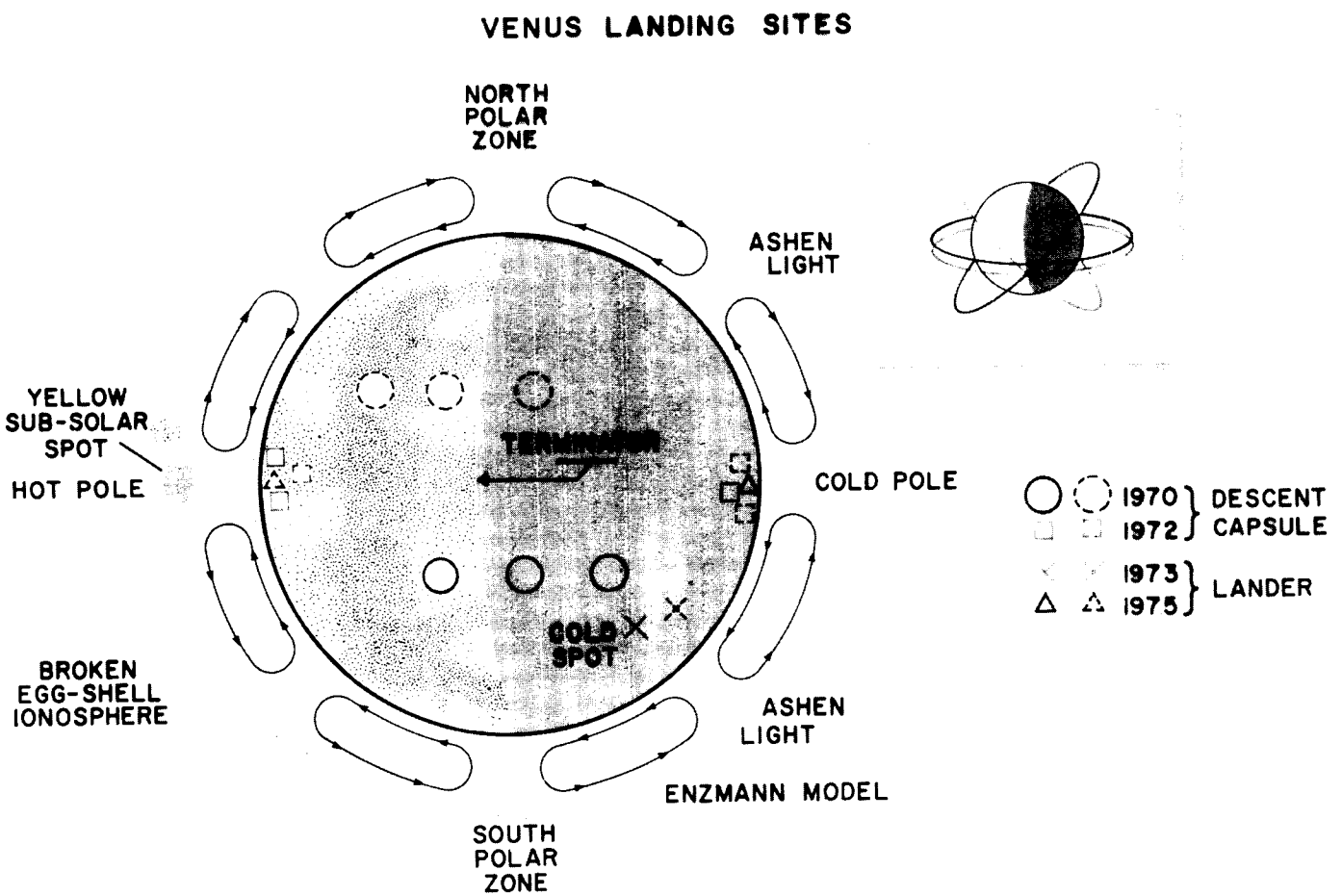


Figure 42 VOYAGER LANDING SITES -- VENUS
63-8480-1

The rotation is slow and the magnetic field is weak, but an ionosphere must be present, particularly on the illuminated side. Evidence of photochemical reactions or sferics on the dark side are evidenced by the ashen light which has been reported for the last century as gray, russet, red, and coppery. The slow rotation, retrograde or forward, has probably resulted in a simple circulatory pattern which is evidenced by the subsolar yellow spot (probably due to silicate dust), atmospheric banding paralleling the twilight zone, polar clouds suggesting multiple convection cells, polar cloud caps and canted lines suggesting planetary waves due to eddy flow, and ultraviolet reflecting bright patches in the colder upper atmosphere suggesting atmospheric eddy waves in the upper atmospheres circulatory regime. Radar measurements suggest that the rotation rate of Venus is slow. Observations at shorter wavelengths are apt to be subject to errors at interpretation because they do not penetrate the massive atmosphere of Venus. In general, the shorter the wavelength, the higher above the surface is the reflection.

