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EXPERIMENT PAYLOADS FOR A MANNED MARS FLYBY MISSION

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ABSTRACT

Based on the deliberations of the Space Science Board of the National Academy of Sciences, a number of fundamental scientific questions concerning Martian biology, geophysics, and meteorology have been defined. An examination of current data and theories on Mars reveals partial answers to some of these questions and suggests a series of experiments which could provide useful data towards a more complete examination of all of them. This report discusses an experiment payload for a manned flyby mission as one means of carrying out the exploration of Mars.

An experiment payload for this mission would include on board remote sensors and four types of unmanned probes for more direct measurements of the Martian environment. One probe, a Mars Surface Sample Return vehicle, will return a sample from the surface of Mars. The return of a sample is felt to be required to conduct a meaningful biologic investigation of Mars. The three other probe types include an impacter for atmospheric measurements, an orbiter, and a soft lander. The total weight of the experiment payload, including on board sensors, a laboratory for bioanalysis, and the probes is about 34,000 lbs.

The probe mix used in the sample payload illustrated in this report provides a comprehensive attack on the major questions concerning Mars. As requirements for data change, the need for a particular probe may be eliminated. It is felt unlikely, however, that a need will be developed for any new probe not considered here. Consequently, regardless of how the specific probe mix may change as our understanding evolves, the basic conclusions of this report should remain essentially valid.

A program of experiments in astronomy and space physics that uses the on board remote sensors has been developed to capitalize on both the Earth-Mars and Mars-Earth phases of the mission.

The experiments designed to investigate the biology, geophysics, and meteorology of Mars will also provide data for the planning and engineering design of subsequent space missions, such as a manned Mars landing.

EXPERIMENT PAYLOADS FOR A MANNED MARS FLYBY MISSION

I. INTRODUCTION

In support of the MSF Planetary Joint Action Group, work has been performed to define an experiment payload for a manned flyby mission to Mars. This document serves as an interim report on this effort. All time dependent mission parameters used in this report are for a 1975 twilight flyby mission. The experiment payload is limited to the investigation of the Mars environment and general space science objectives such as astronomy.

The fundamental questions of both scientific and technological interest concerning Mars have been grouped into three areas - Exobiology, Properties of the Surface and Solid Body, and Properties of the Atmosphere. Four major experiment areas are delineated to answer the questions that have been posed and to provide data for questions about Mars that have not yet arisen. These areas are: sample return, geophysics, meteorology, and photography.

Unmanned probes launched into the Mars environment from a manned flyby vehicle are utilized to take advantage of the salient features of the flyby trajectory. Four different probe concepts are developed: a planetary surface impacter, an orbiter, a soft lander, and a lander with the capability of returning a sample of the surface to the flyby vehicle.

An experiment program with broad application to space science (e.g., solar astronomy) was developed to complement the exploration of Mars. This program will be conducted during the outbound and return portions of the Mars flyby mission.

The experiment payload defined in this report weighs approximately 34,000 lbs.

The potential results of the experiment program are described in terms of the quality and quantity of data, or significant questions that could be answered by a single flyby mission. Also some measure of the value of the astronauts to the execution of the experiment program is provided. In general the areas in which the utilization of man is judged to be particularly effective include probe targeting and tracking, experiment operations, command and control, and data discrimination and processing.

II. THE INVESTIGATION OF MARS: SCIENTIFIC AND TECHNOLOGICAL QUESTIONS

A. Scientific Questions

The Space Science Board of the National Academy of Sciences has established a preliminary ranking of interest in the various objects of the solar system.(1) Interest in a specific object depends on its relevance to questions of the origin of the solar system, the origin of life, and increased understanding of the Earth. The planet Mars was placed at the top of the priority list for exploration in the post-Apollo years.

The questions of scientific interest concerning Mars are grouped into three areas.

1. Exobiology

Is there life on Mars at this time, and if so, what is its nature? If not, was there ever life on Mars or are there, at this time, any recognizable precursors to life? Providing even partial answers to these questions would justify a scope of experimentation which would utilize a major fraction of the scientific mission payload.

2. Properties of the Surface and Solid Body - Including Differentiation, Activity, Composition, and History

The possibility that the interior of Mars is differentiated radially into a crust, mantle, and core as in the Earth should be investigated. Related to this is the question of internal activity of the planet, as evidenced by the possible existence of volcanoes, internal stress build-up and release (Mars quakes), or large scale crustal movements such as faults. Questions of composition concern the chemistry and mineralogic makeup of the planet, particularly as they may relate to the Earth. The role of water in the planet's history is of special interest. Questions of the history of the formation and development of Mars and its relative place in the history of the solar system may be attacked once the present state of planetary differentiation, activity, and composition are understood.

3. Properties of the Atmosphere - Including Dynamics, Composition, and History

Of prime importance here are the characteristics of the circulation of the Martian atmosphere, together with the related problems of dust and water vapor transport. Understanding these circulation patterns may provide new insight into the dynamics of the Earth's atmosphere. The present atmospheric composition is of interest to the general problem of the long term history of the formation of both the solid body and atmosphere of the planet.

B. Technological Questions

The data needed to design a system for a manned Mars landing mission provides a convenient focus for defining the technological questions of interest concerning the Mars environment. Such a focus is needed since a "technology question" is a particular application of a "scientific question" about the environment. A discussion of four areas is provided to identify the major technological questions.

1. Exobiology

The existence and nature of Martian life will be of interest to engineers designing systems to protect the astronauts and prevent back-contamination of the Earth following a manned Mars landing. The resistance of Martian life to various sterilization techniques and its ability to penetrate biological barriers should be known. Any pathogenic effects on humans and human resistance to these effects should also be known.

On the other hand, if it could be demonstrated that life does not exist on Mars, this information would reduce or eliminate the requirements for forward contamination control. Similarly, information indicating that the Martian environment is unsuited to the survival or spread of Earth-type life would affect the requirements on biological control equipment and practices.

2. Atmosphere

Although soft landing probes can probably be successfully designed with our present knowledge of the Martian atmosphere, more certain and detailed knowledge would aid in the efficient design of a manned landing module. Information on the atmospheric density and composition profiles is of particular importance. Increased knowledge of wind characteristics, dust clouds and of the transmission "windows" of the atmosphere that affect communications is also of importance in the design of a manned lander.

3. Surface and Resources

Knowledge of the topography and dynamic bearing strength of the Martian surface is important to the design of a manned landing vehicle. An obstacle avoidance system which would increase landing safety requires topographic information. Trafficability of the surface to roving vehicles and astronauts on foot should be evaluated. Electrical properties of the surface are relevant to the prediction of the performance of landing radars and certain types of antennas.

The existence and availability of certain chemical resources may affect the logistics of manned landing systems. Oxygen or water, perhaps as water of hydration in crystals, might be of considerable importance, especially to more advanced missions.

4. Geodesy

Future missions probably will involve the placement of manned vehicles in Martian orbit with descents to the surface and rendezvous in orbit. The efficiency of these maneuvers would benefit from a better knowledge of the figure and gravitational field of Mars than is presently available. Possible perturbing effects of the two natural satellites should also be known.

Important questions about the interplanetary medium through which the manned spacecraft must travel still remain. The micrometeoroid flux is perhaps of most interest. More information on the radiation environment is of secondary importance. Improved data on these factors should be obtained in time to influence the design of the first manned Mars mission. Without improved data the conservatism which must necessarily be adopted in dealing with such hazards will lead to a large allocation of weight for protective shielding or repair techniques.

III. EXPERIMENT DELIVERY SYSTEMS

As a means of answering the scientific and technological questions about Mars which were discussed in Section II, an experiments program for a manned flyby mission is proposed. The purpose of this section is to briefly discuss the experiment delivery systems, or probes, which aid in carrying out this program. Section IV will discuss our present knowledge of Mars and a specific program of experimentation, consistent with the delivery systems proposed here, which could measurably improve upon our knowledge in each of the question areas.

For the nominal mission the manned flyby vehicle passes Mars at a periapsis altitude of 300 km with a velocity of approximately 31,000 fps. To supplement the brief period during which high resolution remote sensor observations of Mars can be made from the flyby Mission Module (M.M.), four unmanned probes are considered. The function of these probes is to place experiments in direct contact with the Mars environment and extend their time of operation considerably beyond the M.M. encounter phase. All probes are launched from the M.M. between four and seven days prior to periapsis.

The primary objective of the Mars Surface Sample Return (MSSR) probe is to soft land on the surface, collect a sample, and return it to the manned flyby vehicle. A secondary objective is to deliver a remote monitoring surface experiment station to the same site.

Another type of lander probe is envisioned which does not have return sample capability. The objective of this probe is to soft land a second experiment station at some point of interest other than the MSSR site. Without the sample return requirement, a comparable experiment station can be soft landed for a probe gross weight considerably less than the MSSR.

An orbiter probe is proposed to extend the spatial and temporal surveillance of the Mars atmosphere and surface beyond the limited capabilities of the manned flyby vehicle. In its present concept the orbiter mission is primarily photographic.

Finally, an atmospheric drag probe is proposed to provide improved data on the atmospheric density profile to aid in determining entry conditions for the MSSR and lander probes and, possibly, to provide information on the drag forces on low altitude orbiting spacecraft. For this reason the drag probe is the first of the sequence to arrive at Mars (all probes arrive before the flyby vehicle). Data from this probe is transmitted directly to the M.M. before destructive surface impact. The other three probes are intended to survive and continue recording data for a period of about one year.

Appendix A describes those aspects of the flyby mission profile which bear on the experiments program. Detailed descriptions of the conceptual design, mission profile, and payload for each probe are contained in Appendices B-E.

IV. EXPERIMENT AREAS

The flyby mission experiments program consists of four major experiments devoted to the investigation of Mars. The prime objective of sample return is to answer the questions relating to the possibilities of life on Mars. The same sample will also be used for detailed geochemical analysis. The geophysics experiment gathers data on the surface and interior properties of the planet. The objective of the meteorology experiment is to gather data on the composition and dynamics of the Mars atmosphere. The photography experiment will gather imagery of the planet at various wavelength regions and at several scales of resolution. The results of this photographic data will bear either directly or indirectly on each of the scientific disciplines covered by the first three major experiments. These experiment areas are seen to be coincident with the principal scientific and technological questions outlined in Section II.

The state of our current knowledge of the Mars environment is reviewed in order to define a basis for suggesting particular experiments. The current information is based upon a combination of earth-based observations and Mariner IV data. A number of specific experiments are suggested as checks on hypotheses that are based upon extrapolating from the little that is really known to more generally descriptive models of what may be true of the planet as a whole. Another group of experiments are proposed largely because they have provided useful information in previous investigations of the Earth. In general each major experiment area will be covered by a variety of specific experiments and measurements. The intent is to provide sufficient data to make a number of cross-checks on each model or hypothesis.

Discussing the investigation of Mars in terms of four major experiments instead of the several tens of component experiments is a matter of convenience. Perhaps the overriding reason for the selection is that as the exploration of Mars progresses, individual experiment needs will certainly change; but the generality of these major experiment areas is sufficiently great that each one will still be important for an early manned flyby mission.

It should also be stressed that so far as individual experiments and measurements are concerned, there is no sharp dividing line between these four areas. For example, data on the composition of the present Mars atmosphere will also be part of the geophysics experiment area, as it is important information in determining the history of the evolution of the solid planet.

More obviously, as mentioned earlier, photography could be considered a sub-category of each of the other three experiment areas.

In addition to the investigation of Mars, three particular en route experiments are identified as being particularly interesting and challenging. These include taking stereo photographs of the sun in conjunction with an Earth orbiting station, observing the moons of Mars at close range, and capturing a particle sample in the asteroid belts. The roots of these experiments may also be traced back to the deliberations of the Space Science Board on solar system exploration. Appendix F identifies a broad spectrum of en route experiments and observations which could be usefully carried out, although many of them take no special advantage of the unique character of the flyby mission.

A. Sample Return

The purpose of this section is to treat the question of the biologic interest in a sample returned from the Mars surface and to describe qualitatively the sort of examination which will be carried out on board the Mission Module to analyze the sample. Obviously there will also be a great deal of interest in the chemical and physical properties of this sample. In addition to average composition and other bulk properties of the several types of samples, the presence (or absence) of vertical stratification in subsurface core samples will be significant. A comparison between material basic to the Mars planet and meteorite material will also be of interest, and steps should be taken to allow recognition of these differences. These latter topics, however, are more appropriately dealt with in the discussion of the geophysics experiment in the next section. Suffice it to say here that much of the chemical analysis performed as part of the on board biologic examination will also be of interest to geochemistry. Beyond this it will be assumed that non-biologic requirements for early on board sample analysis can be accommodated with little weight penalty to the spacecraft biologic laboratory facilities.

Mars: A Second Biota

The discovery of extraterrestrial life, life precursor molecules, or even a sterile environment would add a new perspective to biology. Exobiological studies are also important in order to ascertain the dangers to Earth from contamination borne in from the outside.

While other organic biochemistries could exist, most exobiologists believe that the carbon based chemistry is decidedly advantageous over even its nearest rival, one based on silica. In addition, most life detecting schemes which have been proposed assume a carbon based chemistry. This assumption eliminates the investigation of the surfaces of Venus and Mercury for life since their temperatures are believed to be above those required for the formation of stable carbon compounds. Mars, the other planet close to Earth, however, has a much lower surface temperature in which a carbon based chemistry could be stable.

The presence of life on Mars has been the subject of speculation for over a century. While green areas and canals have been found to be illusory, Mars does have attributes which could be indicative of life. It has three distinct visual features, polar caps, light areas, and dark areas. The polar caps apparently are CO_2 or H_2O in solid form, while the light areas seem to be deserts of a material similar to terrestrial limonite. The dark areas are basically permanent but undergo seasonal darkening correlated with recession of the polar cap and following a path along which lie the highest surface temperatures. Polarimetric studies indicate that the opaque granules covering the dark areas increase in size during the period after the seasonal darkening. Later, after the summer when the polar cap again grows, these granules decrease in size. No such changes are observed in the bright areas, believed to be deserts. Infrared spectra of the dark areas have been shown to be similar to spectra obtained using terrestrial lichens as subjects, but have not revealed chlorophyl.

The atmosphere would seem hostile, the surface pressure being only 1/100 of that of the Earth's and CO_2 being the main component. Water vapor and some apparent methane derivatives are the only other constituents identified so far. While experiments have revealed that certain terrestrial organisms can grow in atmospheres simulating the detected composition for Mars, the apparent lack of oxygen would allow irradiation of the surface with solar UV at a level which would be lethal even to these rugged organisms in a matter of a few days. However, UV resistance is a molecular and evolutionary phenomenon and there is no reason to believe that Martian evolution could not have coped with the UV irradiation.

The surface temperature is reported to vary diurnally from about $-60^\circ C$ to $+40^\circ C$. While some terrestrial organisms would perish under these conditions, others can withstand such daily freeze-thaw cycles. In addition, the temperature of 27°C is considered ideal for terrestrial organisms, and some organisms have been able to metabolize at sub-zero temperatures while surviving temperatures below -40°C. Furthermore, even if we should accept these temperature conditions for the average surface as unfavorable, there may well be more favorable environments either in the near subsurface or at local warm spots at the immediate surface.

Thus, the Martian environment may not be too severe for survival of organisms similar to terrestrial types. The primary problem then is the unambiguous recognition and identification of Martian life. Even in the absence of living organisms, a chemical study of the Martian surface would aid in the understanding of life's origins since the early physical conditions on Earth and Mars are believed to have been similar.

Sample Analysis and Return

In the MSSR concept no sample analysis other than TV and photography will take place on the Mars surface. A 2 lb sample is returned to the manned spacecraft, 8 oz of which will be analyzed for biological molecules and living organisms in the on board biological laboratory. As pictured in Figure 1, the important activities will be the detection and characterization of life, specimen conservation for sample return to Earth, and contamination control to prevent contaminating the sample, the astronauts, and eventually Earth.

An important function of the flyby mission is the early detection and characterization of life. As a quick scan for detection, morphological methods involving a microscope module are best, since they yield information without assuming a particular biochemistry. With or without visual detection, radioisotopic and physiological techniques could indicate whether gas evolution, growth, and molecular metabolic activities are occurring. The determination of optical activity and molecular type will be done to ascertain the presence of terrestrial biological molecules, or new molecules having general biological properties.

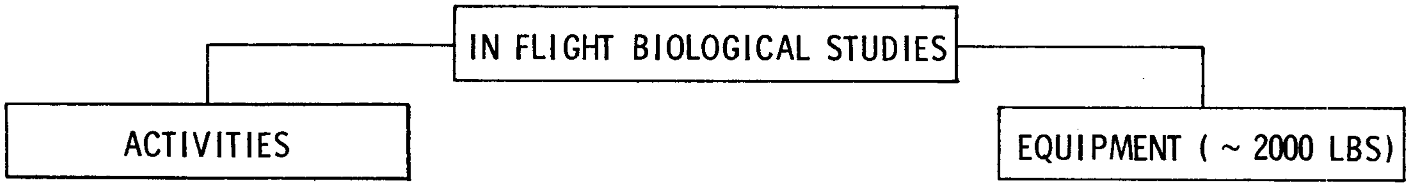
The major portion of the sample must be preserved for Earth laboratory studies which can utilize equipment of greater diversity and resolution and bring to bear the talents of a larger number of highly trained personnel. A variety of known preservation methods would be used to maximize the chance of returning a viable sample. Active state cultivation is an excellent method but may not be possible since it depends upon detecting an organism and determining its growth requirements. Most

- MSSR PROBE MEASUREMENTS

SAMPLE RETURN FOR BIOLOGICAL ANALYSIS

DATA

2 LB SAMPLE RETURNED TO EARTH
8 OZ SAMPLE ANALYZED ON BOARD



A. DETECTION/CHARACTERIZATION
    MORPHOLOGICAL
    PHYSIOLOGICAL AND BIOCHEMICAL
    CHEMICAL
    PATHOLOGICAL

B. SPECIMEN CONSERVATION
    ACTIVE STATE
        CULTIVATION
    DORMANT STATE
        DEEP-FREEZING
        FREEZE-DRYING
        PHYSICAL SEALING
    NON-VIABLE STATE
        CHEMICAL FIXATION
        GRID PREPARATION

C. CONTAMINATION CONTROL
    STERILIZATION
        TEMPERATURE TREATMENT
        CHEMICAL TREATMENT
    ISOLATION
        PARTITIONING (BIOLOGICAL BARRIER)

MICROSCOPY MODULE (PHOTOGRAPHIC RECORDING CAPABILITY)

BIOCHEMISTRY LAB (RADIOISOTOPIC & SEPARATION TECHNIQUES)

PHYSIOLOGICAL LAB (MORPHOGENETIC, GROWTH, & METABOLIC CHARACTERISTICS)

CHEMISTRY LAB (IDENTIFICATION OF BIOLOGICAL MOLECULES)

PATHOLOGY LAB (EARTH LIFE FORMS MAINTENANCE, AUTOPSY & ANALYSIS)

PRESERVATION FACILITY (GROWTH MEDIA, ENVIRONMENTAL SIMULATORS, & TECHNIQUES OF SPECIMEN STORAGE)

ANTI-CROSS-CONTAMINATION FACILITY (BIOLOGICAL BARRIER & STERILIZATION EQUIPMENT)

FIGURE 1 – SAMPLE RETURN EXPERIMENT–EXOBIOLOGY

methods preserve organisms in the dormant state, but additional precautions should include methods which preserve the samples in the non-viable state such as chemical fixation for on-earth microscopy.

Because of the unknown nature of the extraterrestrial materials and the dangers of false discoveries through contamination of the samples with Earth biota, contamination control is necessary. These precautions include isolating the sample and plant and animal subjects exposed to it for pathological tests, as well as sterilizing all materials and probes introduced into the sample.

This program can yield valuable information about the biological properties of the sample. The early on board investigation coupled with the capability of determining pathogenicity to terrestrial organisms are of greatest importance. The greatest success would be the ability to observe and cultivate a Martian organism. However, results of importance to the biological theory of the origin and nature of life will be obtained by chemical analysis alone.

B. Geophysics

The geophysics experiment area includes the charged particle and magnetic field environment above the Martian surface in addition to the properties of the surface and solid body of the planet. The state of our current information in this area is based on a combination of earth-based observations and Mariner IV data.

Physical Observations and Theories

The mass of Mars has been well determined from the orbital constants of its two moons, Phobos and Deimos, and independently by noting the perturbation of the trajectory of Mariner IV. Optical measurements of the planet radius have been reviewed(2) with a recommendation that values for the equatorial and polar radii of 3375 ±10 km and 3350 ±10 km, respectively, be provisionally adopted. More recently a preliminary determination of the mean Martian radius based upon Mariner IV radio occultation data has yielded a value of 3390 ±6 km.(15) This latter value may be somewhat restricted in that it refers to the planet radius at only two points, namely occultation immersion and emersion. If we accept the error in planet radius as ±1/3%, the corresponding error in mean planet density is about 1% (the error in planet mass is only .06%).

Earth-based observations of the orbital constants of Phobos and Deimos have also provided an accurate value for J_2, the second order term in the harmonic expansion of the gravitational potential of Mars. Here $J_2 = \frac{C-A}{Ma^2} = .002$, where C is the moment of inertia about the spin axis of Mars, A is the moment of inertia about an equatorial axis, M is the planet mass, and a is the mean radius. If hydrostatic equillibrium is assumed,* the dynamical flattening is obtained directly from the value of J_2, knowing only the ratio of centrifugal force to gravity at the Mars equator. The calculated hydrostatic flattening turns out to be f = .0052. The optically observed flattening(2) is about twice this value (f = .0105).

So far as the internal constitution of Mars is concerned, one of the more interesting questions is whether the planet is chemically differentiated. An obvious experiment would be the search for evidence of a core. Although no direct evidence pertaining to this question exists now, a number of possible models have been suggested. Using physical models based largely upon what we know about the Earth, with the measured values of M and J_2 as constraints on the models, estimates have been made of possible density distributions for parametric values of planet radius and flattening.(3) While the lack of sufficient data prohibits a unique solution, general trends in the results, and certain specific examples, are of interest. For example, for increased values of flattening, holding the planet radius constant, the surface density of the model increases and the radius of the core decreases. For constant values of the flattening, an increase in the planet radius produces a decrease in the surface density and an increase in the core radius. For the case that Mars is in hydrostatic equilibrium (i.e., f = .0052), and assuming a planet radius of 3390 km as suggested by Mariner IV, a core radius of 1100-1200 km and a surface density of 3.65 g/cm^3 are indicated. This is true for a core material which is either molten iron, solid iron silicate, or solid iron. The introduction of a phase transition in the upper mantle of Mars (600-1000 km deep) serves to reduce both the core radius and surface density. Again for the case f = .0052, and assuming a density change of 10-15% at the transition boundary, the core radius is reduced to 600 km or less and the corresponding surface density to 3.4-3.5 g/cm^3. These latter values are in accord with the mean density of the moon and the density of the Earth's upper mantle.

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*For the Earth there is only about a 1% difference between the observed and hydrostatic values for J_2.

Calculations of the thermal constitution of the Mars interior have also been carried out.(3) If it is assumed that the planet composition was originally that of the chondritic meteorites, the inherent radioactivity would lead to melting and eventual gravitational differentiation. The resulting iron core would contain about 10% of the planet mass. Assuming the Mariner IV value for the planet radius, this core mass would be too great to accommodate the upper mantle phase transition considered above.

Earth-based infrared observations of the Mars surface temperature at perihelion(4) indicate a diurnal fluctuation considerably greater than for the Earth, but less than for the moon. Temperature values range from -49°C at 7 a.m. local time to +39°C at 2 p.m. Observations of the nighttime temperature from Earth are not possible. However, theoretical models for the surface temperature over the entire planet suggest a daily low of -62°C at dawn (still at the perihelion position). The relatively high amplitude for the diurnal temperature cycle may be attributed to very low thermal conductivity in the upper surface layers. This probably means a very porous material, consistent with a meteoroid impact rubble layer. Marial areas have been noted to be about 8° warmer than surrounding areas during the day; this is directly attributable to their greater absorption of the solar radiation.

Mariner IV photographs showed a crater marked surface which appeared more moon-like than Earth-like. The density of craters larger than 20 km in diameter seems to fall in between that observed in the lunar maria and continents.*(4) This suggests the presence of some erosion mechanism, at least in the early history of the planet, which has obscured many of the craters and features which were the result of the original planetary formation process. No direct evidence of volcanism exists, as the best resolution of the Mariner IV photos was about 4 km. Furthermore, these photos covered too small a fraction of the total surface area to reveal much of the variety of surface detail. In general, it seems that both Martian continent and mare areas are covered with similar bright and dark spots having linear dimensions from 10-100 km, the main difference being a higher density of darker spots in the maria.

Mariner IV also carried several particle and field measuring instruments. Particle detectors operating through encounter at a minimum radial distance of 13,200 km failed to record evidence of Martian radiation belts which are in any way analogous to the

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*Recent communication with Professor Bruce Murray of Caltech has revealed that analysis of Mariner IV photos is continuing and may suggest that in at least two photos cratering has reached the saturated stage typical of lunar highlands.

Van Allen belts surrounding the Earth.(5) Using the solar wind-Earth magnetic dipole field as a model, the absence of trapped particles at that minimum distance leads to an upper bound for a dipole magnetic field at the Mars equator of about 100-200 gammas (i.e., 0.1% - .05% of the Earth's magnetic dipole moment). Mariner IV magnetometer data leads to essentially the same conclusion.

Flyby Mission Experiments

From the foregoing discussion it is obvious that more accurate data is needed on the figure of Mars. The geometrical figure can be obtained from stereo photographs and from repeated occultations of an artificial satellite in orbit about Mars. Improved data on the gravitational potential can be obtained by tracking this same satellite.

Data bearing on the activity and internal constitution of Mars will be derived primarily from seismometer and heat flow measurements. Seismic data not only provides a measure of the number and magnitude of possible Mars quakes, it also can determine the acoustic velocity vs. depth profile for the planet. This profile data offers improved control over the density-depth models. The presence or absence of a fluid core can be unambiguously determined. The heat flow experiment measures the thermal conductivity and steady-state heat flux at the planet surface. Surface heat flux measurements serve as boundary values in problems attempting to model the thermal constitution of the Mars interior discussed earlier.

The net result of these additional measurements is to narrow the spectrum of plausible models describing the interior properties of Mars. The immediate goal is to understand as much about Mars as we do about the Earth. This information provides a basis for comparing different planets in the solar system which should lead to some inferences about their early formation.

Measurements of the magnetic field both on the surface and in Mars orbit can provide additional information on the planet interior. Despite the negative results of Mariner IV, this can still be a worthwhile experiment. In the first place, there may be a magnetic field of internal origin which is atypical of the Earth case and would not necessarily be detected at the

Mariner IV altitude. Secondly, even if there is no natural field of internal origin, the magnetic field contained within the solar plasma will interact with the atmosphere and solid body of Mars and should be measured.

A soil mechanics experiment to measure mechanical properties of the surface material would be of interest to the design of future landing spacecraft. Data on the density, cohesiveness, angle of internal friction, and general static and dynamic bearing properties should be obtained.

Evidence of the average surface composition over as much of the planet area as possible should be obtained. This should include returned samples of both loose material lying on the surface and core samples. In situ alpha backscatter measurements may determine the presence of the more common Earth-type silicate minerals. For large aerial coverage at minimum expense, the few detailed local composition samples can be supplemented by spectrometers in the infrared, visible, ultraviolet, and gamma ray portion of the spectrum carried in a high altitude reconnaissance mode (e.g., on board the M.M. and orbiter probe). Composition sampling over the surface will indicate the extent of lateral differentiation and provide a boundary value for extrapolating to estimates of the composition of the planet interior.

Radiometer instruments flown in a reconnaissance mode can search for thermal anomalies in the surface at various wavelengths, as well as appraise the diurnal temperature variations for the average surface. From this data gross inferences can be drawn relating to the geometry, conductivity, and density of surface material.

The experiments discussed here and their applications are summarized in Figure 2 according to the delivery vehicle to which each experiment would be assigned.

C. Meteorology

Prior to Mariner IV, observations of the Mars atmosphere were limited to earth-based telescopic imagery, spectroscopy, and radiometry. Based on these early observations various models were proposed to provide a more general description of the Mars atmosphere, frequently relying on knowledge of the Earth's atmosphere. While Mariner IV data proved to be in general agreement with some aspects of these models, it was in notable disagreement in at least two critical areas, namely, composition and surface pressure.

	APPLICATION
● FLYBY VEHICLE MEASUREMENTS	
I.R., VISIBLE, U.V., AND GAMMA RAY SPECTROMETERS;	SURFACE COMPOSITION
I.R. AND MICROWAVE RADIOMETERS	SURFACE TEMPERATURE
● ORBITER PROBE MEASUREMENTS	
MAGNETOMETER	PLANETARY MAGNETIC FIELD, SOLAR WIND INTERACTION
SPACECRAFT TRACKING	GRAVITATIONAL FIELD
GAMMA RAY SPECTROMETER	SURFACE COMPOSITION
I.R., MICROWAVE RADIOMETERS	SURFACE TEMPERATURE
● LANDER PROBE MEASUREMENTS	
SEISMOMETER	MARS QUAKES, PLANETARY ACTIVITY
MAGNETOMETER	INTERNAL MAGNETIC FIELD, IONOSPHERIC MOTIONS
HEAT FLOW EXPERIMENT	INTERNAL HEAT FLUX AND SURFACE CONDUCTIVITY
SOIL MECHANICS EXPERIMENT	MECHANICAL PROPERTIES OF SURFACE MATERIAL
ALPHA-BACKSCATTER EXPERIMENT	SURFACE COMPOSITION
● MSSR PROBE MEASUREMENTS	
ALL THE LANDER PROBE MEASUREMENTS PLUS -	
2 POUND SAMPLE RETURN	CHEMICAL COMPOSITION OF SURFACE

FIGURE 2 – GEOPHYSICS EXPERIMENTS

Mariner IV data does, in fact, represent only a preliminary step in our understanding of the Martian atmosphere. A comprehensive program designed to investigate the meteorology of Mars must include a broad study of the several atmospheric parameters as a function of latitude, longitude, altitude, and time. The meteorology experiment program for the manned Mars flyby mission represents a reasonable next step towards this goal.

Physical Observations and Theories

The temperature of the Mars surface is an important boundary value in the study of the atmospheric parameters. By making certain assumptions about the radiative properties of the Mars surface, the observed value of optical albedo leads to an inferred average temperature of 220°K. Infrared observations(6)(7) yield an average temperature somewhat higher, namely, 250°K. By analogy with dry, sandy regions on Earth, the near surface atmosphere temperature has been estimated to be about 50° lower than this,(8) or about 200°K. This is in substantial agreement with an estimate of the temperature from the Mariner IV occultation data of 180 ± 20°K at immersion and 250°K at emersion.

Careful analysis of Martian spectra has established a lower abundance limit of about 10 gm cm^{-2} for CO_2. The presence of water vapor in the atmosphere has also been established, although estimates of its quantity range from $\sim 1.4 \times 10^{-3}$ gm cm^{-2}(9) to 2×10^{-2} gm cm^{-2}(10). Recent reports on results of spectroscopic observations of Mars with a high resolution interferometer(11) indicate the presence of a surprisingly high fraction ($\sim 10^{-3}$) of methane derivatives in the atmosphere. No other components have been unambiguously identified.

Pre-Mariner IV calculations of surface pressure were suspect to considerable uncertainty. Although observational astronomy provides a number of methods for probing the pressure of planetary atmospheres, interpretation of the data relies heavily on assumptions about other properties of the same atmosphere. The simplest methods are based on polarization studies and photometry. Surface pressures deduced from polarization measurements ranged from 30 - 200 mb,(12) while for the photometric technique the range was approximately 60 - 110 mb.

The most accurate remote method of pressure determination is spectroscopy where the pressure effect on spectral line broadening can be observed. With certain assumptions it can be shown that the line width for weak line absorption depends on gas particle density, while for strong line absorption it depends on both pressure and density. In principle, then, measurement of the line width for both lines can determine both the total abundance of absorbing gas and its total surface pressure, assuming some atmospheric profile. When this method was applied to the Martian atmosphere using weak CO_2 bands at 8700 Å and strong bands at 1.57 and 1.60 μ, the calculated minimum pressure varied between 4.2(13) and 6.4 mb,(9) on the assumption that the atmosphere was pure CO_2.

Although these last pressure values were consistent with the observed CO_2 pressure (∿ 10 mb), most investigators felt that the Mars atmosphere, like that of the Earth, contained a preponderance of nitrogen which, owing to its spectroscopic inertness, had never been identified directly. The accepted value of the surface pressure centered about 85 mb, with the 4-6 mb values considered as possible lower limits.

The Mariner IV occultation experiment confirmed the earlier estimate of CO_2 abundance, but indicated that CO_2 is a major constituent of the Martian atmosphere. The possibility of a large admixture of A (up to 50%) or N_2 (up to 20%) is, however, not excluded by the data. A total surface pressure of 5-10 mb is consistent with the occultation data. Values for the surface number density and mass density have also been calculated from this data.

The Mariner IV occultation experiment yielded the first glimpse into the actual structure of the Martian atmosphere by obtaining data which refer to distinctly different regions of the atmosphere. Based upon certain plausible assumptions, the occultation data provides a measure of the scale height in the lower atmosphere from which temperature can be derived. In addition an ionosphere was detected with a peak density of about 10^5 electrons/cm^3 occurring near 120 km, a plasma scale height of about 25 km, possibly a secondary density peak near 100 km, and a nighttime electron density of less than 10^3 cm^{-3}.

While nothing is known explicitly about the properties of the neutral atmosphere at these upper altitudes, models have been proposed which attempt to predict them based on the measured electron density profile. These models rely on an understanding of the physical processes in the Earth's atmosphere. The two principal stable layers in the terrestrial ionosphere are the E and F regions, with the latter actually subdivided into F_1 and

F_2. Substantially different physical models apply to each of these regions, and it is not clear which one, if any, fits the observed character of the Martian ionosphere. Most of the work for Mars has been done on E- and F_2-type models, although many aspects of both models seem inappropriate. Typical values for neutral number density (CO_2) predicted by these two models differ by as much as three orders of magnitude at 100 km, while for temperature the two models differ by nearly 100°K at 100 km and 300°K at 300 km.

The only measure of dynamic processes in the Mars atmosphere is based on the telescopic observation of clouds and dust storms from which a peak wind speed of 150-200 meters/sec has been estimated.

Flyby Mission Experiments

Atmospheric composition at 300 km and above is measured directly with a mass spectrometer on board the flyby vehicle. IR, visible, and UV spectrometers provide indirect measurements of the composition profile from the same vehicle. The atmospheric drag probes add data on the composition profile by making mass spectrometer and UV radiometer measurements along the vehicle path during descent. Mass spectrometer measurements will be complicated by the presence of ablation products but their usefulness cannot at this time be eliminated. Repeated occultation measurements made with the orbiter probe determine lower atmosphere refractivity from which composition may be inferred. Gas chromatographs on board the MSSR and lander probes provide intermittent measurements of the atmospheric composition at two different points on the surface during the lifetime of the stations.

An ultraviolet polarimeter aboard the orbiter provides information on the presence and structure of aerosols by examining the optical properties of the atmospheric medium. Part of the MSSR probe mission includes the return of a near surface aerosol sample to the M.M.

The parameter whose study will be given the widest coverage is temperature. Both the M.M. and the orbiter are equipped with infrared and microwave radiometers which measure surface temperature. While measurements from the flyby vehicle are confined to the hour or so bracketing encounter, the orbiter with a nominal lifetime of one year and a near polar orbit will obtain a synoptic survey of surface temperatures at all latitudes of the planet rotating through its orbital plane. Surface temperature is also continuously monitored by the weather stations on the MSSR and lander probes which will be emplaced at locations far apart, say near the pole and in the equatorial region. Sounding rockets launched from the lander probe site to altitudes of 30 km at intervals of a month or so will record the temperature profile in the lower atmosphere. Indirect measurements of the temperature profile both in this altitude range as well as at ionospheric altitudes will be obtained from repeated radio occultations of the orbiter in a manner similar to that of Mariner IV. Temperature profiles in the lower atmosphere will also be measured from the drag probes once they decelerate to the region of Mach 1 velocities.

Direct pressure measuring instruments are included in the drag probe payload to record the profile in the lower atmosphere. Similar instrumentation is included in the weather station package, as well as on the sounding rockets.

Neutral atmosphere density measurements are made on the drag probe. Three axis accelerometers record the deceleration profile, from which the upper atmosphere density profile can be inferred. Density measurements in the lower atmosphere are inferred from the refractivity values determined by the orbiter occultation experiment. Depending on the orbit geometry, this may cover a wide range of latitudes and longitudes.

A broad synoptic survey of the ionospheric profile will be obtained from occultation measurements, as well as from the topside sounder aboard the orbiter. The topside sounder aboard the M.M. will probe the upper ionosphere during encounter. Repeated local measurements will be performed with ionosphere sondes at the weather stations.

The above summary indicates that the structural parameters of the Martian atmosphere will be sampled over a wide range of positions on the planet's surface and above it, with the possible exception of the intermediate altitude range between $\sim$ 30 km and the ionosphere. This should facilitate a fairly reliable reconstruction of the planet's atmosphere upon successful completion of the flyby mission.

The dynamic processes in the atmosphere will be explored primarily through photographic techniques. Relevant clues to the general circulation pattern of the Martian atmosphere will be obtained from photography of clouds and their motion from the orbiter and, to a lesser extent, the M.M. This approach has been found to be of great utility with Earth circling weather satellites. These observations on a planetary scale will be supported by local surface wind measurements and cloud photography at the weather stations.

Figure 3 summarizes the meteorology experiments and applications discussed here.

	APPLICATION
● FLYBY VEHICLE	
I.R., VISIBLE, AND U.V. SPECTROMETRY	COMPOSITION, STRUCTURE
I.R. & MICROWAVE BOLOMETRY	SURFACE TEMPERATURE
MASS SPECTROMETER	COMPOSITION
TOPSIDE SOUNDER	IONOSPHERE PROFILE
CLOUD PHOTOGRAPHY	CIRCULATION
● AERO-DRAG PROBE	
ACCELEROMETER	DENSITY PROFILE
COMPOSITION PROBES	COMPOSITION PROFILE
THERMODYNAMIC PROBES	TEMPERATURE AND PRESSURE PROFILE
● ORBITER	
OPTICAL AND RADIO SENSORS	SURFACE TEMPERATURE SCAN ATMOSPHERIC SCATTERING
TOPSIDE SOUNDER	IONOSPHERE DENSITY PROFILE
RADIO OCCULTATION	STRUCTURE OF IONOSPHERE & LOWER ATMOSPHERE
CLOUD PHOTOGRAPHY	CIRCULATION
● WEATHER STATIONS ON MSSR & LANDER SITES	
THERMODYNAMIC PROBES	TEMPERATURE AND PRESSURE
COMPOSITION PROBE	COMPOSITION
ANEMOMETER	WIND VELOCITY
IONOSPHERE SONDE	IONOSPHERE PROFILE
CLOUD PHOTOGRAPHY	LOWER ATMOSPHERE CIRCULATION
● SOUNDING ROCKET	
THERMODYNAMIC PROBES	TEMPERATURE & PRESSURE PROFILE

FIGURE 3 – EXPERIMENTS IN METEOROLOGY

D. Photography Experiment

Photography as an experiment is not an end in itself, but rather it supports the three scientific disciplines - biology, geophysics, and meteorology - which categorize the experimental program for the investigation of Mars. In its supporting role, then, the requirements for photography - and here we include imagery at other than visible wavelengths - will be set by these three disciplines. Imagery showing the planet surface ranging from its gross shape down to the nature of its microrelief is considered part of geophysics. Imagery of the atmosphere at various wavelengths showing cloud coverage and temperatures is considered part of meteorology. Finally, while there may be no photography which bears directly on biology, certainly photographic information does aid in the description of the general environment which will be investigated for life forms. Telescopic photography, of course, supports the en route astronomy program.

The best earth-based photographs of the Mars surface obtained to date have been at a resolution of about 80 km. Infrared scans to record surface temperature are capable of resolving little more than one tenth of the planet diameter. Mariner IV photography, while covering only about 1% of the surface at no better than 4 km resolution, proved to be a major step in our understanding, destroying old myths about Martian "canals" and revealing instead a moon-like cratered surface. Major questions such as the nature of the darkening wave still remain and will probably continue to puzzle us until such barriers as the Earth's atmosphere and the large Earth-Mars distance are surmounted.

Camera Systems and Objectives

The photography experiment area includes nine imaging instruments, or cameras, each considered to be a separate experiment. Figure 4 shows the cameras used on each spacecraft and the primary objectives of these experiments. The following paragraphs describe the objectives, camera type, and expected performance of the photography experiments.

1. Telescope Camera

The primary objective of this experiment is to provide probe targeting data. This requires high angular resolution to obtain data early enough to be useful and multispectral capability because the targeting data will consist of photographs and spectrographs in the UV, visible and IR regions. A telescope of this size has many secondary experiment objectives. These include measuring the shape of the planet, obtaining photographs of geologic processes, taking high resolution photographs during flyby, and making

● FLYBY VEHICLE	
TELESCOPE CAMERA	EARLY MULTISPECTRAL DATA FOR PROBE TARGETING
WIDE ANGLE CAMERA	WIDE AREA HIGH RESOLUTION MAPPING PHOTOGRAPHS
MULTISPECTRAL CAMERA	MULTISPECTRAL PHOTOS FOR COMPARATIVE SURFACE IDENTIFICATION
I.R. IMAGING RADIOMETER	MAP OF SURFACE BRIGHTNESS TEMPERATURE AT SEVERAL WAVELENGTHS
● ORBITER PROBE	
PHOTO SUBSYSTEM	SUPPLEMENTARY PHOTO COVERAGE AT ALL LATITUDES
TELEVISION SUBSYSTEM	SYNOPTIC COLOR PHOTOS OF SEASONAL CHANGES
● MSSR PROBE	
RECOVERED FILM CAMERA	HIGH RESOLUTION COLOR PHOTOS OF LANDING SITE
FACSIMILE CAMERA	LANDING SITE PHOTOS BEFORE SAMPLE ACQUISITION
● LANDER PROBE	
TELEVISION CAMERA	PHOTOS OF CHANGING SKY AND SURFACE CONDITIONS

FIGURE 4 – PRIMARY OBJECTIVES OF PHOTOGRAPHY EXPERIMENTS

multispectral reflectance and polarization measurements of the surface. Cloud coverage, structure, color, motion, temperature and composition can also be measured. Astronomy objectives include observing the moons of Mars at close range, charting asteroids, observing interplanetary dust and using the multispectral capability to make stellar brightness measurements over a wide wavelength band. If the telescope can be adapted to solar observations, stereo photographs of the sun can be taken in conjunction with Earth orbiting telescopes.

A diffraction limited reflecting telescope with a single primary mirror of one meter aperture is considered for this experiment. For some purposes it would be operated docked to the flyby vehicle; for long exposures it would be undocked from the manned vehicle and pointed remotely or automatically.

This telescope would provide photographic resolution from Earth orbit about equal to that of the best available earth-based telescope (80 km). Photographs at encounter have better than 1 meter resolution compared with 4 km resolution available from Mariner IV.

2. Wide Angle Camera

The primary objective of this experiment is to take high resolution photographs of a wide swath of the surface at encounter. Either a conventional wide angle aerial camera or a moving film strip camera could be used. The conventional camera has a wider field of view but is somewhat more complex and bulkier than a strip camera providing the same resolution.

A large wide field camera can provide surface resolution of about 1 meter near periapsis and covers a swath initially stretching from horizon to horizon and narrowing to about 600 km near the terminator. This experiment generates more photographic data than all others combined.

3. Multispectral Camera

The objective of the multispectral camera is to photograph the surface at encounter in various bands of the UV and visible spectrum at various polarization angles. These data are used to help identify the surface type by comparison with known surfaces.

A conventional multi-lens aerial camera could be used to expose up to 16 pictures of the same area through various filters onto the same piece of film. A separate film might be needed if it is desired to extend coverage into the IR region.

Because of the small film size and wide field of view, the surface resolution is only about 100 meters. This is three orders of magnitude better than that obtainable from Earth and forty times better than the very limited multispectral coverage provided by Mariner IV. Multispectral and multipolar measurements can be made at phase angles up to about 90°, well beyond the 43° obtainable from Earth. This may improve the discrimination in identifying surface composition.

4. Infrared Imaging Radiometer

The purpose of this mechanically scanned infrared imaging system is to provide a map of the brightness temperature of the surface at several wavelengths during encounter. This provides a means of localizing anomalous temperature variations as possible locations of volcanic activity and life and, in conjunction with the multispectral camera and an IR spectrometer, provide a possible means of mapping regions of similar molecular composition.