Research on Venus could be very helpful to Earth meteorologists and geologists. It is judged to have a simpler pattern of circulation, and observation of this pattern should lead to better understanding of circulation in Earth's atmosphere. The surface is thought to be without water, and metamorphism of sediments is therefore likely to be anhydrous except for the presence of juvenile water (water being released from the mantle of Venus to its surface). The temperatures at the surface seem to be in the vicinity of 800°F, which represents the most extreme physical conditions to which rock-forming materials are subjected before forming magmas. To observe such conditions on a global scale in what is expected to be a simpler-than-Earth anhydrous environment would be very helpful in finally understanding the more complicated processes of Earth's lithosphere. The presence of second-, third-, fourth-, and fifth-order geomorphic features, and their association with internal energy generation in Venus, is of enormous importance to terrestrial geological sciences. If these features appear, it will be possible to form a more quantitive judgment as to the role of Earth's oceans in forming continental and oceanic domains and all their associated features. Seismic, thermal, and electrical fluxes from the interior of Venus will indicate the rate of internal energy generation. The development of various geomorphic orders will indicate the degree of coupling of endogenetic and exogenetic energy to the lithosphere of this planet. Among the first and most difficult things to discover will be the rate of rotation, and orientation of the axis of this planet. Perhaps the best method will be to observe surface features with radar over many years, and therewith continually refine the measurements.

Exploration of Venus is planned by the use of orbiters, atmospheric probes not intended to survive on the surface, and landers. In 1970, three descent capsules from the first vehicle should be placed as shown on figure 42, two on the dark side away from the cold pole where conditions may be less turbulent, and where light scattering photometric measurements of the cloud composition is most feasible, and one on the illuminated side so that a comparison may be made. The second launch vehicle should place three capsules in the northern

hemisphere, with two on the light side and one on the dark. The wheel-spoke markings and the connecting bands between spokes should be avoided on the chance that these may represent atmospheric volumes of greater turbulence and rougher surface areas. The objectives in 1970 are to determine the composition of the atmosphere and of the clouds to increase the probability of success of later experiments, and to measure turbulence of the atmosphere from the upper exosphere to as close to the surface as possible, so that surface turbulence will be known. Knowledge of surface turbulence is vital to planning a lander vehicle, and knowledge of turbulent layers is important to meteorologists trying to depict circulatory regimes. The base of the cloud layer, if present, should be determined so that the possibility of using later atmospheric flyers may be considered. Finally, the surface should be mapped by orbiter radar with definition sufficient to show the presence and distribution of second-, third-, and fourth-order geomorphic features. In summation, the objectives of 1970 should be directed toward gaining sufficient understanding of the atmosphere and gross surface features to improve the chances of success of the later expeditions.

In 1972, a series of six descent vehicles is also planned. They should be used to forward the above objectives (together with an orbiter radar-mapper) and to further define circulatory patterns of the atmosphere. With the knowledge gained in 1970 of the atmospheric conditions, the capsules in 1972 can more safely be directed towards the hot-pole (subsolar spot) and cold-pole regions. It is expected that these regions will provide measures of the extreme conditions on Venus in terms of temperature, turbulence, and ionosphere structure. Again, the landers from each launch vehicle should be directed to both poles if such a capability is available in order to increase the probability of at least some measurements at each pole.

Two surface landers are planned for the 1974 window. These landers should be devoted to securing information concerning the interior of Venus. This is information extremely valuable to geology, geophysics, and astronomers. It may be gained by mechanical coupling of seismographs to the surface, or, if aerodynamic drag is prohibitive, coupling could be accomplished with small explosions through the atmosphere. Airbursts are used on Earth in prospecting for structures that might be petroleum reservoirs. However, the information gained this way would be considerably less than that which could be gained by recording the natural seismicity of a planet.

In 1975, data concerning atmospheric and surface conditions of Venus will be somewhat advanced; at this time, the more difficult problem of securing and analyzing lithospheric samples should be attempted. Further seismic work, and further atmospheric work could be done concurrently. The main effort should be devoted to the difficult task of securing surface samples, bringing them inside the capsule, analyzing them and transmitting the data to Earth. The sites have been selected to avoid extreme subsolar, antisolar, and supposed convective extremes. If second- and third-order geomorphic features have been found and

located by the earlier flights, seismic experiments should be conducted close to the boundaries of the equivalents of continental and oceanic domains and geochemical analyses should be attempted in each. One lander could be directed toward a "plateau" region, the other to a "basinal" region. The cold spot detected by Mariner II may be a manifestation of such a geomorphic feature.

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