The IR radiometer is similar to those used on the Nimbus satellites but with larger optics and possibly cryogenically cooled detectors. Up to six wavelength bands would be used with a field of view approximating 90° being scanned. The scanner optical axis would point generally downward like the wide angle and multispectral cameras, but scanning would continue across the entire face of the planet rather than stopping at the terminator.

The resolution of the surface brightness temperature maps can be three to four orders of magnitude better than obtainable from Earth and can include wavelengths not possible at the Earth's surface. It is also possible to measure surface temperatures on the dark side, thereby providing data for analyzing the thermal properties of the surface.

5. Orbiter Photo Subsystem

The objective of the orbiter probe photo subsystem is to take moderate resolution photographs not possible from the flyby vehicle. The polar orbit of the orbiter probe provides accessibility to almost all latitudes and enables the photographs to be taken at different sun angles.

The photo subsystem is essentially that used on the Lunar Orbiter with some modifications to increase the picture readout rate. Since communications limit the time available for transmitting pictures, it is desirable to transmit them at a high rate when the communication distance to the M.M. is short.

The orbiter photo subsystem will provide photos with about 7 meter resolution - about 500 times better than Mariner IV. It can take vertical photos of the polar regions and the landing sites of all the other probes.

6. Orbiter Television Subsystem

The objective of the orbiter probe television experiment is to provide synoptic color photos of the seasonal changes in the Martian surface and atmosphere.

A three-color slow scan vidicon camera using color-separating mirrors or filters is considered for this experiment. The television camera has a demonstrated long life capability and a data output compatible with communications direct to Earth. The television camera might use the lens of the photo subsystem, operating only after the photo experiment was completed.

With this lens the surface resolution would be over 100 times better than Mariner IV. Design lifetime of the experiment is one-half of a Martian year, thereby giving coverage of all four seasons since both hemispheres are observed.

7. Recovered Film Camera

The objective of this experiment is to provide high resolution color stereo photographs of the MSSR landing site showing the interaction of the probe and the surface. Pictures of retrorocket cratering, footpad penetration, sample acquisition, and dust deposits on the spacecraft will provide information about the mechanical properties of the soil. These photos will also provide useful data on the surface area in which the return samples are collected.

A small conventional camera, possibly using both color and fine grain black and white film, would be mounted on an articulated arm. The spacecraft programmer would control the picture taking sequence and then cause the camera to deposit the film magazine in the rendezvous rocket for return to the flyby vehicle.

This camera can provide the very high surface resolution (∿1 mm) needed to view the surface microrelief directly. It is adaptable to artificial illumination so that pictures can be taken immediately after landing in the dark before the wind disturbs the surface interactions.

8. Facsimile Camera

The primary objective of the facsimile television camera on the MSSR is to provide a panoramic photograph of the landing site so that the astronauts can target the surface samplers to the most promising areas. This camera has a number of secondary objectives including making stereo measurements of the surrounding topography at various sun angles, observing the deployment of the other experiments, and observing changing sky and surface conditions.

A mechanically scanned facsimile television camera is necessary to meet the primary objective of this experiment because it can make a panoramic picture in a single quick scan. Other television cameras produce narrow field pictures which must be mosaiced into a panorama. The facsimile camera can probably also be adapted to make narrow field pictures if these are more applicable to the secondary objectives.

Cameras of this type have been used on the Russian moon landing probes and produce angular resolutions of ∿3 milliradians. At the minimum range to the surface, this camera would give a surface resolution of ∿5 mm.

9. Television Camera

The primary objective of the television camera on the lander probe is to observe the local terrain and sky conditions. It has secondary objectives similar to the MSSR facsimile television camera.

Because a quick panoramic scan is not needed before sample collection, this camera need not be a facsimile camera. It is likely that a facsimile camera would be used unless a conventional vidicon television camera such as on Surveyor proves much more adaptable to the secondary objectives. The Surveyor camera provides higher resolution (∿1/2 milliradian) but is heavier and bulkier.

E. En Route Experiments

In addition to the observations of Mars itself, there are many scientific measurements of prime importance to be performed going and coming back which this mission will make possible for the first time. Three such experiments of especial interest will be: 1) stereo photographs of the sun, 2) close range photographs of the moons of Mars, and 3) sampling of micrometeoroids in the asteroid belt between Mars and Jupiter.

The complex physical processes occurring in the sun's visible surface are as yet largely unexplained. We know that the photosphere (the inner brightest region) is characterized by granulations, super granulations, and weak magnetic fields, but we need to resolve them to smaller dimensions and analyze their velocity patterns. We know that the chromosphere (the much hotter layer between the photosphere and the outer corona) exhibits cell structures and spicules with large magnetic fields, but we need to resolve the microstructure of the cells and analyze their vertical and horizontal velocity components and oscillatory behaviour. Similarly, much study at high resolution of flares throughout their lifetime, sunspots, and prominences is especially important in learning to predict the very large solar events.

The first diffraction limited space telescope of about one meter diameter placed outside the Earth's atmosphere will make a large contribution toward solving many of the above problems. This telescope should improve by about three times the best resolution heretofore achieved on the Earth, which is limited by turbulence in the atmosphere to the equivalent of about a 12-inch telescope in space. This pushes the resolution on the sun in the visible from about 750 km down to 250 km. The resolution for low contrast surface features on the sun is somewhat less than what the actual diffraction limit would allow.

The Mars flyby mission should offer a great bonus to this type of solar observation by making possible the simultaneous observation of the sun by two one meter diffraction limited telescopes, one on the Mars Mission Module and one in Earth orbit. By choosing observing times during the early and late phases of the mission, stereo angles between the two telescopes subtended by the sun of from 5° to 20° can be utilized for about 30 days. By time synchronizing the photographs from the two telescopes, accurate three-dimensional constructions can be made over the entire field of view of details of the sun's surface at high resolution. Furthermore, by taking timed sequences of exposures, velocities of movement throughout the three dimensional field can also be constructed. This could also be done at selected wavelengths to look preferentially at different depths or phenomena, such as flares at $H\alpha$. Thus, the combination of high resolution and stereo observation promises a wealth of valuable information which at present cannot be obtained.

The close range telescopic photographs of the moons of Mars, Phobos and Deimos, may tell us a good deal about the environment of Mars and the origin of Mars and its moons. Specifically, we are anxious to know their shape, spin behaviour, and surface characteristics. While many observations of these satellites have been carried out from Earth, little is known of their surface appearance or structure. A detailed observation of any new body in the solar system greatly increases our total knowledge (we have thus far been able to observe only two closely - the Earth and the moon).

Since the spacecraft passes close to Mars it will pass well within the orbits of its moons, the nearest approach to them depending upon their phase. The one meter telescope could resolve structure smaller than five meters on their surfaces at closest approach. While prime observing time for Mars may preclude observing Phobos and Deimos with the one meter telescope during the few hours they will be within 50,000 miles, some division of time should be worked out that gives good coverage of both.

The last major en route experiment is the sampling of micrometeoroids in the asteroid belt. The spacecraft will enter into the belt and will provide an opportunity to measure the flux, velocities and energies of these particles. If an in situ chemical analysis can be carried out on some of the trapped particles, a valuable clue as to the source and possibly the epoch of origin of such asteroidal matter would be provided. This would be useful in explaining the origin and evolution of the solar system.

V. SAMPLE PAYLOAD

The purpose of this section is to show an experiment payload which illustrates the potential of a manned flyby mission to Mars. The elements of the payload, namely the on board instruments and the probes, are such that the combination selected will provide a broad experimental attack on the scientific and technological questions posed earlier in this report. The question of whether this sample payload represents a meaningful probe mix will be discussed at the close of this section.

A. Flyby Vehicle

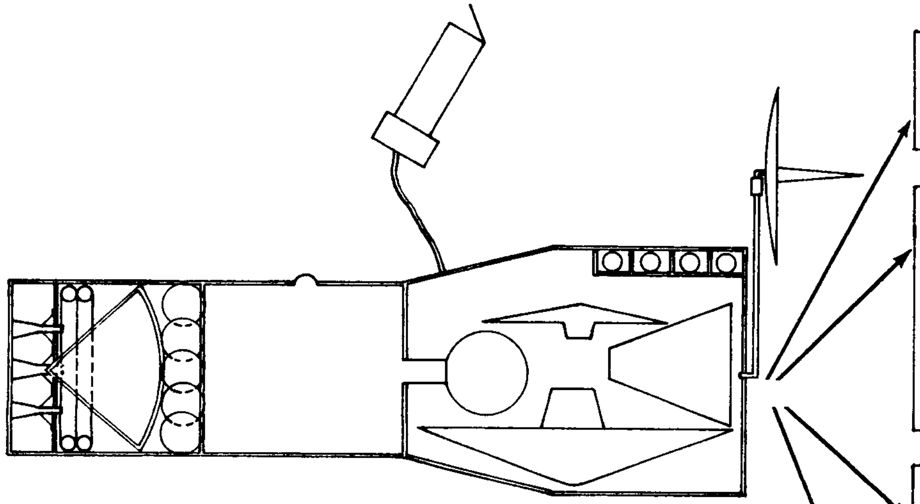
Figure 5 summarizes the classes of observations of Mars which will be carried out on board the flyby vehicle. The individual experiment equipments are grouped according to major experiment area, as discussed earlier. The weight numbers shown are for the detectors and sensors alone and do not include the weight for necessary power, structures, etc. A measure of the information expected from each experiment group is indicated wherever it is felt justified. Obviously the greatest data producers are the photographic experiments. In terms of the value of the data the returned sample has the highest priority.

The drawing on Figure 5 indicates the conceptual design of the manned flyby vehicle. Briefly, the large volume to the right shows the probe storage hangar, the blank volume in the center is the astronaut living and working space, and the volume to the left contains life support system storage, the Earth reentry vehicle, and spacecraft propulsion. The 40" aperture optical telescope is shown operating in a tethered mode above the manned vehicle.

Much of the spectrometer and radiometer remote sensing instrumentation carried on the flyby vehicle is duplicated on the orbiter probe. Its value here is that a better instrument can be used on the flyby vehicle to make a few sample measurements that may ultimately serve as calibration information for the probe carried experiments.

B. Drag Probe

Figure 6 summarizes the experiment payload and the subsystem weights for the aerodynamic drag probe. Meteorology is the only experiment area investigated by this probe, but the combination of its relatively light weight, simplicity, and the potential benefits of early return of data (in advance of the final midcourse corrections for the lander and MSSR probes) makes this probe a useful investment. As several different regions of the atmosphere may warrant investigation by this technique, three probes are included in the sample payload.



ON BOARD INSTRUMENTATION WEIGHT

BIOLOGICAL LABORATORY		2000 LBS
40" TELESCOPE, CAMERA, & FILM		3500
WIDE ANGLE CAMERA		500
MULTISPECTRAL PHOTOGRAPHY		70
MULTISPECTRAL CAMERA	30 LBS	
IR IMAGING RADIOMETER	40 LBS	
SPECTROMETER & RADIOMETER INSTRUMENTATION		110
ADDITIONAL METEOROLOGY INSTRUMENTATION		42
EN ROUTE EXPERIMENTS		1315
TOTAL		7537 LBS

SAMPLE RETURN

BIOLOGICAL LABORATORY	2000 LBS	

PHOTOGRAPHY

40" TELESCOPE & CAMERA	3000 LBS	3×10^{12} BITS DURING FLYBY
WIDE ANGLE SURFACE AND CLOUD PHOTOGRAPHY	500 LBS	10^{13} BITS DURING FLYBY
MULTISPECTRAL SURFACE AND CLOUD PHOTOGRAPHY	70 LBS	10^{11} BITS DURING FLYBY

GEOPHYSICS

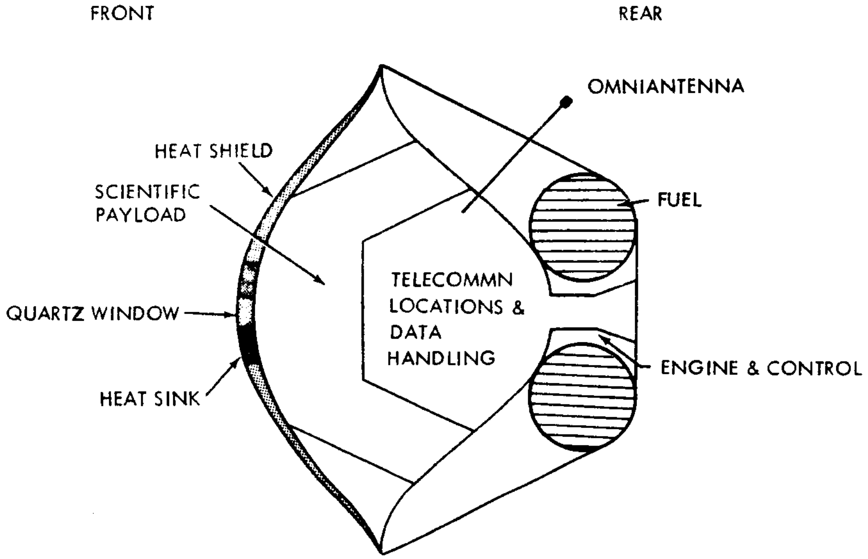
I.R., VISIBLE, U.V., & GAMMA RAY SPECTROMETERS; I.R. & MICROWAVE RADIOMETERS.	110 LBS*	5×10^8 BITS DURING FLYBY

METEOROLOGY

I.R., VISIBLE & U.V. SPECTROMETERS; I.R. & MICROWAVE RADIOMETERS;	110 LBS*	5×10^8 BITS DURING FLYBY
U.V. POLARIMETER; TOPSIDE SOUNDER	35 LBS	
MASS SPECTROMETER	7 LBS	10^5 BITS DURING FLYBY

*COMMON INSTRUMENTATION

FIGURE 5 – FLYBY VEHICLE



METEOROLOGY

ACCELEROMETERS
PRESSURE TRANSDUCERS
TEMPERATURE PROBES
RADIOMETER
MASS SPECTROMETER

16 LBS 10^4 BITS

GROSS LAUNCH WEIGHT 173 LBS

DIAMETER	36"
$M/C_D A$	.17 SLUGS/FT^2
EXPERIMENTS	18 LBS
COMMUNICATIONS	13 LBS
STRUCTURE AND HEAT SHIELD	25 LBS
PROPULSION	52 LBS
STERILIZATION CANISTER	65 LBS

FIGURE 6 – AERODYNAMIC DRAG PROBE (IMPACTER)

C. Orbiter Probe

The experiment equipment and subsystem weights for the orbiter probe are illustrated in Figure 7. In summarizing the data expected from each type of experiment, the nomenclature "bits during flyby" refers to the total number of bits of information transmitted from the probe to the manned spacecraft. Bits per second, or "BPS", refers to the bit rate for transmission directly to Earth. The total number of bits will depend on the actual lifetime of the system. A period of one to two years would be desirable to cycle through a full Martian season.

It will be noticed that an additional experiment area, namely "space environment", has been added to the payload description for this probe. These two experiments are more concerned with the environment the planet moves through than Mars itself, and in a sense they use the planet's motion to carry them around the sun.

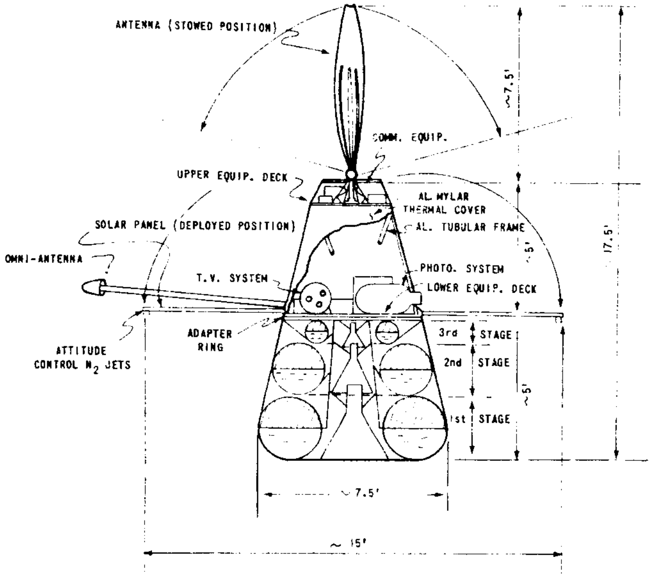
One orbiter probe is included in the payload. The experiment complement aboard the orbiter investigates each major experiment area directly except sample return. Even here, however, the photographic information should provide at least indirect evidence of any Martian biota, which is the prime objective of the sample return.

D. Mars Surface Sample Return Probe

The MSSR probe, shown in Figure 8, is capable of investigating directly each of the four major experiment areas. 4084 lbs of its landed payload go into sample return (4016 lbs for the rendezvous vehicle and 68 lbs for the sample collection mechanism). This probe returns approximately 2 lbs of Martian surface material to the flyby spacecraft. 8 oz of this material is analyzed in the on board biological laboratory as soon as possible. The complete sample is analyzed in greater detail at the end of the mission either on Earth, in Earth orbit, or in lunar orbit, depending on back-contamination requirements.

The film from the panoramic color camera is returned to the flyby spacecraft with the surface sample. Terrain photography is transmitted to the M.M. during planet flyby, ultimately switching to a direct Earth link.

The geophysics and meteorology experiments operate as remote surface instrument packages sharing a common power and telemetry system for communication directly to Earth. These experiments are deployed in the immediate vicinity of the descent stage of the MSSR after the ascent stage has been launched.



GROSS LAUNCH WEIGHT = 10,766 LBS

PHOTOGRAPHIC AND GEOPHYSICAL PAYLOAD	294 LBS
POWER SUPPLY SYSTEM	172 LBS
COMMUNICATIONS SYSTEM	130 LBS
STRUCTURAL AND MECHANICAL SYSTEM	59 LBS
ATTITUDE CONTROL SYSTEM	63 LBS
PAYLOAD-BUS INTEGRATION	75 LBS
TOTAL PROBE WEIGHT IN ORBIT	793 LBS
STERILIZATION CANISTER	276 LBS

PHOTOGRAPHY

CAMERA	150 LBS.	10^{11} BITS DURING FLYBY
TELEVISION	54 LBS	10^4 BPS TO EARTH

GEOPHYSICS

MAGNETOMETER, GAMMA-RAY SPECTROMETER	20 LBS	500 BPS TO EARTH
GEODESY (TRACKING FROM EARTH & M. M.)		
I.R. & MICROWAVE RADIOMETERS	25 LBS*	200 BPS TO EARTH

METEOROLOGY

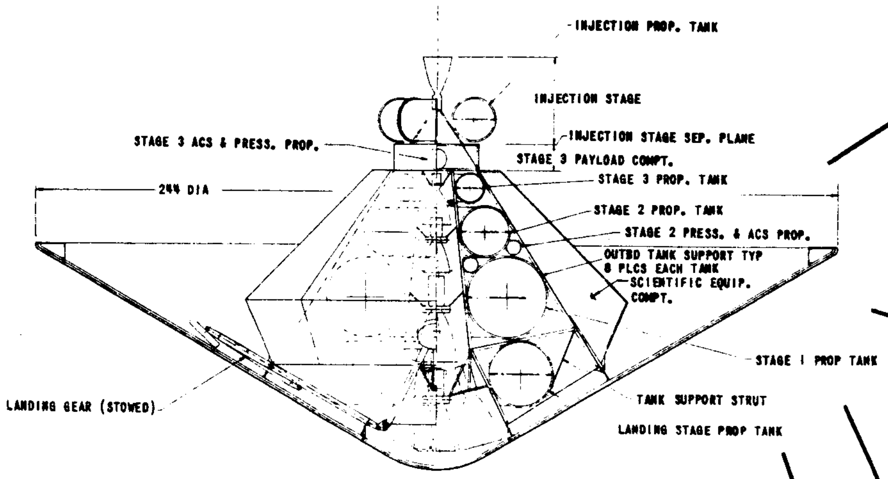
TOPSIDE SOUNDER, U.V. POLARIMETER,	35 LBS	1000 BPS TO EARTH
I.R. & MICROWAVE RADIOMETERS	25 LBS*	

SPACE ENVIRONMENT

SOLAR WIND MICROMETEOROID DETECTORS	10 LBS	< 100 BPS TO EARTH

*COMMON INSTRUMENTATION

FIGURE 7 – ORBITER PROBE



GROSS LAUNCH WEIGHT = 12,538 LBS

STERILIZATION CANISTER	1,013 LBS
INJECTION PROPULSION	1,154 LBS
ENTRY SHELL	1,450 LBS
RETRO PROPULSION	2,265 LBS
SPACEFRAME	1,680 LBS
RENDEZVOUS VEHICLE	4,016 LBS
FLIGHT CONTROL, COMMUNICATIONS, AND POWER	692 LBS
SAMPLE COLLECTION AND SURFACE EXPERIMENTS	268 LBS

SAMPLE RETURN

SAMPLE ACQUISITION AND RENDEZVOUS VEHICLE	4084 LBS	2 LB SAMPLE RETURNED TO EARTH 8 OZ ANALYZED DURING FLYBY

PHOTOGRAPHY

PANORAMIC COLOR CAMERA	20 LBS	10^{11} BITS AT FLYBY
TERRAIN PHOTOGRAPHY	10 LBS*	10^{8} BITS AT FLYBY
SEASONAL TERRAIN PHOTOGRAPHY	10 LBS*	10 BPS TO EARTH
SYNOPTIC CLOUD PHOTOGRAPHY	10 LBS*	500 BPS TO EARTH

GEOPHYSICS

SURFACE EXPERIMENTS	105 LBS	500 BPS TO EARTH

SEISMOMETER, MAGNETOMETER
HEAT FLOW EXPERIMENT, DRILL, SOLAR PROTON & MICROMETEOROID DETECTORS, SOIL MECHANICS EXPERIMENT

METEOROLOGY

SURFACE WEATHER STATION	20 LBS	10 BPS TO EARTH
IONOSPHERIC SOUNDER	45 LBS	10 BPS TO EARTH

*COMMON INSTRUMENTATION

FIGURE 8 – MARS SURFACE SAMPLE RETURN PROBE

A single MSSR probe has been included in the present payload.

E. Lander Probe

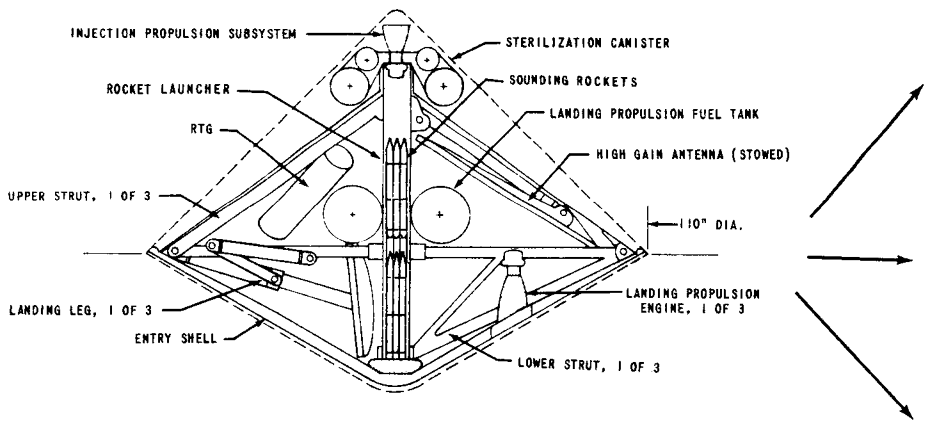
The lander probe experiment payload and subsystem weight breakdown are illustrated in Figure 9. The experiment payload here is essentially the same as that for the MSSR with the exception that it carries several small atmospheric sounding rockets instead of a sample return system. The function of this probe is to deliver a surface monitoring instrument package some place sufficiently removed from the MSSR delivered package to sample another part of the Mars environment. Without the return sample capability, this can be done for about 1/5 the weight of the MSSR probe.

Several examples of the desirability of separated surface landings may be cited. Simultaneous weather stations operating on opposite sides of the equator and at the poles would provide a clearer picture of planet-wide meteorologic phenomena. In the geophysics experiment area simultaneously operating seismic stations spaced several hundred to a thousand kilometers apart (three stations would be desirable) would aid in locating the source (areographic position and depth) of possible seismic disturbances. In order to determine the average surface heat flow, representative measurements should be made in the distinctly different terrain types. With the little we know about the surface at this time, probably all we can say is that heat flow measurements in both the bright and dark areas would be desirable. Finally, whether there is an appreciable internal magnetic field or not, it would still be worthwhile having magnetometers operating on opposite sides of the equator and at least at one pole to monitor magnetic disturbances due to the solar wind interaction with the planet.

A single lander probe is included in the sample payload.

F. Payload Mix

Figure 10 summarizes the elements of the sample payload and their respective weights. The weight figures listed under the column labelled "scientific payload" include only the instrument weights and not any of the supporting subsystems. The figures for probe weight under the "gross weight" column include the entire weight of the probe and its sterilization canister as it is stored in the flyby vehicle hangar. The weights for the experiments aboard the flyby vehicle itself do not include the subsystem support.



GROSS LAUNCH WEIGHT = 2562 LBS

INJECTION PROPULSION (FOR 5 HRS EARLY ARRIVAL)	270
STERILIZATION CANISTER	208
ENTRY SHELL	292
RETRO PROPULSION	484
SPACEFRAME	440
FLIGHT CONTROL, COMMUNICATIONS, AND POWER	588
SOUNDING ROCKET AND STRUCTURE	100
SCIENCE PAYLOAD	180

PHOTOGRAPHY

TERRAIN PHOTOGRAPHY	10 LBS*	10^8 BITS AT FLYBY
SEASONAL TERRAIN PHOTOGRAPHY	10 LBS*	10 BPS TO EARTH
SYNOPTIC CLOUD PHOTOGRAPHY	10 LBS*	500 BPS TO EARTH

GEOPHYSICS

SURFACE GEOPHYSICS SEISMOMETER, MAGNETOMETER, HEAT FLOW EXPERIMENT, DRILL, SOLAR PROTON & MICROMETEOROID DETECTORS, SOIL MECHANICS EXPERIMENT	105 LBS	500 BPS TO EARTH

METEOROLOGY

SOUNDING ROCKET PRESSURE & TEMPERATURE TRANSDUCERS	3 LBS (100 GROSS)	10^4 BITS/ROCKET
SURFACE WEATHER STATION	20 LBS	10 BPS TO EARTH
IONOSPHERIC SOUNDER	45 LBS	10 BPS TO EARTH

*COMMON INSTRUMENTATION

FIGURE 9 – LANDER PROBE

		SCIENTIFIC PAYLOAD	GROSS WEIGHT
● ORBITER (1)	PHOTOGRAPHY (CIRCULAR)	204 LBS	
	ATMOSPHERE, PARTICLES AND FIELDS, SURFACE PROPERTIES	90	10,766 LBS
● IMPACTERS (3)	ATMOSPHERIC	54	519
● LANDER (1)	GEOPHYSICS AND PHOTOGRAPHY	180	
	ATMOSPHERIC SOUNDER	3	2,562
● MSSR (1)	SAMPLE RETURN	2	
	FILM RETURN		
	GEOPHYSICS AND PHOTOGRAPHY	200	12,538
● FLYBY	40" TELESCOPE AND FILM	3500	3500
	ENCOUNTER EXPERIMENTS	722	722
	EN ROUTE EXPERIMENTS	1315	1315
	BIOLOGICAL LABORATORY	2,000	2,000
	TOTAL WEIGHT		33,922 LBS

FIGURE 10 – EXPERIMENT PAYLOAD

In considering the overall probe mix for this mission, a number of other probe types were studied and eventually eliminated. Examples of these include Ranger-type photographic probes and slow descent atmospheric probes. These were eliminated on the grounds that the four probes selected could provide a better selection of data on the total planet environment within the allowed weight constraints. The total payload weight of about 34,000 lbs shown in Figure 10 is within the margin of allowed payload determined by the flyby mission study (of which this report is but one part).

There are a number of factors, all mutually interdependent, which must necessarily be considered in an attempt to refine the probe mix. One of the more obvious factors is which probe types are amenable to unmanned delivery direct from Earth. The MSSR probe is most critically dependent on the manned flyby mission profile for targeting, sample collection control, and recovery. The drag probes are probably too light weight to enter the discussion -- and they may provide valuable information for MSSR targeting. Both the orbiter probe and the lander concepts are in principle duplicated in the Voyager program, namely, the orbital bus and the capsule lander. Certainly the tradeoffs between these competing modes deserve more study. A more competitive orbiter concept for the manned flyby mission would be one which uses atmospheric braking to remove most of the velocity required to get into orbit.(14) This method could cut the orbiter probe weight by a factor of two and make more use of the astronauts' abilities to target and control the entry maneuvers. However, further study is necessary before this technique and the resulting benefits can be accepted with high confidence.

A second factor affecting the probe mix is the value of data retrieved from each probe type. The preceding discussion in this section has shown that most major experiment areas are attacked on each of the probes, generally from a somewhat different point of view. This makes the sample payload fairly diverse. It may be concluded, however, that sample return from two different regions of the Mars surface on a single flyby mission is the overriding objective, in which case the orbiter and lander probes could be eliminated.

Another factor for consideration is the development cost of four different probe types. Assuming it is desirable to land the geophysics and weather monitoring stations at two different places on the same mission, it might be argued that it would be cheaper to develop just the MSSR, carry two per mission and drop the orbiter, and then put the lander development funds into making the Voyager bus perform the desired photographic mission. In the cost assumption here we imply not only money but also research and development manpower, facilities, etc.

Perhaps all that can be said at this time is that as competing program alternatives become better defined, as we learn more about the planets themselves, and as we learn more about man's capabilities to perform in space, the rationale for what is the best exploration system, even in this limited case, will become better defined. The sample payload indicated here is merely meant to show, within the known constraints of the flyby mission, an experiment program for Mars exploration which could be carried out and would advance our understanding of the solar system in general, and the Martian environment in particular.

VI. CONCLUDING REMARKS

A. Significant Results Gained From Manned Mars Flyby

The experiment program which has been described here offers the potential of providing significant data bearing on what have generally been recognized as the more fundamental and interesting problems of the Mars environment. Solutions to these problems will necessarily provide new evidence in our understanding of the formation and history of the solar system, as well as provide the environmental data critical to the design and planning of advanced manned Mars landing systems. In addition to Mars itself a number of en route experiments have been identified which make good use of the astronauts' observing time and take special advantage of the location of the flyby spacecraft in its orbit about the sun.

Sample return is judged to be the most important experiment for this mission. The return of a sample of the Martian surface, as facilitated by the MSSR probe, seems to offer the greatest possibilities for the quantitative examination of existing or fossil life short of actually landing men on the surface. The question of the existance of extraterrestrial life is one of the major scientific questions of our time.

Specific results which would be derived from sample return would be evidence of the existence of any present or fossil life on Mars, the chemical composition of the surface material in the vicinity of the landed probe, and some of the physical properties of the sample. The biological evidence is of obvious relevance in reexamining our ideas on the development of life on Earth, and in considering the prospects for life on other planets, both within the solar system and beyond. The chemical and physical properties of the sample will be compared with average properties of meteorites and the surface of the Earth and moon to provide yet one more source of data in unraveling the history of the formation of the planets and solar system. These properties will also provide a boundary value for extrapolations concerning the interior properties of Mars.

Photography of Mars during the approach and encounter phases of the mission should be a particularly rewarding endeavor. Photography taken with the aid of the large aperture optical telescope between approximately 2 and 1 days before planetary encounter will provide better coverage for Mars than existed for the moon prior to Ranger VII (1964). Specifically, about 85% of the Martian surface area can be photographed at resolutions better than 1 kilometer. In addition to being able to map the predominant features on the Mars surface, stereo viewing of the entire planet disk at resolutions of about 1 km and smaller portions of the disk at proportionately greater resolutions will allow a determination of the gross shape of the planet. Photography of the surface at greater resolution with the telescope will approach 0.5 meters at encounter for selected areas, while the maximum resolution will be approximately 1 millimeter achieved in viewing the surface microrelief with the soft landed recovered camera system. Close scrutiny of the pattern variations in the wave of seasonal darkening will be maintained with the orbiter probe. This global view coupled with the surface microrelief observations should reveal the nature of the wave of darkening. The orbiter probe can also survey areas of the surface inaccessible to photography of comparable resolution from the flyby vehicle, as well as monitor atmospheric phenomena such as dust storms and the blue haze. Multispectral imagery of the surface and atmosphere, especially at visible and infrared frequencies, will provide additional evidence bearing on the chemical composition and thermal emission properties of the segment of the planet observable from the flyby vehicle near its point of closest approach.

Meteorological observations will be conducted through a series of time sequenced sounding rockets launched from a single point on the ground and continuous surface weather stations operated at the site of each soft landed spacecraft. The objective here is to provide altitude profiles of the critical atmospheric parameters at selected times throughout the Martian season and to supplement these with a continuous record of the weather at selected ground locations, such as the equator and the poles. This information would, of course, be supplemented by photography of atmospheric events such as clouds and dust storms recorded by the orbiter probe. One of the more interesting regions to monitor with a ground station would be an area which, subsequent to probe landing, would be covered by the polar cap. In this way the cap formation process could be monitored locally as well as from the global perspective (orbiter probe). Composition measurements could determine whether the cap is CO_2 or H_2O, and, if it is H_2O, sounding rockets could monitor the atmospheric water vapor content which is being transported to the cap region.

Significant results which could be expected from the geophysics experiment are the determination of whether Mars has a fluid core or not, whether the planet has ever been chemically differentiated (and the history of the differentiation process), and the frequency and magnitude of Mars quakes (and an explanation of their probable cause). Related to this would be a measure of the magnetic field properties, as this would provide the basis for determining whether any observed field is of external or internal origin. Finally, a close measure of the external gravitational field (by tracking an orbiting satellite) would provide evidence for the degree of departure of the planetary body from hydrostatic equilibrium (which is a measure of the internal stresses which must be supported within the planet).

A number of exciting investigations can be carried out as part of the en route experiments program. Stereo photos of the sun will be possible at interesting periods in its activity cycle using similar telescopes in Earth orbit and on board the flyby spacecraft for simultaneous observations. Not only can three-dimensional views of prominences be obtained, but the life history of these visible events can be traced more completely than has been possible to date (the 27 day solar rotation periodically obscures these events from Earth observation). Telescopic views of the moons of Mars near the time of planet passage will provide valuable information on topography, although questions relating to the history of the formation of Mars and its moons will probably have to wait for soft lander probes on Phobos and Deimos. And finally, the possibility of analyzing a sample from the asteroid belts will shed new light on the composition of the major elements of the solar system. Certainly the similarities between the Mars surface sample and the asteroid sample will be of interest in determining what is primary vs what is secondary (meteoroid influx) material.

Figures 11 and 12 summarize the significant results outlined in this section.

B. The Utilization of Man

Appendix A of this report, which deals with the gross aspects of the flyby mission profile, brings to light a number of areas in which the presence of man, with his observational and decision making powers, does in fact contribute quite measurably to the accomplishment of the experiment program objectives. The purpose of this section is to identify a number of specific activities, as they occur chronologically during the mission, and to point out for each activity just what the role of the astronauts is and how this will improve the experiment program. It is not the intent here to deal with the more detailed question of the relative advantages and disadvantages of manned vs unmanned exploration of Mars.

1. One of the functions of the astronauts, which continues throughout the entire approach phase, is probe targeting. Most of this effort is directed towards the MSSR probe, as this probe has the most extensive interaction with the Mars environment and the most important scientific objective, namely, sample return.

Some degree of targeting would certainly have been done before the mission begins, most likely based on data gathered by observing Mars with a 40" telescope, similar to the one proposed here for the flyby mission, during a manned Earth

- SAMPLE RETURN
    - EXISTING OR FOSSIL LIFE FORMS
    - CHEMICAL COMPOSITION
    - PHYSICAL PROPERTIES
- PHOTOGRAPHY:
    - MAPPING 85% OF THE MARTIAN SURFACE WITH RESOLUTION BETTER THAN ONE KM
    - PHYSICAL SHAPE OF THE PLANET
    - SMALL-SCALE SURFACE TOPOGRAPHY
    - SEASONAL VARIATIONS IN THE SURFACE AND ATMOSPHERE
    - MULTISPECTRAL IMAGING OF THE SURFACE AND ATMOSPHERE FOR COMPOSITION AND TEMPERATURE DISTRIBUTION
- METEOROLOGY:
    - ALTITUDE PROFILES OF ATMOSPERIC TEMPERATURE, PRESSURE, DENSITY, AND COMPOSITION
    - LOCAL WEATHER VARIATION AT THE MARS SURFACE

FIGURE 11 – SIGNIFICANT RESULTS GAINED FROM MANNED MARS FLYBY

- GEOPHYSICS:
  - INTERNAL ACTIVITY OF MARS
  - GRAVITATIONAL AND MAGNETIC FIELDS
  - PHYSICAL PROPERTIES OF THE SURFACE AND INTERIOR
- EN ROUTE EXPERIMENTS:
  - TELESCOPIC OBSERVATIONS OF THE MOONS OF MARS
  - STEREOPHOTOGRAPHS OF SOLAR FLARES
  - LIFE HISTORY OF SUN SPOTS
  - MICROMETEOROID COLLECTION IN THE ASTEROID BELTS

FIGURE 12 – SIGNIFICANT RESULTS GAINED FROM MANNED MARS FLYBY (CON'T)

orbital flight. Indeed, it is assumed that prior to manned planetary missions a series of long duration Earth orbital missions will test spacecraft and subsystem reliability and repairability concepts and evaluate man's capabilities to operate effectively in space on planetary missions. In particular, his ability to operate a large optical telescope will be understood before the flyby mission.

In addition to the telescopic photography from Earth orbit for advanced targeting, there will no doubt be some improvement in our knowledge of smaller scale features on the Mars surface as the schedule of Mariner and Voyager flights for the late '60's and early '70's is realized. While supplying valuable data at higher resolution than can be obtained from Earth orbit, such missions are usually limited to covering a small fraction of the planet surface. Also their imagery is generally confined to the visible range, whereas valuable portions of the near IR and UV spectrum may be observed with the large telescope during the approach phase of manned flyby.

At this point in time it seems reasonable to assume that the situation in the mid '70's will be such that we should have global imagery of Mars from Earth orbit, improved high resolution photos (compared to Mariner IV) over a small percentage of the surface, and possibly Mariner IV quality photos over a larger fraction of the surface than is currently available. In other words, without a considerably more ambitious precursor program than is currently envisioned, it is necessary that targeting be carried out during the approach phase.

As improved data is acquired during the approach phase of the mission previous concepts and strategies for targeting may be revised. Two independent factors must be weighed in this process. One is surface topography which directly affects the ability of the spacecraft to land. The second factor is the scientific merit of the site. Here we confine our attention to the MSSR, and consequently the overriding factor will be the prospects for finding life at the proposed site. Assuming we are unable to detect life remotely from these distances, scientific merit will be judged on the basis of observed physical properties which are thought to be most conducive to an active biological community. Possible parameters for consideration are surface temperature, altitude, inferred composition, or albedo. For example, a possible initial targeting strategy might be to land in the dark areas because they are both warmer and at lower altitudes than the light areas. For the sake of argument we will assume that both these qualities lead to more favorable biologic environments. As improved observations are made during the approach phase, two types of analysis will take place. One is fairly mechanical and will lead to improved Mars coordinates (latitude and longitude) for the smoothest dark area in the accessible landing zone. A second more subjective type of analysis may lead to the conclusion, again for example, that dark areas are not the lowlands, but rather the mountains. In this case, the fundamental models of what characterized a biologically favorable area would have to be revised. It would no doubt take considerable training on the part of the scientist-astronaut to recognize this latter problem, but once it was discovered a new targeting strategy could be worked out in conjunction with experts on Earth by transmitting selected photos and supporting data.

Admittedly the degree to which this targeting exercise is employed depends on the amount of information, largely photography, supplied earlier by unmanned missions to Mars. In this context it should be understood, however, that necessary data includes not only high resolution photography for topographic evaluation of the accessible landing zones, but also global data at a variety of resolutions during several different seasonal periods to select the most favorable biologic localities. In any event, it seems that with the immense data gathering capability supplied by the 40" optical telescope during the approach phase of the flyby mission, vital use can be made of the astronauts' time both in the mechanical repositioning of the target area and in the reevaluation of just what constitutes a biologically favorable area.

2. A second astronaut activity which will be carried out at intervals throughout the approach phase will be probe checkout. The most prohibitive assumption here is that the probes will be in sealed sterilization canisters which cannot be opened until the probes are released from the manned spacecraft. Even in this situation checkout via a hard wire link would allow accurate diagnosis of the failure. If an alternate path design approach were used, such a diagnosis would permit the crew to switch vehicle functions to alternate modes and still perform a nominal mission. Alternatively the failure could be at least partially compensated by the use of a back-up mission plan. Looking at an extreme case, if the probe were found to be totally incapacitated prior to its launch, valuable time during the late approach and early encounter phases would not be wasted in useless efforts.

The actual situation may well be better than envisioned above if current efforts to develop a biological isolation suit are successful. This device would permit direct access to the probes by an astronaut without violating planetary quarantine requirements.

3. Approximately 12-18 hours before the manned spacecraft encounters the planet a first midcourse correction is made to the MSSR probe trajectory. Knowledge of the probe trajectory is gained by some combination of optical and radar tracking of the probe and Mars from the M.M.

4. Approximately ten hours before periapsis current data on the atmospheric density profile (and possibly other parameters) will be received from the drag probes. As the MSSR traverses the atmosphere ballistically, its path, and hence the landing point, will be determined by its entry conditions and the atmospheric properties. The drag probe data will be used to update the atmospheric model, and from this the corrected entry point and angle will be determined for the selected surface site. Six hours before periapse passage a second correction to the MSSR probe trajectory will be initiated based on the drag probe data.

5. After the MSSR probe has landed on the Mars surface, the astronauts will take control of the sample collection operation. Based on a panoramic scan of the immediate locality taken by the facsimile camera and transmitted to the M.M., the astronauts can select the most promising areas for sample collection. For example, it may be desirable to collect loose granular material from the surface and subsurface to a depth of, say, one meter, and also a small stone, if there is one accessible. Different mechanical devices will be employed for each type of sampling, and their actions must be guided by the astronauts. A Surveyor-type TV system could be used to provide a sequential view of an experiment operation, such as a small shovel digging a hole in granular material. A logical consequence of selecting a more promising area for sample collection is the avoidance of topographic features which could disrupt the collection mechanism.

6. The command for MSSR ascent stage ignition is given by the astronauts based upon a determination of the relative positions and velocities of the two spacecraft. This determination is made by analyzing tracking data taken on board the M.M. The first two stages of ascent have programmed guidance, but the third stage, which must rendezvous with the flyby vehicle, is controlled from the M.M. by a command guidance scheme. The terminal stage of rendezvous will rely on astronaut vision. Only by keeping the majority of the responsibility for rendezvous at the flyby vehicle can the third stage weight be kept within a modest level. This division of function is utilized since each pound of weight of usable payload in the third stage costs about 300 pounds at probe separation from the flyby spacecraft.

7. Perhaps the most significant use of the astronauts will be the bioanalysis of the returned sample on board the M.M. Within a matter of hours after the surface samples are collected and packed in sealed containers, they will be delivered to a biological laboratory where examination by a trained scientist will take place. For contamination reasons the sample will be contained behind a biological barrier.

The emphasis here is on early bioanalysis. The fact that the return trip to Earth exceeds 500 days leaves little guarantee that any life forms which may exist in the sample when it is collected will survive the journey to an earth-based laboratory without either perishing or at least mutating. Naturally steps will be taken to preserve the sample during the return trip so that its eventual examination in earth-based laboratories can bring to bear the full weight of the biologic community in solving what is at best a difficult problem. It does seem prudent, however, to use a small portion of the sample (and here we have arbitrarily assumed eight ounces) for careful on board analysis as soon as is practical. To say the least, continued analysis during the long return trip may be considered absolutely necessary before returning to the Earth's environment anything which has been in contact with the Mars surface or atmosphere. These activities have been outlined in the Section IV discussion of the sample return experiment, namely, detection and characterization of life, specimen conservation and contamination control.

Whether in fact man can operate as a trained biologist in a functional laboratory in a space vehicle is a subject which will be dealt with in the Earth orbital phase of post-Apollo flights. This is essentially the same statement made regarding manned operation of the large optical telescope during the flyby mission. It does seem, however, that regardless of what measures need be taken (within reason) man's versatility either in the laboratory or at the telescope would demand that he be used wherever and whenever possible. Perhaps this point is most strong in the case for the biologic laboratory, especially as we consider the exceeding difficulty in attempting to define a small and explicit set of measurements which could be made to demonstrate the existence or nonexistence of life.

The above list of activities is not meant to be inclusive; it is meant to show that within the framework of the Mars flyby mission plan, man contributes measurably in a number of different areas towards the accomplishment of the experiment program. Obviously before we can evaluate this mission as an effective use of our resources and time, adequate descriptions of competing candidate missions, both manned and unmanned, must also be analyzed. What can be said at this time, however, is that manned planetary flyby is at least a competitive mode of exploration of Mars based upon both the quantity and quality of scientific and technological data which could be returned.

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REFERENCES

(1) Space Research: Directions for the Future, Space Science Board, NAS, NRC, December, 1965.

(2) de Vaucouleurs, G., Icarus, Vol. 3, No. 3, 1964.

(3) MacDonald, G. J. F., Journal of Geophysical Research, Vol. 67, No. 7, July, 1962.

(4) Opik, E. J., Science, Vol. 153, No. 3733, July 15, 1966.

(5) "Mariner IV Measurements Near Mars: Initial Results," Science, Vol. 149, No. 3689, September 10, 1965.

(6) Fjeldbo, G. et al, Journal of Geophysical Research, Vol. 71, p. 2307, 1966.

(7) Sinton, W. M., The Solar System, Vol. III, Satellites and Planets, ed. by G. P. Kuiper and B. M. Middlehurst, p. 429, U. of Chicago Press, 1961.

(8) Mintz, "Studies of the Physical Properties of the Moon and Planets," Technical Report RM-2769-JPL, p. 81 Rand Corp., 1961

(9) Kaplan, L. D. et al, Astrophysical Journal, Vol. 139, p. 1, 1964.

(10) Dollfus, A., Comp. Rend. Ac. Sci., Paris, Vol. 256, p. 3009, 1963.

(11) Connes, J., P. Connes, and L. D. Kaplan, Science, Vol. 153, p. 739, August, 1966.

(12) Chamberlain, J. W. and D. M. Hunten, Reviews of Geophysics, Vol. 3, p. 299, 1965.

(13) Spencer, D. F., AIAA/AAS Symposium, "Stepping Stones to Mars," p. 532, AIAA, New York, 1966.

(14) Cassidy, D. E., "Atmospheric Braking of an Unmanned Mars Orbiter," Bellcomm Memorandum for File, September 29, 1966.

(15) Bullen, K. E., Nature, Vol. 211, p. 396, July 23, 1966.

PREFACE TO THE APPENDICES

The probe concepts presented in Appendices B-E represent point designs to allow an initial sizing of the Mars flyby mission experiment system. Mission profiles for the probes are also preliminary. The intent here is to examine the questions of feasibility, not to present an optimized system. Using what are judged to be feasible probe systems, a preliminary experiment program has been constructed to provide some measure of the information return from this mission.

Any comprehensive mission system design represents an evolutionary thought process involving numbers of individuals and organizations. Other members of Bellcomm, together with members of NASA, the aerospace industry and the scientific community, have directly contributed to the concept outlined here. The authors wish to acknowledge that, for the sake of completeness, they have utilized much of this effort in the preparation of this report.

APPENDIX A

THE FLYBY MISSION PROFILE: GROSS ASPECTS

The mission description for the purposes of the experiments program begins when the manned spacecraft is on its coast trajectory towards Mars and terminates before arrival back at Earth. The reference mission used here is based on a free return flight leaving Earth in September of 1975, taking about 130 days to reach Mars and another 537 days to return to Earth. The orbital path takes the spacecraft out past the Mars solar orbit to a maximum distance of 2.2 A.U. from the sun. Approximately halfway through the mission the spacecraft and Earth are on opposite sides of the sun.

The flyby geometry at Mars is such that the spacecraft approach asymptote is about 10° off the sun line. The periapsis altitude is about 300 km at a point 13° beyond the terminator on the dark side of the planet. Periapsis velocity is approximately 31,000 fps ($V_\infty \simeq 28{,}000$ fps), or about twice Mars escape velocity. Due to the high flyby velocity, very little angular change is produced in the spacecraft's flyby path. This means that the approach hemisphere is almost fully illuminated, the periapsis view of the planet is biased towards the dark side, and the hemisphere facing the departure path is almost completely in shadow. Flyby occurs on the side of the planet which is rotating towards the approaching manned spacecraft.

It is convenient to divide the entire experiments mission into three phases: approach, encounter, and departure. The encounter phase is defined as approximately ±1/2 day centered around the periapsis time. The following parts of this appendix will deal chronologically with the major events of the experiment mission as they occur during these three phases.

A. Approach Phase

The primary experiment program functions during the approach phase are en route experiments, probe targeting, and probe launch. En route experiments will begin early in this phase and will include telescopic observations of Mars and its moons, observations of the sun, and general astronomy. The telescope referred to here is a one meter diameter, six meter focal length astronomical quality optical telescope. Operating close to its diffraction limit, this instrument will have a resolution of about 10^{-6} radians.

Observations of Mars with this telescope will also provide the information for the on board targeting of the probes prior to their deployment. Resolution of the Mars surface at the beginning of the approach phase will be about equal to the best resolution (∿ 80 km) of the planet ever achieved with earth-based telescopes. Progressively better quality observations of the planet will be made as the approach phase progresses.

The MSSR probe has the most complex mission, and, with its interaction with the Mars surface, constitutes the most demanding targeting problem. Target selection will be made on the basis of scientific interest and probe spacecraft performance. With the high scientific priority on the question of Martian biology, the sample should be collected from a biologically favorable area. Choice of an interesting area for the experiments which make up the remote monitoring station may also influence the selection of a site.

Targeting must also consider several factors related to vehicle performance. First, a shallow atmospheric entry angle must be selected to achieve the necessary aerodynamic braking. Secondly, the general region of landing must be such that sample collection can proceed in sunlight with line of sight communications to the M.M.* It should also place the landed vehicle in the flyby plane at the time of ascent stage liftoff. And finally, within this general region, performance of the descent stage landing system may bias the site selection toward the smoother topographic areas.

Ground resolution at the time of MSSR probe launch is approximately 6 km, which is an order of magnitude better than the best resolution with the same telescope in Earth orbit. Subsequent to launch from the M.M. the probe is tracked on its way to Mars with a combination of optical and radar techniques. Based on this data a first midcourse correction is made some 12-18 hours before planetary encounter. At this time ground resolution with the one meter telescope is 300-450 meters. For the 1975 flyby mission this is the last time the MSSR landing

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*Each probe carries its own experiment package, power supply, data handling system and communications system. The nominal quality of the S-band receiving system on board the Mission Module is such that the break-even point for probe transmission direct to the M.M. vs direct to Earth occurs about one week after encounter. This assumes an earth-based S-band network of Goldstone Mars station quality (210 foot diameter dish).

zone is visible from the M.M. This would suggest the need for either prior unmanned photo reconnaissance of the landing zone at higher resolution to supplement the approach photography, or the consideration of alternate mission modes for the MSSR for which higher resolution targeting could be done.

Much greater flexibility exists in the selection of a site for the lander probe since it does not suffer the constraints imposed by rendezvous with the flyby vehicle. Target selection will be based on scientific interest in the areographic placement of this second monitoring station coupled with a consideration of the vehicle landing performance and local topography. Targeting for this probe continues into the encounter phase and will be considered further in the following section.

Guidance for the orbiter probe is comparatively easy as this probe does not interact appreciably with either the planet atmosphere or surface. The only targeting to be done is what is required to deboost the probe into approximately a 300 km altitude circular polar orbit.

Guidance for the drag probes is also a relatively easy task, namely, to aim for the approximate center of the visible disk. The primary function of these probes is to get improved data on the atmospheric density profile back to the M.M. in time to affect the targeting of the MSSR and lander probes, both of which decelerate aerodynamically and are therefore sensitive to atmospheric drag forces.

The plan described in this report has the drag probes entering the atmosphere around the sub-solar point, and the MSSR entering near the terminator. It is assumed here that prior data, such as repeated occultation measurements from an unmanned orbiting vehicle, would have determined the atmospheric density structure to the extent that the relationship between sub-solar and terminator density profiles is understood. Drag probe data can then provide a current picture of sub-solar entry conditions from which terminator entry conditions can be reexamined.

The drag probe concept envisioned in Appendix B does not make valid measurements for entry angles much less than 90°; in particular, it would be of little use at the low entry angles characteristic of MSSR probe entry near the terminator. If precursory measurements have not provided the data necessary to extrapolate from sub-solar to terminator entry conditions, it is likely that a more complex drag probe scheme needs to be evolved (e.g., one which can make measurements near the terminator).

B. Encounter Phase

One of the first significant events during the encounter phase will be the acquisition of atmospheric data from the drag probes. On the basis of this information final corrections can be made to the MSSR probe entry angle. As the data is obtained approximately six hours before orbit injection for that probe, there may be time for analysis and trajectory retargeting.

Targeting for the lander probe continues well into encounter phase and takes advantage of improved telescopic resolution at the Mars surface. It is assumed that this probe can remain in darkness for the first one-half day after landing, and that it does not have to communicate with the M.M. at encounter. Consequently, landing can occur on the side of the planet rotating away from the approaching M.M. In this geometry good viewing of the prospective site may be available up to about six hours before periapsis giving a ground resolution of approximately 100 meters. The final correction of the lander probe trajectory would be made about one hour before landing.

At approximately six hours prior to M.M. periapsis the planet disk completely fills the film plate of the telescope camera. Beyond this point the astronauts perform selective photography of the planet surface based on a combination of what they presently see and what appeared interesting in previous photos.

Some four hours before M.M. periapsis the photographic orbiter probe becomes operational and begins its photographic mission. Close monitoring by the astronauts on board the M.M. will allow early adjustments to be made in the probe orbit and operational plan to optimize the data return.

The lander probe reaches its destination at approximately this same time. Depending on the amount of astronaut participation required for experiment deployment, this remote monitoring station may not become operational until after the return sample is retrieved.

Remote observations of Mars from the M.M. continue throughout the encounter phase with a substantial drop-off in visible observations in the post-encounter period since most of the observable disk will be in shadow. Due to the high experiment activity on board, especially during the brief period of maximum resolution at the time of periapsis, most of the observations will probably have to be automated, with the astronauts confining themselves to decision making during non-routine occurrences. Remote observations of the moons of Mars, Phobos and Deimos, will also be carried out during this period of time.

The major task during the encounter phase will be execution of the sample collection experiment. Entry and landing of this probe are automatic. Once the landed spacecraft comes into the sunlight, facsimile pictures of the surrounding terrain are transmitted to the M.M. Based on this observational data the astronauts select the appropriate areas for sample collection and then give the necessary commands to proceed with the mission. The final stages of the sample collection experiment are the command for probe ascent initiation, command guidance of the probe to rendezvous with the M.M., and retrieval of the third stage of the ascent vehicle with its sample containers.

Following this the commands are given to deploy and begin remote operation of the surface instrument packages on both the lander and MSSR probes. Initially high data rate capability in monitoring these instruments could provide the basis for adjusting the response of each instrument (frequency range, dynamic range, etc.) to the observed level of the parameter to be recorded.

C. Departure Phase

One of the most important phases of on board activity takes place during departure, namely, the bioanalysis of the returned surface sample. This function will be more or less continuous throughout the entire return mission and has been discussed more fully in the earlier section titled "Sample Return." Also, activity in the en route experiments program resumes during the departure phase. Perhaps the high point of this phase occurs around the midpoint of the total mission (∿ 340 days from Earth) when the M.M. is on the opposite side of the sun from the Earth. Simultaneous observations of the sun may be made at this time from the two positions. The maximum penetration (∿ 2.2 A.U. from the sun) of the spacecraft into the asteroid belts also occurs at this time.

APPENDIX B

ATMOSPHERIC DRAG PROBE FOR A MARTIAN FLYBY MISSION

I. INTRODUCTION

The drag probe is utilized to obtain information about the structure of the Martian atmosphere. It enters the atmosphere with a high velocity, then undergoes continual aerodynamic "braking". In the initial entry phase, accelerometers of different sensitivities measure the deceleration directly, while at the same time a radiometer and mass spectrometer determine atmospheric composition. When the probe has decelerated sufficiently, gauges to measure total temperature and pressure directly are set into operation. In this flight regime the mass spectrometer alone measures atmospheric composition. Combination of accelerometer and composition data, taken in the initial entry phase, with pressure, temperature, and composition data recorded in the final flight phase yields an altitude profile of the atmospheric structure.

A probe of this type, to be launched from Mariner and Voyager vehicles, is presently being developed under the general direction of Ames Research Center.(1) (2)

Knowledge of the thermodynamic state of the atmosphere about ten hours before periapsis is desirable for at least the following reasons:

1. The entry angle of the MSSR, or any other soft landers, could be adjusted to allow for more accurate targeting on the Martian surface.
2. The possibility that the trajectory of low altitude orbiting spacecraft could be adjusted if it were found that the density profile of the atmosphere was significantly different from previous Mariner or Voyager based measurements.

II. MISSION PROFILE (SEE FIGURE B-1)

The probe is separated at time T (measured from M.M. periapsis) from the Mission Module and given a ΔV increment sufficient in magnitude, direction, and accuracy to place it on a collision course with Mars at a predetermined lead time ΔT (time of early probe arrival, measured from periapsis). For an entry angle of 30° or less (measured from the local vertical), tolerable errors at separation are ±2% in magnitude of ΔV, and ±.25° in thrust angle. Figure B-2 shows the relationship between ΔV and lead time ΔT, while Figure B-3 presents the relationship between ΔV and the growth factor.

As an example of the order of magnitude of the relevant parameters, T may be set equal to four days. A ten hour lead time will then require a ΔV of approximately one thousand meters/sec, and the weight of propulsion system necessary will be about fifty pounds.

The constraint on entry angle is desirable for a number of reasons, two of which are:

1. Near vertical entry minimizes the time of descent through the atmosphere, thereby reducing that portion of the error in altitude determination which arises from the length of time spent by the probe in the atmosphere.

2. Near vertical entry minimizes the change in angle between the probe's axis of symmetry and its velocity vector, thereby minimizing the change in drag coefficient with change in altitude.

After the probe enters the atmosphere, it proceeds to make measurements while descending ballistically to the surface. Figure B-4 shows the probe velocity, drag force, communication blackout, and range of instrument operation as a function of altitude for simulated flight through a particular model of the Mars atmosphere.

During a large portion of the descent through the atmosphere, a communications blackout between the probe and the Mission Module exists. Data acquired during blackout are stored and then transmitted, together with the real time data, once communication with the Mission Module is reestablished (probe velocity is then about 3 km/sec).

III. PAYLOAD SUBSYSTEM

The scientific instrumentation selected for this probe is similar to that contained in the Ames drag probe referred to in the Introduction. Table B-1 contains a listing of the instruments, as well as a tabulation of their requirements and capabilities. Table B-2 contains the weight breakdown of the scientific payload as well as that of the other subsystems.

IV. OPERATIONAL SUPPORT SUBSYSTEMS

A. Communications and Data Handling

As pointed out in the Introduction the integrated mission profile of the manned flyby mission suggests the desirability of relatively long ΔT (about .5 days) for the drag probes. Hence, communication ranges of about three hundred thousand nautical miles have to be considered.

The required information rate can be estimated conservatively at 500 bits/second for the transmission of both real time data acquired after exit from blackout and concurrent readout of the data accumulated during blackout. This information rate is due to both wide coverage of the atmosphere as well as reduced communication time due to high entry velocity. Taking into account the communication capabilities foreseen for the Mission Module(3), i.e., utilization of S-band frequencies, a thirty foot diameter antenna, and a three hundred watt transmitter, it is found that the gain requirement of the probe antenna for the command link Mission Module-to-probe is well satisfied by an omnidirectional antenna. This choice should facilitate both signal acquisition and integration into the aerodynamic structure of the probe.

Choice of an omnidirectional antenna, in turn, determines both the power requirement of the probe transmitter for the probe-to-Mission Module data transmission link and the modulation technique. The required power, which is obtained from the transmission equation after the assumed parameters are inserted, is thirty watts. The modulation technique, under this power constraint, has to be narrow band of about a five hundred Hertz bandwidth. The weight of a solid state transmitter with the required characteristics is estimated at three pounds.

From the above considerations it is seen that the probe communications subsystem described here is somewhat different from that envisioned for the Ames drag probe,(2) but is similar in character to the low antenna gain - low power mode proposed for some phases of the Apollo mission.(4)

The two basic components of the data handling subsystem are the multiplexer-encoder and the data storage subsystem. It appears that these subsystems can be adapted with minor modifications from the data handling subsystem prescribed for the Ames drag probe.(2)

The basic functions of the data handling subsystem are as follows:

1) repeated sampling of analog signals from the various components of the probe instrumentation;
2) encoding these samples into data words in a suitable frame format;

3) cumulative storage of these data frames during blackout and buffer storage of real time data after blackout;

4) interlacing of real time and blackout data frames; and

5) provision of output signals for suitable modulation of the telemetry subcarrier wave.

B. Power Subsystem

The peak power requirement from all components (probe instrumentation, communication and data handling, propulsion), is estimated at about one hundred fifty watts, while the total energy requirement is about ten-to-twenty watt-hours. The preferred power sources are Ag-Cd batteries which provide an energy density about seventy percent higher than that of Ni-Cd cells. Six pounds is then the required weight of the batteries. Two batteries are employed: one, which is inside the probe and which weighs four pounds, feeds the instrumentation and communication subsystems; the other, which is attached to the afterbody cone, is jettisoned with the cone after thrusting.

C. Structural Subsystem

Figure B-5 presents a cross section of the drag probe, showing an outline of the major subsystems. The basic structure of the probe is a light beryllium shell, with an ablative heat shield covering most of the front surface, apart from a region around the center which contains an optically transparent quartz window surrounded by a thickened beryllium heat sink. Use of a heat sink rather than an ablative shield in this region prevents the presence of ablation products in the field of view of the radiometer looking through the quartz window. The front portion of the probe contains the scientific payload with the data handling and communication subsystem to its rear. Behind these is the propulsion subsystem to be jettisoned after burning. This afterbody of the probe which includes the fuel tanks is covered by a thin beryllium shell.

The nominal diameter of the probe is 3 ft, but could be increased if reduction of M/C_DA proves necessary in order to increase communication time after blackout. The structural weight as shown in Table B-II is approximately 25 lbs.

D. Propulsion Subsystem

One rocket engine, which generates about 162 pounds of thrust at constant 1.6 'g' acceleration, and which uses a liquid propellant of three hundred second specific impulse, is specified. The mass fraction for this engine subsystem is .7, while the engine burning time is about sixty seconds. After burning has been completed, the rocket engine, which is mounted at the rear of the probe along its axis, is jettisoned in order to reduce the vehicle M/C_DA.

E. Sterilization Subsystem

The sterilization canister, which contains the probe until time of separation and which is hermetically sealed up until this time, performs three distinct functions:

1) protection of the probe and its associated propulsion subsystem from recontamination with microorganisms subsequent to the terminal sterilization process (the main function);

2) micrometeoroid impact protection for the probe during its interplanetary cruise; and

3) facilitation of the thermal control of the probe during the cruise.

The pressurized canister is constructed to allow for venting at any desired time. Prior to separation, the canister cover is jettisoned to allow the probe to be ejected.

REFERENCES

(1) Seiff, A. and D. E. Reese, Jr., "Use of Entry Vehicle Responses to Define the Properties of the Mars Atmosphere," Unmanned Exploration of the Solar System, Adv. in the Astronaut. Sci., Vol. 19, G. W. Morgenthaler and R. G. Morra, Eds., Am. Astronaut. Soc., Washington, D. C., 1965.

(2) "A Feasibility Study of an Experiment for Determining the Properties of the Mars Atmosphere," AVSSD-0047-66-RR, Avco Corp., Lowell, Mass., 1966.

(3) Chen, R. K. and R. K. Selden, "Communications Systems Design for Manned Flyby Mission," TM-66-2021-8, Bellcomm, Inc., Washington, D. C., 1966.

(4) "Lunar Orbiter Communication Relay (LOCR) for Apollo Mission Support," DZ-10664-1, Boeing Co., Seattle, Washington, 1966.

TABLE B-I - PROBE SCIENTIFIC INSTRUMENTATION

INSTRUMENT	RANGE	QUANTITY	DATA RETURN* (BPS)
Accelerometers	Axial: 0-400'g's	2	
	0-40	2	
	0-4	2	
	Transverse: 0-100	2	
	0-20	2	
			40 R.T.** + 40 B.O.***
Mass Spectrometer	6 Channels (O,H_2O,O_2,A,CO_2,N_2)	1	42 R.T. + 84 B.O.
Pressure Gauge	0-50 Millibars	5	35 R.T.
Temperature Gauge	0-1500°K	2	12 R.T.
Radiometer	4 Spectral Lines of C,CN,NH,C_2 between 2478 and 5165 Å.	1	48 B.O.

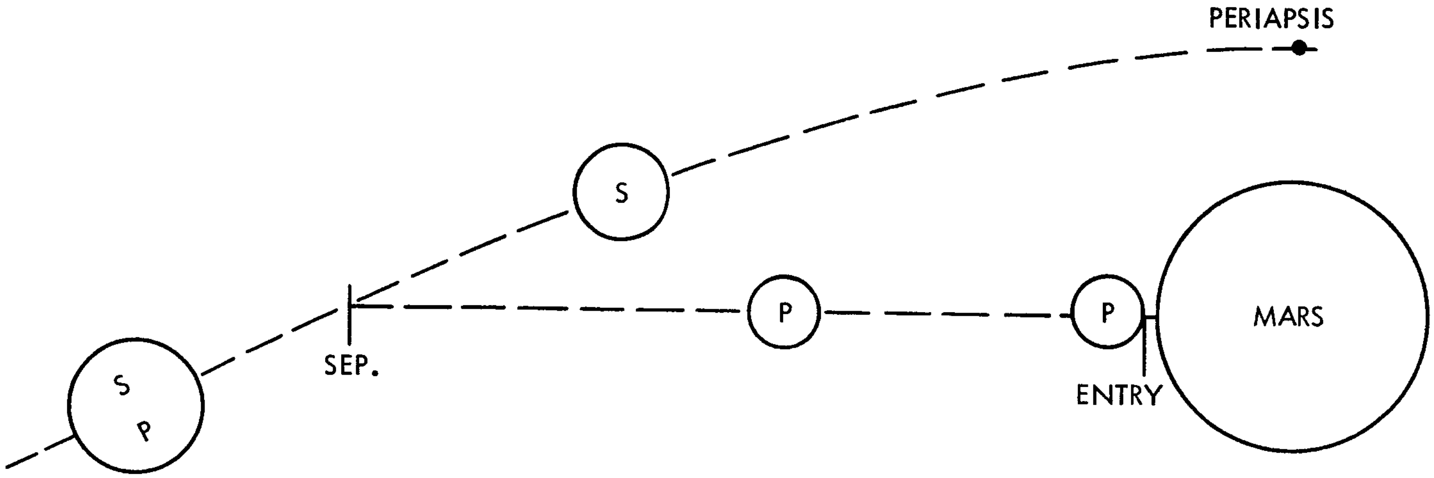
*Total data return is proportional to communication time which is not known beforehand. For the VM-7 atmosphere, communication time is estimated at 8 seconds.

**R.T. is Real Time Data.

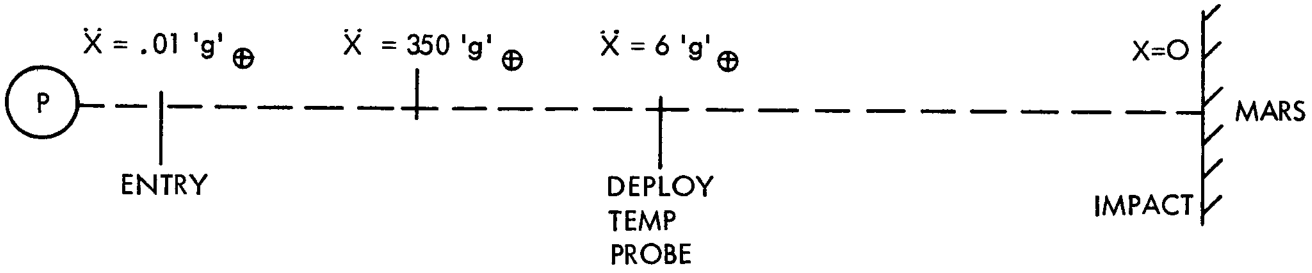
***B.O. is Blackout Time Data.

TABLE B-II - SUBSYSTEM WEIGHT BREAKDOWN

SUBSYSTEM	WEIGHT (LBS)	TOTALS
A) Scientific Payload		
Accelerometers	2	
Pressure and Temperature Probes	4	
Radiometer	2	
Mass Spectrometer	9	
Miscellaneous	1	18
B) Communication and Data Handling		
Battery	4	
Avionics and Data Storage	9	13
C) Vehicle Structure and Heat Shield	25	25
D) Propulsion		
Battery and Avionics	2	
Support Structure	4	
ΔV Engine and Propellant	46	52
E) Sterilization Canister	65	65
		173



A) SEPARATION TO IMPACT



B) ENTRY TO IMPACT

FIG. B-1 SCHEMATIC VIEW OF MISSION PROFILE

P - PROBE
S - MISSION MODULE

LEAD TIME	10 HOURS
SEPARATION TIME	4 DAYS
ENTRY TIME	30 SECONDS
COMMUNICATION TIME	10 SECONDS

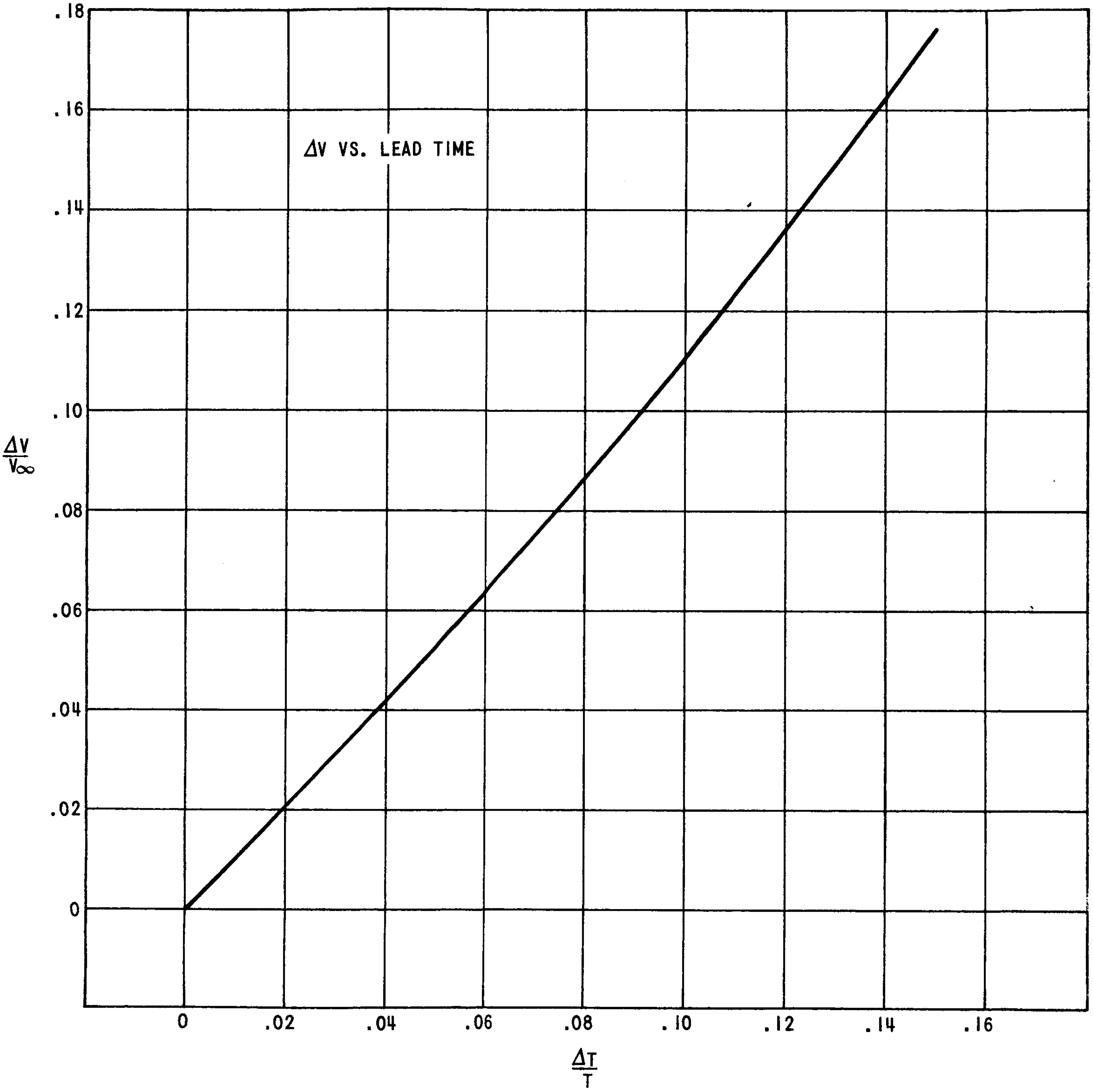


FIG. B-2 PROPULSION REQUIREMENTS FOR EARLY SEPARATION. V-HYPERBOLIC EXCESS VELOCITY, ΔV-REQUIRED VELOCITY INCREMENT, T-SEPARATION TIME, ΔT-PROBE ENTRY LEAD TIME

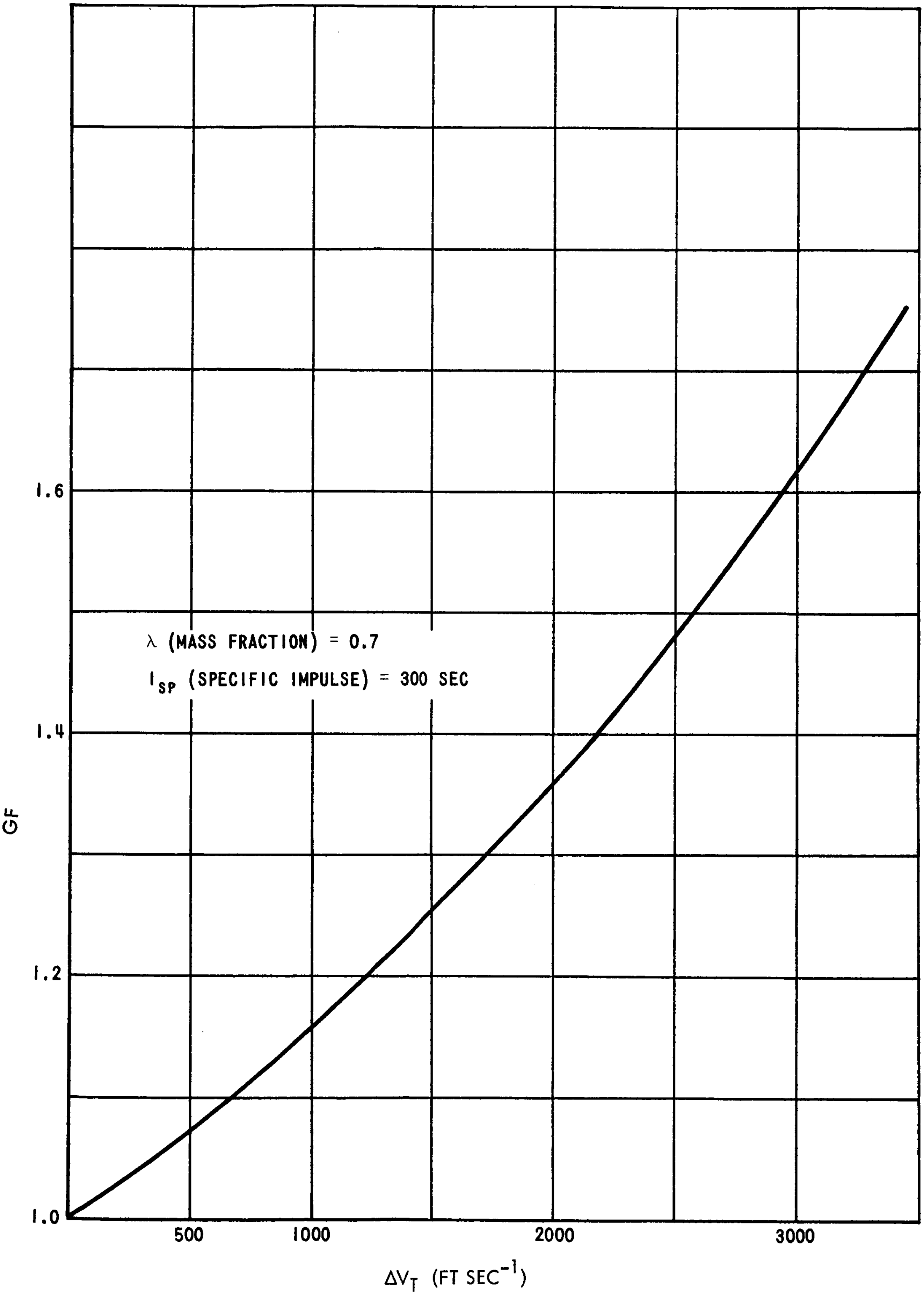


FIG. B-3 GF, GROWTH FACTOR, VS ΔV_T, TOTAL VELOCITY INCREMENT

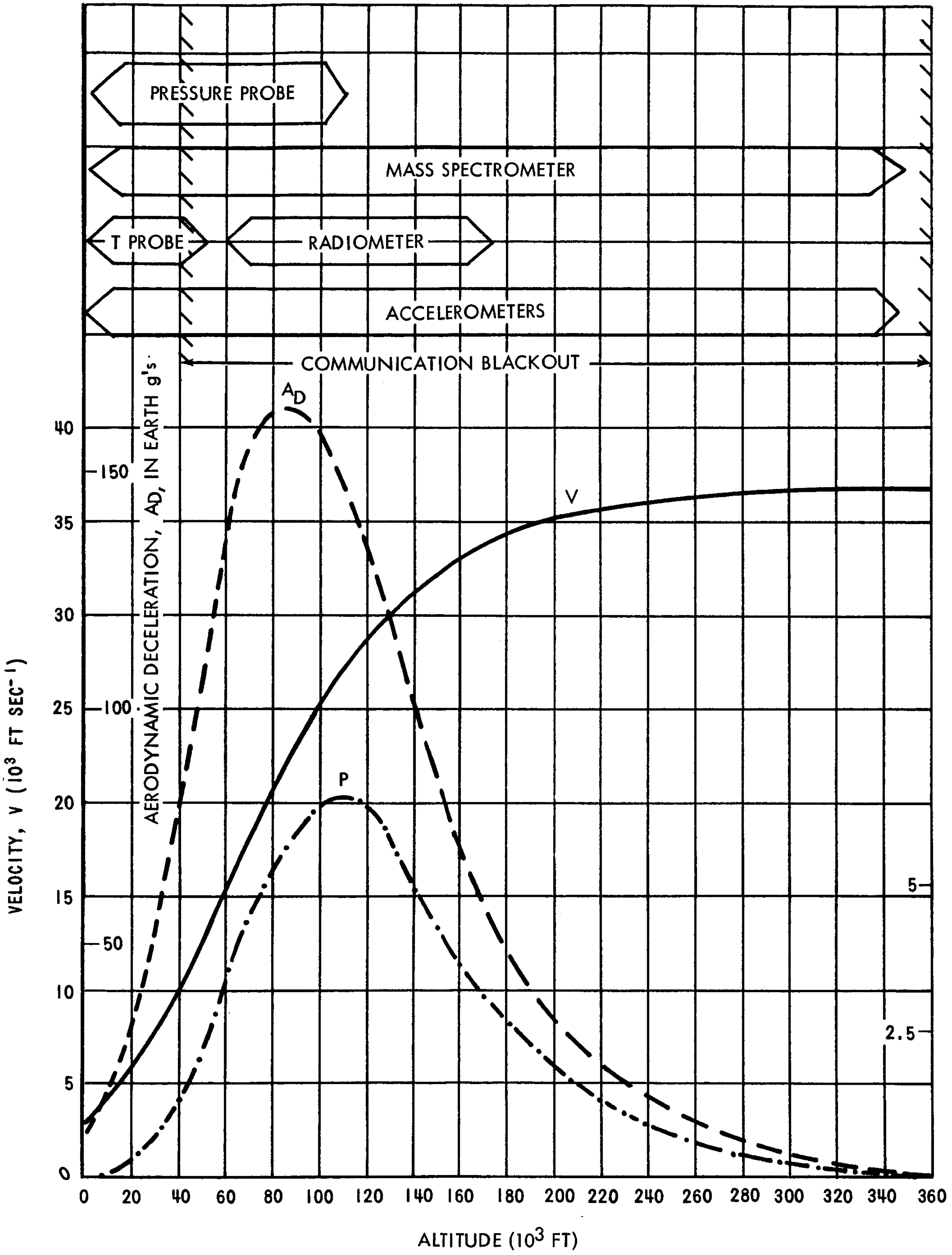


FIG. B-4 TYPICAL ALTITUDE PROFILE OF PROBE DYNAMIC PARAMETERS AND OPERATION; VERTICAL ENTRY INTO VM-7 ATMOSPHERE, $\frac{M}{C_D A} = 0.17 \frac{\text{SLUGS}}{\text{FT}^2}$

BOXES AT TOP INDICATE RANGE OF OPERATION OF SCIENTIFIC INSTRUMENTATION

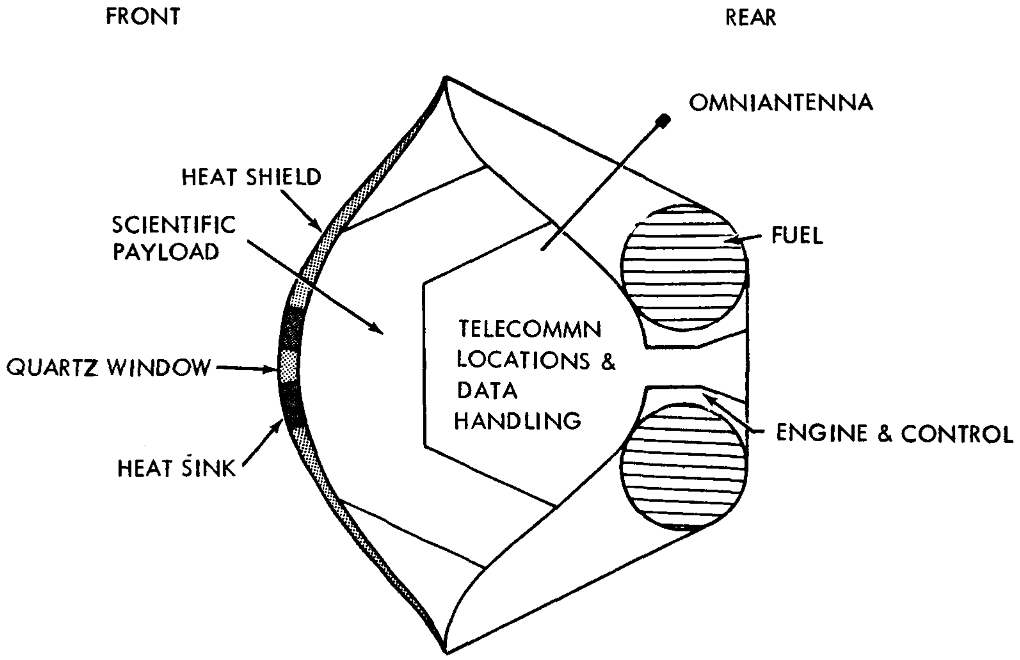


FIG B-5 SKETCH OF DRAG PROBE

APPENDIX C

MARS ORBITER PROBE

I. INTRODUCTION

In the following discussions the currently envisioned orbiter probe mission profile, its instrument payload, and conceptual engineering design are described.

There are numerous possible mission profiles, each having somewhat different objectives. The profile described here is oriented largely toward the acquisition of high resolution imagery of the Martian surface. This type of mission objective suggests insertion into a low altitude circular orbit and thus large velocity change requirements, reflected in the need for large, high performance propulsion systems. Therefore, the profile presented should be regarded as an approximate bounding mission in regard to probe energy requirements.

The payload instruments are listed according to applicable areas of interest, and appropriate weights and data return information are given. A brief description of the photographic and T.V. portions of the payload is given separately.

The probe conceptual design consists primarily of a perturbation on the existing Lunar Orbiter system with some allowance for anticipated extensions in the state-of-the-art.(1) The gross weight for each major subsystem is given, as well as the assumptions and pertinent information used to determine the subsystem weights. The propulsion system required to place the payload and supporting systems into a 300 km circular polar orbit about Mars is sized and its gross performance characteristics presented.

The probe design is summarized by a weight tabulation of the major subsystems which results in an initial weight at injection of 10,490 lbs and an orbit weight of 793 lbs. A preliminary layout showing the gross configuration of the probe is also presented as part of the summary.

II. MISSION PROFILE

The mission profile presented is one which is designed in favor of high resolution photography and T.V. of the Martian surface. This implies a low altitude circular orbit for best photography and T.V. results, which in turn necessitates large probe velocity change capability. There are two methods of providing the required retrograde velocity change: all propulsive deboost or aerobraking. The latter holds the potential of considerable launch weight reduction from the former, perhaps as much as 5000 lbs to 6000 lbs.(2) However, feasibility of this approach has not yet been established and therefore attention will be confined to an all-propulsive profile.

Separation from the M.M. and jettison of the sterilization canister is assumed to take place five days prior to M.M. periapsis passage, i.e., M-5 days. An injection velocity change of 1100 fps provides for probe arrival at 300 km altitude at M-4 hrs approximately over the north pole of the planet. The maximum midcourse velocity change is estimated to be 100 fps and is performed via tracking and radio command from the M.M. The orbital insertion maneuver uses all three stages to supply the required 22,280 fps velocity change with orbital velocity achieved at third stage shut down. During the first orbital pass over the sunlit face of Mars, the probe will be tracked and its systems checked out from the M.M. This will allow preliminary orbit determination as well as the initiation of corrective or contingency operation in the event of a probe subsystem malfunction. Figure C-1 presents a pictorial summary of the mission profile with pertinent data included for each phase, and Table C-I gives a probe weight history by mission phase.

III. PAYLOAD SUBSYSTEM

The orbiter probe instrument payload is listed in Table C-II and includes the appropriate information concerning estimated weights and expected data return. The two major elements of the payload are the high resolution photographic system and T.V. vidicon cameras weighing about 150 lbs and 54 lbs, respectively. The remaining geophysical and atmospheric instrumentation is estimated to weigh about 90 lbs, leading to a total payload weight of 294 lbs.

The high resolution photographic system is derived from its Lunar Orbiter predecessor and has many of the same characteristics. It is envisioned as a 70 mm film system including film developing, transport, storage, and slightly modified readout capability in a single hermetically sealed package. From a 300 km altitude the system is anticipated to provide about one hundred 40 x 40 km pictures of 8 m resolution for transmission to the nearby M.M. during the encounter phase of the mission.

Subsequent to the encounter phase the long duration (i.e., seasonal) surface imaging requirement is fulfilled by the on board T.V. system. There are a total of three T.V. cameras of the Ranger 9 "A" and "B" variety modified with Ranger 3 camera lenses.(3) Each of these cameras is fitted with a different color filter in order to observe possible seasonal changes in coloration of the same surface location. From 300 km altitude the cameras provide images 3 km on a side with 8 m resolution for direct transmission to Earth or possible interim on board storage. Assuming six hours of transmission time per day the number of vidicon image trios transmitted each day will vary between three and 43 as a function of Mars-Earth distance. Each camera is estimated to weigh 18 lbs including the electronics necessary to convert the vidicon images into electrical impulses, thus yielding a total T.V. system weight of 54 lbs. The addition of 90 lbs of geophysical and atmospheric instrumentation as listed in Table C-II results in a total payload weight of 294 lbs.

IV. OPERATIONAL SUPPORT SUBSYSTEMS

In the following paragraphs the Lunar Orbiter system is used as a point of departure in conceptually designing the individual Mars orbiter subsystems. The primary objective was to arrive at reasonable subsystem weight estimates within the constraint of modest increases in the state-of-the-art for the following subsystems:

A. Propulsion
B. Power Supply
C. Communications
D. Attitude Control
E. Structure
F. Payload-Bus Integration
G. Sterilization Canister

A. Propulsion

In order to transfer the probe from the high energy flyby hyperbola to the relatively low energy circular orbit, a large high performance propulsion system is required. Based on the required deboost velocity change of 22,280 fps (for the profile described herein), and an injection and midcourse velocity change of about 1200 fps, a three stage storable propellant system utilizing torroidal tankage was chosen. The deboost velocity change is divided up evenly among the three stages with the injection and midcourse velocity change being an additional requirement for the first stage.

The estimated mass fractions and specific impulses for the system result in a weight growth factor of 13.2 yielding an initial weight at injection of 10,490 lbs, of which 9697 lbs is the propulsion system. The velocity change, mass fraction, specific impulse, and gross weight of each stage are given in Table C-III, while the gross configuration of the propulsion system as well as the probe is presented in Figure C-2.

B. Power Subsystem

The power supply subsystem is designed to satisfy an estimated peak requirement of 340 watts. This peak requirement occurs while the probe is in orbital flight over the sunlit side of the planet during the M.M. encounter phase of the mission. The constituent power requirements are as follows:

General Housekeeping	∿ 5 watts
Communications	∿ 41 watts
Attitude Control	∿ 19 watts
Photography	∿ 75 watts
Battery Recharge	∿ 200 watts
Peak Power Requirement	∿ 340 watts

The Mariner IV solar panels produced about 9 w/lb at Earth and it is estimated that the application of existing, more refined fabrication techniques would allow the construction of panel systems producing 25 w/lb.(4) This solar panel output power density is different at Mars due to the greater distance from the sun and because of the lower average temperatures of the solar cells in that locality. While increased distance from the sun decreases the available solar energy, the consequent lower operating temperature of the solar cells tends to increase their efficiency. The net result is a reduction in panel output power density by a factor of about two yielding an output at Mars of 12.5 w/lb. By 1970 state-of-the-art solar panel specific weight should be about .5 lbs/ft^2, resulting in an output power area density at Mars of 6.25 w/ft^2. For the peak power requirement of 340 watts and a 10 per cent area factor of safety for anticipated solar cell degradation, the solar panel area required is 60 ft^2 with a corresponding total panel weight of 30 lbs.

The 200 watt battery recharge requirement represents the amount of power required for probe functioning while in orbital flight over the dark side of the planet during the encounter phase of the mission. Since .93 hrs (i.e., 1/2 period of 300 km altitude circular orbit) is spent in darkness, a total of 186 watt-hrs of electrical energy would be consumed. Allowing a 22 per cent depth of discharge for the storage batteries results in a total storage requirement of 845 watt-hrs. Silver-cadmium batteries provide a maximum energy density of 26 watt-hrs/lb, and an operational life of about 1600 one hour discharge cycles resulting in a gross lifetime per battery of about 123 days.(5) Three of these batteries weighing a total of 98 lbs are employed to achieve an estimated probe lifetime of 369 days, which is slightly longer than one-half of a Martian seasonal cycle. Other elements of the power supply subsystem such as solar panel actuation and deployment mechanisms, voltage regulation equipment, and miscellaneous wiring and cabling amount to an additional 44 lbs. The total weight of the power supply system is therefore estimated to be 172 lbs.

C. Communication Subsystem

The communication subsystem is essentially the same as that employed by the Lunar Orbiter with the exception of an enlarged high gain antenna and minor changes in circuitry in order to provide some data compression and coding capability. One other exception is the inclusion of data storage capability other than that existing in the photographic subsystem.

The variation from the Lunar Orbiter communications system is a function only of the difference between the earth-based DSIF and M.M. receiving systems. The difference consists of a reduction in antenna diameter from the 85 ft DSIF installations to an assumed 30 ft M.M. antenna size as well as a factor of about six increase in receiver noise temperature over the maser receivers of the DSIF. To compensate for the decrement in receiving capability without compromising Lunar Orbiter photo quality, the probe transmission antenna diameter is increased by a factor of five (compared to Lunar Orbiter) to the estimated feasible limit of 15 ft. In addition, data compression and coding are modestly assumed to reduce the Lunar Orbiter data rate by factors of two yielding a total rate reduction by a factor of four. Applying these numerical values to the transmission equation results in a maximum range over which Lunar Orbiter quality pictures can be transmitted of 1.44 Earth-moon distances, i.e., about 555 x 10^3 km. This would allow the acquisition of about 70 photographs of the previously mentioned area coverage and resolution.

Collapsible (umbrella type) nichrome mat construction is used in order to minimize the weight of the enlarged antenna as well as reduce the required probe storage volume in the M.M.(6) Extrapolating the 15 lbs weight of the 10 ft diameter Apollo erectable antenna by the ratio of the squares of diameters results in an antenna weight of about 34 lbs.

Provision must be made for sufficient data storage capability to satisfy both encounter and post encounter phase operational requirements. The former of these two criteria is currently anticipated to govern and would require equipment capable of storing 5 x 10^8 bits of information. An erasable magnetic tape storage system is used to fulfill this requirement and its weight is estimated at about 45 lbs.(7) Use of the data storage capacity as a buffer allows the transmission of approximately 30 additional photographs resulting in a total of about 100 photos.

Allowing 79 lbs for data storage and the antenna, the remaining 51 lbs of the communication subsystem is composed primarily of a flight programmer, transponder, and amplifier, thus yielding a total subsystem weight of 130 lbs.

D. Attitude Control Subsystem

Attitude control during the large velocity change deboost maneuver will be provided by the attitude control subsystem of the three stage propulsion system.* The required angular momentum for attitude control in orbit is provided by eight solenoid operated low thrust gas jets mounted on the solar panel tips in order to provide the maximum total moment for the available system impulse. Based on this configuration and Lunar Orbiter operations data it is estimated that about 1.68×10^{-2} lbs of nitrogen are required for each photographic maneuver.(8) Assuming 70 separate photographic maneuvers and two maneuvers per day for 369 days for acquisition of vidicon images, 13.85 lbs of nitrogen would be required. Furthermore, for a ±2° deadband attitude hold the gas consumption rate is about 6.6×10^{-5} lb/hr resulting in an additional requirement of .59 lbs of gas for the 369 days of probe lifetime, yielding a total requirement of about 14.5 lbs of gas (including .4 lbs reserve).

Storage of the gas in the same thermodynamic state as in the lunar mission case (i.e., the same pressure, temperature, and density) permits the use of a smaller and therefore lighter weight gas bottle constructed of the same material as on the Lunar Orbiter. Through manipulation of the probe-to-Lunar Orbiter ratio of required nitrogen weight, and using the known Lunar Orbiter gas bottle weight, the probe gas bottle weight is estimated at 16.8 lbs. The entire subsystem including bottled gas, plumbing, inertial reference unit, sun and Canopus sensors, and other miscellaneous items is estimated to weigh 63 lbs.

E. Structural Subsystem

The general shape of the structural subsystem is that of a truncated cone with the large and small bases serving as lower and upper equipment decks, respectively. The two decks are connected by a rigid aluminum tubular frame which is the primary load bearing element of the structural subsystem. The lower deck is fitted with an adapter ring which serves as a severable structural connection between the probe and third stage of the propulsion system. Equipment mounted on the lower deck would reside within the truncated conic envelope, while that fixed to the upper deck would be outside of the envelope. The foldable antenna would be mounted on its support structure and gimbal mechanism on the upper deck which also would be a logical location for the remainder of the communications subsystem equipment. As in the case of the Lunar Orbiter this truncated conic shaped

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*Included in total propulsion system weight.

probe would be wrapped in an aluminized mylar thermal shield in order to moderate the effects of environmental temperature extremes. The total weight of the structural subsystem is estimated to be about 59 lbs.

F. Payload-Bus Integration Subsystem

The final subsystem to be discussed is one which is envisioned as the interface between the T.V. (and instrumentation) portion of the payload and all other subsystems of the probe; this is therefore designated the payload-bus integration subsystem. Due to current uncertainties in payload integration this part of the probe is perhaps the least defined of the subsystems. However, it is anticipated that it would consist of data management equipment, signal conditioning and switching circuitry, various performance transducers such as thermocouples and potentiometers, cabling, and vibration isolation as well as miscellaneous bracketry. From existing Rangers 6 - 9 specification data, and allowing a modest weight decrease of 20 to 30 percent in anticipation of advances in the state-of-the-art, the estimated total weight of this subsystem is about 75 lbs.(9)

The estimated probe weight in orbit tabulated to the subsystem level is presented in Table C-IV, and a layout showing the gross probe configuration is presented in Figure C-2.

G. Sterilization Canister

During the Earth-to-Mars interplanetary transfer the probe is enclosed in a sterilization canister which is jettisoned subsequent to probe separation from the M.M. The canister must be of sufficiently large volume and appropriately shaped to contain the probe, including the folded high gain antenna and the propulsion system. The canister walls are assumed to be of aluminum honeycomb structure with a weight denisty of about 1.2 lb per square foot of surface area. From the required propellant weight and its density, and using Lunar Orbiter dimensions for the spacecraft structure injected into Mars orbit, it is possible to determine an approximate required canister volume of 220 ft^3. The generally conic shape results in a total surface area of about 230 ft^2, thus yielding a total canister weight of 276 lbs.

REFERENCES

(1) "Agena Class Lunar Orbiter Photographic Project, Vol. I. Technical Proposal," Boeing Co., October 2, 1963.

(2) Cassidy, D. E., "Atmospheric Braking of an Unmanned Mars Orbiter," Bellcomm Memorandum for File, August 15, 1966.

(3) Grenning, E. M., "Feasibility of Photographic Probes to be Launched from a Manned Martian Flyby Vehicle," Bellcomm Memorandum for File, July 7, 1966.

(4) Rappaport, Paul, "Solar Cells Today," RCA Laboratories, Princeton, N. J., IECEC, September, 1966.

(5) Mandel, Hyman J., "Recent Developments in Secondary Batteries," Electronic Components Lab., U. S. Army Electronics Command, Fort Monmouth, N. J., IECEC, September, 1966.

(6) Personal Communication with R. L. Selden of Bellcomm, Inc.

(7) Personal Communication with E. L. Gruman of Bellcomm, Inc.

(8) Personal Communication with D. Carter of Langley Research Center.

(9) "Ranger RA-6 through RA-9 Spacecraft Design Specification," Book: RL-4-120B, Jet Propulsion Laboratory, November 1, 1962.

TABLE C-I - PROBE WEIGHT HISTORY BY PHASE

PHASE	TIME	EVENT WEIGHT (LBS)	WEIGHT CHANGE (LBS)
Separation & Jettison Sterilization Canister	∿ M-5 days	10,766	
			276
Injection	∿ M-5 days	10,490	
			1050
Midcourse	∿ M-1 day	9,440	
			100
Deboost:			
1st Stage Burn & Jettison expended stage	∿ M-4 hrs	9,340	
			5330
2nd Stage Burn & Jettison expended stage	∿ M-4 hrs	4,010	
			2238
3rd Stage Burn & Jettison expended stage	∿ M-4 hrs	1,772	
			979
Orbit	∿ M-4 hrs	793	

TABLE C-II - PAYLOAD (WEIGHTS AND DATA RETURN)

AREA OF INTEREST	WEIGHT (LBS)	DATA
Photography:		
Camera	150	1×10^{11} bits at flyby
T.V.	54	10^4 bps to Earth
Solid Body and Surface Properties:		
Magnetometer, Gamma-Ray Spectrometer	20	500 bps to Earth
I. R. and Microwave Radiometers	25*	200 bps to Earth
Geodesy (Tracking from Earth and M.M.)	0	
Atmospheric Properties:		
Topside Sounder, U.V. Polarimeter	35	1000 bps to Earth
I.R. and Microwave Radiometers	25*	
Space Environment:		
Solar Wind and Micrometeoroid Detectors	10	<100 bps to Earth
Payload Weight =	294 lbs	

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*Common Instrumentation

TABLE C-III - PROPULSION SYSTEM

	ΔV (FPS)	MASS FRACTION	SPECIFIC IMPULSE (SEC)	GROSS WEIGHT (LBS)
Stage 1	8620	.91	325	6480
Stage 2	7420	.91	325	2238
Stage 3	7420	.90	325	979

Total Propulsion System Weight = 9697 lbs

TABLE C-IV - SUBSYSTEM WEIGHT SUMMARY

SUBSYSTEM	WEIGHT (LBS)
Payload	294
Power Supply	172
Communications	130
Attitude Control	63
Structural	59
Payload-Bus Integration	75

Probe Weight in Orbit = 793 lbs

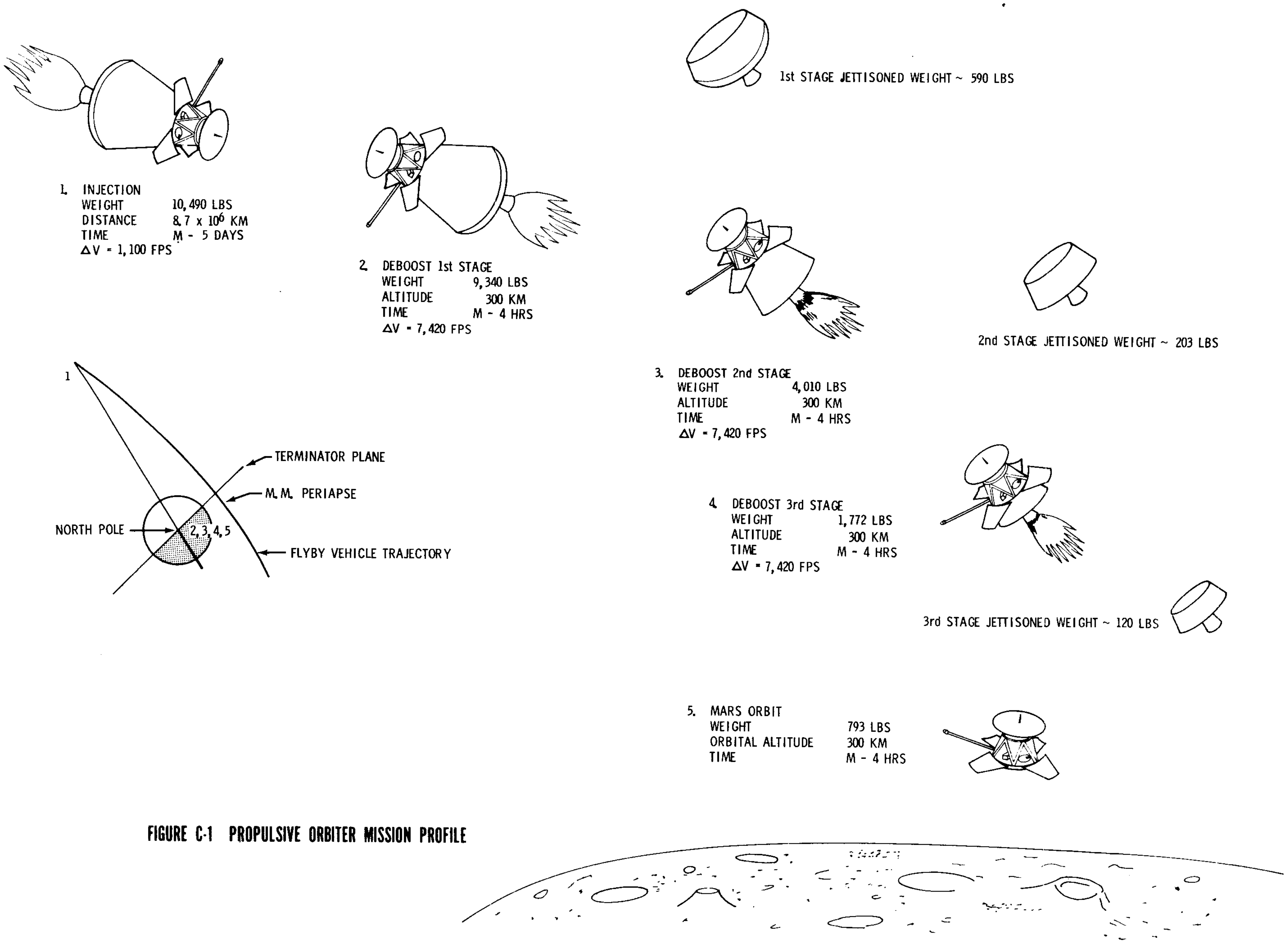

FIGURE C-1 PROPULSIVE ORBITER MISSION PROFILE

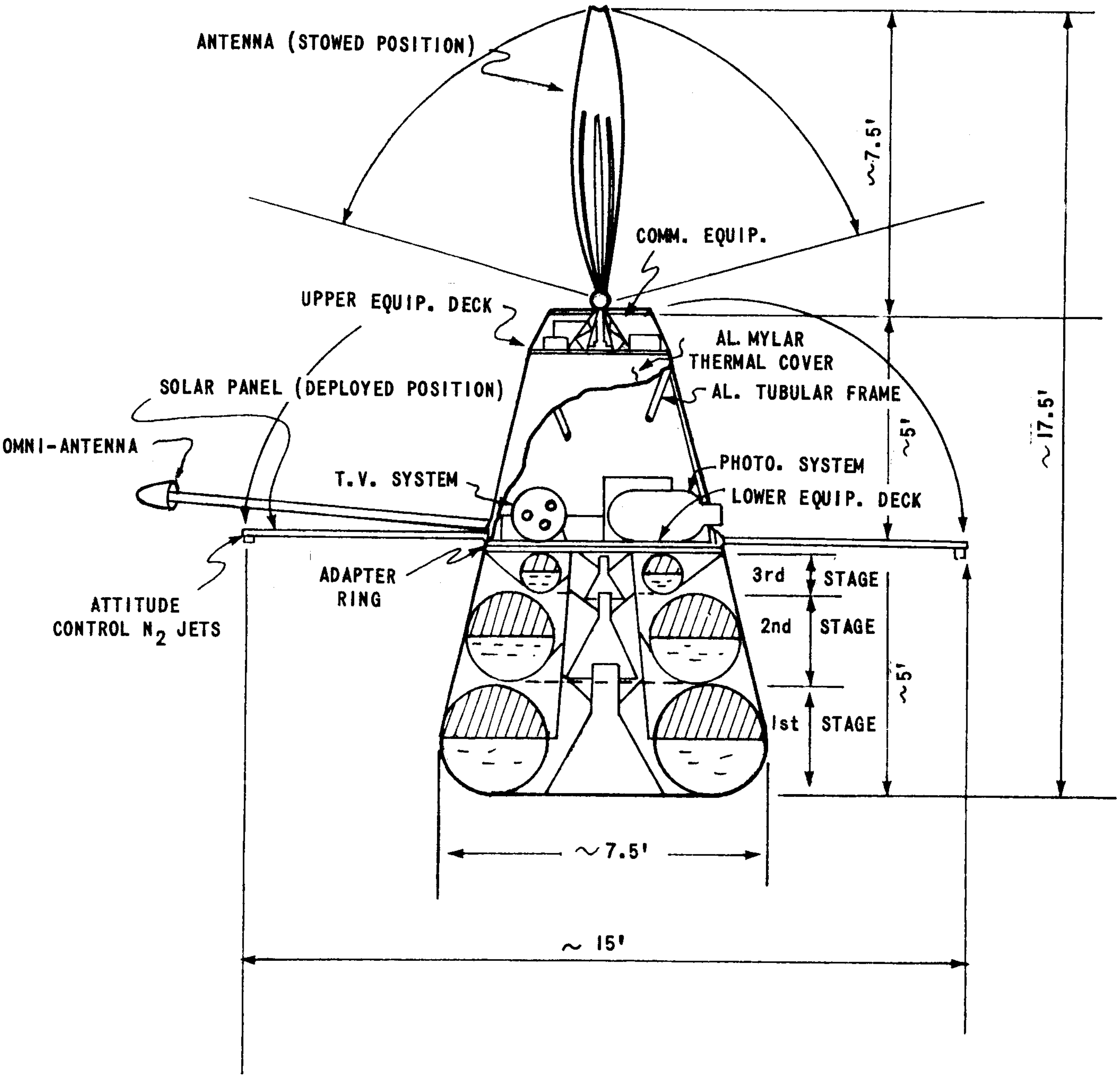

FIGURE C-2 - SKETCH OF PROPULSIVE DEBOOST ORBITER PROBE

APPENDIX D

MARS SURFACE SAMPLE RETURN PROBE

I. INTRODUCTION

The primary purpose of the Mars Surface Sample Return (MSSR) probe is to collect samples of the surface material and return them to the flyby vehicle. Secondary objectives include returning color photographs and emplacing a long life geophysics laboratory on the surface. The MSSR mission profile, payload, and operational support subsystems are described in this appendix.

II. MSSR PROBE MISSION PROFILE

The MSSR Mission Profile has five phases:

1. Deployment and space flight
2. Atmospheric entry and landing
3. Pre-launch surface operations
4. Launch and rendezvous
5. Post-launch surface operations

Figure D-1 shows significant events in the mission profile of the MSSR probe.

Prior to deployment the MSSR is encased in a sterilization canister and stored in the probe compartment of the flyby vehicle. Deployment occurs about 5 days before flyby vehicle periapsis passage (M-5 days) and consists of ejecting the MSSR in its sterilization canister from the flyby vehicle and then separating the canister from the MSSR in a manner which prevents re-contamination of the probe. Space flight operations begin with the injection burn of the injection propulsion subsystem. This maneuver causes the probe to intercept the planet and to land about two hours prior to the periapsis passage of the flyby vehicle. This provides time for pre-launch operations before the rendezvous vehicle is launched. A velocity increment of about 600 fps is required when injection takes place 5 days before periapsis.(1)(2) Optical tracking and transponder ranging of the probe from the flyby vehicle provides data for the midcourse corrections. Two corrections executed at 12 hours and 6 hours prior to periapsis reduce the entry corridor to 18 km. The injection propulsion stage can provide a total velocity change of 1000 fps for injection and midcourse maneuvers, and is jettisoned prior to entry into the Martian atmosphere.

The probe enters the atmosphere at about 220 km with an entry angle of -19° and descends on a ballistic trajectory. Because of the low density atmosphere, a low ballistic coefficient $(\frac{M}{C_D A})^*$ in the range of 0.6 to 0.8 is needed to provide optimum aerodynamic braking;(3) therefore, a high drag blunt entry cone of 60° half angle is used. This reduces the velocity to about 2000 fps at an altitude of 20,000 feet.(4) Gimbaled variable thrust landing rockets and attitude control rockets are ignited at this point and are controlled to achieve a nominal zero velocity landing through the use of a doppler radar and autopilot system similar to Surveyor. About 2300 fps velocity change is delivered by the landing rockets. After the velocity has been reduced to about 1000 fps, the entry cone is jettisoned and the landing legs are extended. Touchdown vertical velocity is about 5 fps; anticipated landing errors (3σ) are about ± 120 km down track and ± 20 km cross track.

Pre-launch surface operations begin by unfolding the equipment panels encircling the rendezvous vehicle, thereby exposing the equipment and providing platforms for the experimental operations. Antennas are extended, the flyby vehicle location and trajectory plane are established, and communication is begun. A 360° facsimile T.V. camera scan is transmitted to enable the astronauts in the flyby vehicle to select the most interesting areas for surface sample acquisition. Since it is necessary to collect surface samples at least 100 feet from the MSSR probe to minimize rocket contamination, the surface sample acquisition devices are propelled radially outward by mortars remotely aimed in the favorable directions. Drag line buckets or vacuum cleaner type samplers or a combination of these are used to collect samples of surface material. A rock drill is to be used to recover subsurface material and an aerosol filter is used to collect samples of material suspended in the atmosphere. The entire sample acquisition procedure and other interactions of the probe with the surface such as footpad penetration and rocket cratering are photographed in color. The film is placed in the rendezvous vehicle along with the surface samples, and the probe is prepared for the launch phase.

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*Units are slugs/ft^2.

The conical structural shells which surround and support the rendezvous vehicle during the previous phases are folded outward over the equipment panels freeing the rocket for launch and protecting the equipment from damage. Communications between the rendezvous vehicle and the flyby vehicle are established and the antennas and cameras of the MSSR are retracted. At 11.5 minutes before periapsis when the rotation of Mars has moved the MSSR into the plane of the flyby vehicle trajectory, the rendezvous vehicle is launched. The first stage rocket provides a velocity increment of 13,500 fps and burns for 5.5 minutes. The second stage is ignited and burns for 4.5 minutes increasing the velocity by 12,500 fps. Guidance is programmed thus far. During the 5.5 minute third stage burn radar command guidance from the flyby vehicle is used to achieve a rendezvous. Terminal maneuvers using the attitude control system of the third stage are accomplished under direct optical observation from the flyby vehicle. Docking and transfer of the payload from the rendezvous vehicle to the flyby vehicle are done in a manner which prevents contamination of the payload and back-contamination of the flyby vehicle.

Post-launch surface operations begin soon after launch and continue indefinitely nominally for two earth years. Nine geophysics experiments are deployed and begin operation. Communication is reestablished with the flyby vehicle, transmitting data for about eight hours a day. When the increasing distance to the flyby vehicle reduces the transmission rate below that of a direct Mars-Earth link, the MSSR antenna acquires the Earth and communicates directly for the remainder of the mission.

III. MSSR PROBE PAYLOAD SUBSYSTEMS

The MSSR payload consists of three subsystems: the rendezvous vehicle, the payload acquisition subsystem, and the geophysics laboratory. The rendezvous vehicle has the mission of returning its payload to the manned flyby vehicle. The payload acquisition subsystem acquires and stows surface samples and photographs in the rendezvous vehicle. The geophysics laboratory conducts long term experiments on the planet surface.

The rendezvous vehicle has a useful payload of five pounds which includes samples, film and canisters. An additional operational support payload consisting of communications, power supply, autopilot, and structure bring the total rocket payload to 42 pounds. The 36,000 fps needed for rendezvous requires three stages with sterilizable storable propellants. Very high propellant mass fractions are achieved by designing the structure to be self-supporting only during the launch acceleration, and supporting the rendezvous vehicle during the high entry and landing accelerations with conical structural shells which are removed prior to launch (Figure D-2). Pump fed first and second stage engines further reduce tankage weight.(4) Total weight of the rendezvous vehicle is 4016 pounds. Table D-I shows the weight breakdown of the payload, and Table D-II gives details of the three propulsion stages.

The payload acquisition subsystem includes the equipment which obtains photographs and samples and then stows them in the rendezvous vehicle. A still camera, possibly using 35 mm color film and probably mounted on an articulated boom, is programmed to photograph the various sampling devices during operation, the footpad-surface interactions, and the surrounding surface. Some exposures might be made during landing to help determine the effects of the rocket on the surface. Film is transported to the payload compartment by a pneumatic tube or cable mechanism. The weight of the camera, articulating mechanism and film transport is estimated at twenty pounds.

The surface sampling devices might use either the dragline concept or the vacuum cleaner concept or perhaps both. The dragline sampler is a bucket on a line deployed by a spring to a distance about 100 feet from the landed MSSR. As the line is taken in by a winch, the bucket scoops up samples of loose material. The contents of the bucket are deposited mechanically in the payload compartment. The vacuum cleaner sampler consists of a sampler head equipped with brushes or scrapers to stir up sample particles and a hose to transport the sample particles back to the payload compartment. The dragline has the advantages of simplicity and the ability to recover samples larger than particles. It is subject to snagging and would not work in the absence of loose material.

An aerosol sampler is included to collect surface material suspended in the atmosphere. A blower forces Martian air through a filter in the payload compartment of the rendezvous vehicle, thus accomplishing both collection and sample transport.

A rock drill is provided in the geophysics laboratory to emplace the heat flow experiment. This drill also acquires subsurface samples which are transported to the rendezvous vehicle payload compartment by the sample acquisition subsystem. Simple pneumatic transport of dust samples might be used or a more elaborate mechanism might be used to insure recovery of sticky or cohesive samples and to preserve recovery depth information with the sample. The weight of the sample gathering and transport mechanisms exclusive of the rock drill is estimated at 68 pounds, bringing the total weight of the payload acquisition subsystem to 88 pounds.

The geophysics laboratory consists of ten experiments which gather information about the atmospheric and solid body properties of Mars. It weighs about 180 pounds not including the communications, data handling, and long term power supplies. Table D-III gives the estimated weights and the approximate power and peak data rates of these experiments during operation.

The heat flow experiment is a device to measure the conductivity and thermal gradient at a point far enough below the surface to be shielded from the diurnal temperature variations. It is one of the most significant single point geophysical measurements which can be made. Implantation of the sensor may require drilling about two meters below the surface. Disturbances of the steady state thermal conditions by the drilling process would mean that a reliable measurement might not be made for several months. The drill accounts for most of the weight of this experiment.

A three-axis passive seismometer is included to measure the planet's internal activity and elastic properties. It is lowered from its protective canister by a cable and set on the surface near the landed probe.

The three-axis magnetometer is used to monitor the steady state magnetic field and fluctuations such as would be caused by interaction of the solar wind with the planetary ionosphere. It is projected by a spring or mortar to a distance of at least 100 feet from the probe to avoid interference from the probe itself. A cable connects the deployed magnetometer to the landed probe.

The solar proton experiment uses a scintillation detector to measure the solar proton flux in the energy range > 10 Mev. Monitoring solar proton flux from a point far removed from Earth provides increased azimuthal coverage of flares, storms, and other occurrences. The sensor is mounted on a boom to clear the shadow of the landed probe.

The weather station monitors the atmosphere temperature and humidity and the wind velocity. It is also mounted on a boom to avoid thermal and airstream interference from the landed probe.

The facsimile television camera is used to monitor the local terrain, sky conditions, and the deployment and operation of other experiments. It makes a panoramic scan of the landing area just after touchdown to provide a basis for targeting the sample collection mechanisms. This scan is transmitted to the flyby vehicle as it is taken since the communication subsystem has ample data rate capacity at the short ranges involved. The estimated maximum scanning rate of one panoramic scan per minute results in a generated data rate of 660,000 bits per second. The camera is housed in a small tubular case which is elevated vertically, like a periscope, from the probe to obtain unobstructed panoramic coverage. Varying the height of the camera provides a baseline for stereo pictures. The camera can be commanded to make panoramic scans, narrow-field scans, or sky scans. When the data handling capability of the communications system falls below the 660,000 bits per second produced by the camera, the output is recorded on video tape for transmission at a slower rate. The 10 pound weight shown is for the camera alone and does not include the tape recorder.

The soil mechanics experiment is similar to the Surveyor soil mechanics experiment consisting of a small claw-like scoop on a pantograph arm. The scoop is used to strike, probe, and dig in the soil measuring cohesiveness, bearing strength, and density. Data rates as high as 10^6 bits per second are produced momentarily by accelerometers measuring the impact of the scoop being dropped on the surface. Since the flyby vehicle is not likely to be close enough to allow real time transmission of these accelerometer traces, they are recorded on video tape or digitized and stored in a memory for transmission at a slower rate.

The micrometeoroid impact detector is folded in one of the equipment doors and is erected after launch of the rendezvous vehicle. Total sensor area of about 1000 square centimeters is anticipated, and a combination of acoustic and capacitor transducers will probably be used. Impact data is digitized and stored until transmission.

The atmospheric sounder transmits a pulsed radio signal upward toward the ionosphere at frequencies varying from 1 Mc to 10 Mc and measures the time for the reflected signal to return. From this data the ionospheric electron density profile can be inferred. Because of the high power consumption the experiment is operated intermittently.

The gas chromatograph makes repeated measurements of the atmospheric composition. This instrument separates the atmospheric constituents according to their adsorptive properties by using special adsorption materials packed into columns. The atmospheric sample is pumped into one end of the column, and the different chemical species encounter different flow resistances due to the selective adsorbing qualities of the column materials. The gas components meeting the least resistance emerge first, and a spectrum of composition with time is produced by a detector sensing the emission of gas from the end of the column. The atmospheric spectrum and a calibration spectrum from a known gas would be digitalized and stored until transmission. The data rate is very low.

IV. MSSR PROBE OPERATIONAL SUPPORT SUBSYSTEMS

Estimates of the weight of the various operational support subsystems of the MSSR have been made to arrive at a total probe weight. The weight of several of the subsystems was based on Surveyor(5) or Voyager '75(6) landing capsule subsystems; since these weights do not depend on the vehicle size, they are also applicable to the smaller geophysics lander probe. For convenience, the geophysics lander probe operational support subsystems will also be discussed in this section and referred to later. Table D-IV shows the subsystem weight allotments for these four landing vehicles.

The payload is the scientific or engineering instrumentation and directly associated support structure and mechanisms. It does not include data handling, communications, or electrical power except for special purposes like the rock drill batteries. The composition of the payload is arbitrary and might be changed without affecting the successful operation of the probe as long as the engineering interface constraints are not violated.

A) Flight Control

The flight control sensors and electronics subsystem include gyros, accelerometers, star and sun sensors, programmer, and the autopilot needed to control the probe during space flight, atmospheric entry and landing. The 60 pound weight of this subsystem estimated for Voyager is used for both the MSSR and the lander probe.

B) Radars

An altitude marking pulse radar and a doppler altitude and velocity sensor comprise the radar subsystem. The weight is estimated at 43 pounds based on the old but proven Surveyor radars.

C) Communications

The communications subsystem weight is based on the Voyager estimate. It includes a 20 watt high efficiency S band transmitter with a 27 db trainable antenna giving a data transmission rate conservatively estimated at 500 bits per second to Earth from the maximum Earth-Mars distance of 2.3 A.U.(7). A low rate (1 BPS) transmitter using an omnidirectional antenna is included for critical diagnostic measurements. The transponder receiver also uses an omnidirectional antenna and provides a 100 BPS command link from Earth. The Voyager communication subsystem weight shown in Table D-IV includes a 12 pound UHF relay communication system not used with the manned flyby probes.

D) Data Handling

The data handling subsystem consists of analog-to-digital converters, commutators, and command decoders. The Voyager, MSSR, and lander probe data handling subsystems also include a video tape recorder, digital memory, and logic circuitry. The weight is based on the Voyager estimate for a subsystem which can store 3×10^5 bits in memory and 3×10^7 bits on tape. The latter accommodates one scan of the facsimile television camera in the sky scan mode.

E) Mechanisms

Mechanisms are the electromechanical devices used to move various parts of the spacecraft, particularly the high gain antenna. For the geophysics lander probe the Voyager mechanism weight is used. Twenty-five pounds is added for the MSSR to account for the actuators which operate the equipment doors and the conical structural shells.

F) Power Supply

The power supply subsystems for the Voyager landing capsule, the MSSR, and the lander probe are based on radioisotope thermoelectric generators (RTG) with a nominal life of two years. For the MSSR and lander, 100 watts of d.c. power are supplied by two RTG's weighing a total of 110 pounds including radiators and shielding. A long life silver-cadmium secondary battery of 800 ampere hour capacity weighing 40 pounds is used principally to power the transmitter during the eight hour daily communication period of the post-launch phase. Charging control equipment is estimated at 18 pounds based on Surveyor. A 4500 watt-hour silver-zinc primary battery weighing 75 pounds provides power for the MSSR during the entry and landing and the pre-launch phases. A smaller 3500 watt-hour battery is provided for the geophysics lander since it has less electrical load because of the absence of the payload acquisition subsystem.

G) Attitude Control

The weight of the attitude control propulsion subsystems (ACS) for the two manned flyby landing probes is based on the 60 pound estimated weight of the Voyager landing capsule ACS subsystem. The total impulse required was assumed to be proportional to the weight of the landed vehicle since most of the attitude control propellant will be expended during the landing phase. The geophysics lander probe uses cold nitrogen jets like the Voyager capsule; therefore, the weight of the ACS is reduced from 60 to 51 pounds in proportion to the reduced landed probe weight. Similar scaling calculations for the MSSR probe would yield an ACS weight of 225 pounds. However, the MSSR probe is assumed to use a hydrazine monopropellant ACS, thereby reducing the ACS weight by the ratio of the specific impulse of hydrazine to that of nitrogen, i.e., $\frac{200}{70}$.

H) Cabling

The cabling subsystem accounts for a surprisingly high percentage of the landed weight of the probes - about 5.3% for Voyager. This percentage was used to estimate the weight of the cabling subsystem for the geophysics lander since it is very similar to the Voyager capsule in size, complexity, and landed weight. The MSSR probe is not much more complex than the Voyager capsule, but it is considerably larger and therefore the cables will be longer. Since the MSSR is about four times as heavy as the Voyager capsule and has an M/C_DA twice as great, the cabling weight was scaled by $(4)^{1/3}/(2)^{1/2}$. Scaling up the 90 pound Voyager cabling subsystem by this ratio gives an estimated cabling subsystem weight of 100 pounds.

I) Spaceframe

A spaceframe, as such, is not used in the design of the MSSR discussed here; however, the heading is used to permit comparison with other probe designs. Conventionally the spaceframe subsystem consists of the vehicle structure including frame, landing gear, hardware, pyrotechnics, and the thermal control devices including coatings, thermostatic heat switches, heaters, and insulation. The effective payload of this subsystem is all the other subsystems discussed so far. The Surveyor spaceframe subsystem weighs 47% of its payload; the Voyager spaceframe subsystem is estimated at 52% of its payload. The Voyager landing capsule incorporates a separate interchangeable "landed stage" structure which contains the payload subsystems, and this structure is believed to account for some of the additional spaceframe weight. Therefore, the spaceframe weight of the geophysics lander probe which does not have an interchangeable payload structure is estimated at 50% of its payload. According to previous analyses(8) the weight used in the MSSR design to accomplish "spaceframe" functions amounts to only about 34% of its payload. This is largely because more than 80% of the payload is a single subsystem, the rendezvous vehicle, which is centrally located in the spaceframe so that its loads can be efficiently transferred to the landing gear, entry shell, and landing rocket attachment points.

J) Landing Propulsion

The landing propulsion subsystem weights for the manned flyby landing probes are calculated on the basis of a velocity change of 2300 fps and specific impulse of 315 seconds. The MSSR landing rockets have a total thrust of about 15,000 pounds and a propellant mass fraction of 0.8. The geophysics lander rocket thrust is about 3000 pounds with a mass fraction of 0.75. Both systems use turbopumps to feed the sterilizable liquid propellants. For comparison, the propellant mass fraction of the pressure fed Surveyor vernier rockets having a total thrust of only about 300 pounds is 0.66, and the specific impulse is about 320 seconds.

K) Entry Shell

The entry shell weight for the MSSR probe is based on previous Bellcomm correlations of Voyager entry shell weights which indicate that the entry shell will be about 14% of the total entry weight.(4) Since the geophysics lander has the same entry velocity and ballistic coefficient as the MSSR probe, it undergoes similar heating rates and dynamic pressures. Therefore, the entry shell weight was based on the same weight per unit area as for the MSSR. This weight per unit area is about 45% greater than for the Voyager capsule, but since the manned flyby landing probes have a ballistic coefficient of 0.7 compared with 0.3 for the Voyager capsule, the entry shell is smaller and lighter in proportion to vehicle weight.

L) Injection Propulsion

Injection propulsion subsystem weights for both of the manned flyby probes are based on a velocity change of 1000 fps and a specific impulse of 325 seconds. Propellant mass fractions are assumed to be 0.9 for the MSSR and 0.8 for the smaller geophysics lander. Figure D-3 shows the MSSR probe with entry shell and injection propulsion subsystems attached.

M) Sterilization Canister

Both manned flyby landing probes are enclosed in similar sterilization canisters consisting of mating right circular cones. The lower cone has a half angle of 60° corresponding to the entry shell; the upper cone has a 45° angle to provide more height for the payload. The canister weight is estimated on the basis of 1.2 pounds per square foot, somewhat less than the 1.6 pounds per square foot for the Voyager landing capsule.

REFERENCES

(1) James, D. B., "Probe Targeting and Probe Guidance Near Mars," Bellcomm Memorandum for File, October 7, 1966.

(2) Schoch, J. J., "1975 Mars Flyby Mission - Trajectories of Probes from Manned Spacecraft," Bellcomm Memorandum for File, July 6, 1966.

(3) Cassidy, D. E., "Unmanned Entry Probe Sizing for a 1975 Manned Mars Flyby Mission," Bellcomm Memorandum for File, July 11, 1966.

(4) Macchia, D., M. H. Skeer, J. Wong, "Conceptual Design of Structural and Propulsion Systems for an MSSR Rendezvous Vehicle," Bellcomm Memorandum for File, August 5, 1966.

(5) "Surveyor Spacecraft A-21 Model Description," Hughes Aircraft Company, August 15, 1964.

(6) "Voyager Project Study," Jet Propulsion Laboratory presentation to NASA, September 14, 1966.

(7) Chen, R. K., R. L. Selden, "Communications Systems Design for Manned Mars Flyby Mission," Bellcomm Memorandum for File, July 29, 1966.

(8) "Planetary Exploration Utilizing a Manned Flight System," Office of Manned Space Flight, National Aeronautics and Space Administration, October 3, 1966.

TABLE D-I - RENDEZVOUS VEHICLE PAYLOAD

Useful Payload (samples, film, canister)	5 lbs
Communications (antenna, transponder, diplexer, decoder)	8 lbs
Power Supply (batteries, power conditioner, cabling)	16 lbs
Three Axis Autopilot (gyros, programmer, shaping networks)	8 lbs
Structure	5 lbs
Total Payload	42 lbs

TABLE D-II - RENDEZVOUS VEHICLE PROPULSION STAGES

	First Stage	Second Stage	Third Stage
Specific impulse (Sec.)	327	325	315
ΔV (fps)	13,500	12,500	10,000
Propellant mass fraction	0.934	0.900	0.788
Stage weight (lbs)	3,106	706	162
Thrust (lbs)	3,000	650	125
Chamber pressure (psia)	1,000	750	150

TABLE D-III - GEOPHYSICS LABORATORY

		Weight(lbs)	Power(watts)	Data(bps)
1.	Heat flow experiment and drill	30	3	low
2.	Passive seismometer	30	2	150
3.	Magnetometer	10	5	100
4.	Solar proton experiment	10	3	low
5.	Weather station	10	3	low
6.	Facsimile T.V. camera	10	3	660,000*
7.	Soil mechanics experiment	20	3	10^6*
8.	Micrometeoroid detector	5	2	low
9.	Ionospheric sounder	45	25*	low
10.	Gas chromatograph	10	4	low
	Total subsystem weight	180		

*Intermittent operation

TABLE D-IV - LANDING PROBE SUBSYSTEM WEIGHTS (LBS)

	Surveyor	Voyager '75	MSSR	Lander
Payload	91	289	4284	280
Flight control sensors and electronics	36	60	60	60
Radars	43	60	43	43
Communications including antennas	32	82	70	70
Data handling	11	30	30	30
Mechanisms	29	32	57	32
Power	65	313	243	226
Attitude control propulsion	16	60	89	51
Cabling	43	90	100	76
Spaceframe	171	524	1680	440
Landing propulsion	1606	565	2265	484
Entry shell	-	620	1450	292
Injection propulsion	-	415	1154	270
Sterilization canister	-	860	1013	208
Total probe weight	2143	4000	12538	2562

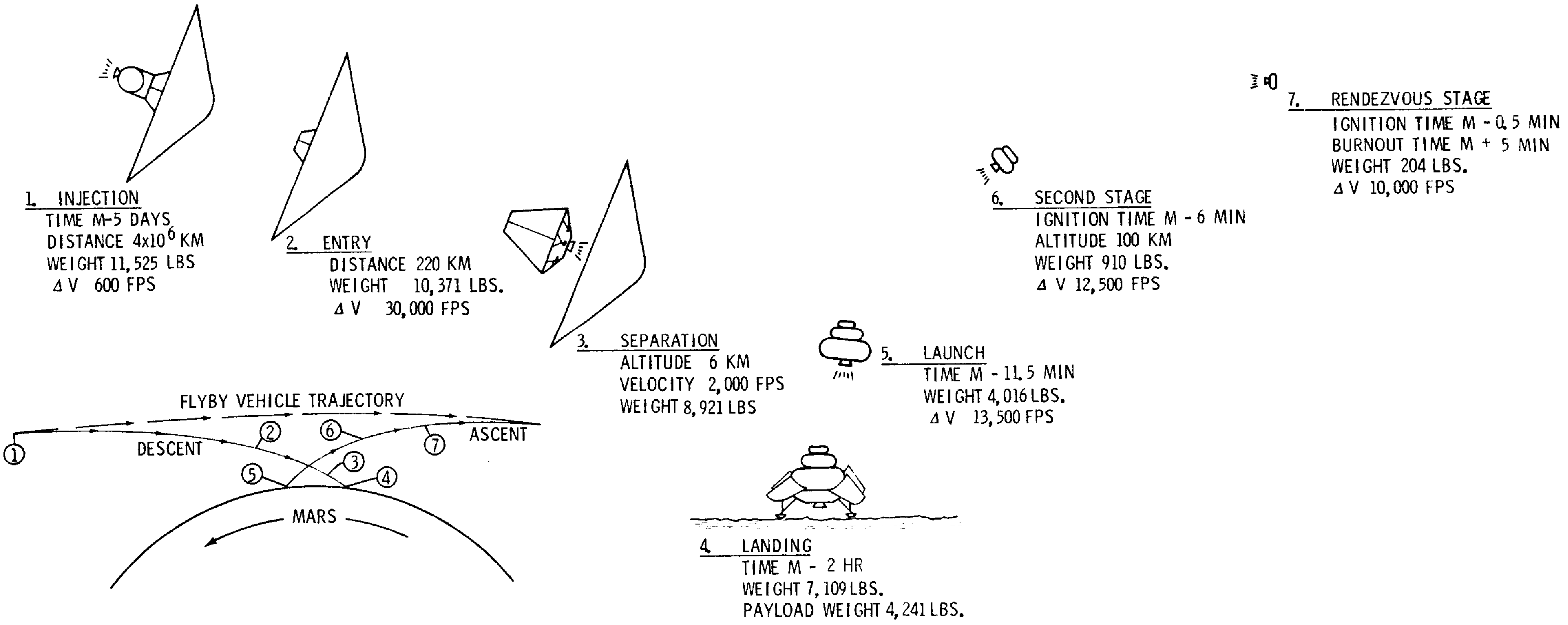

FIGURE D-1 MSSR MISSION PROFILE

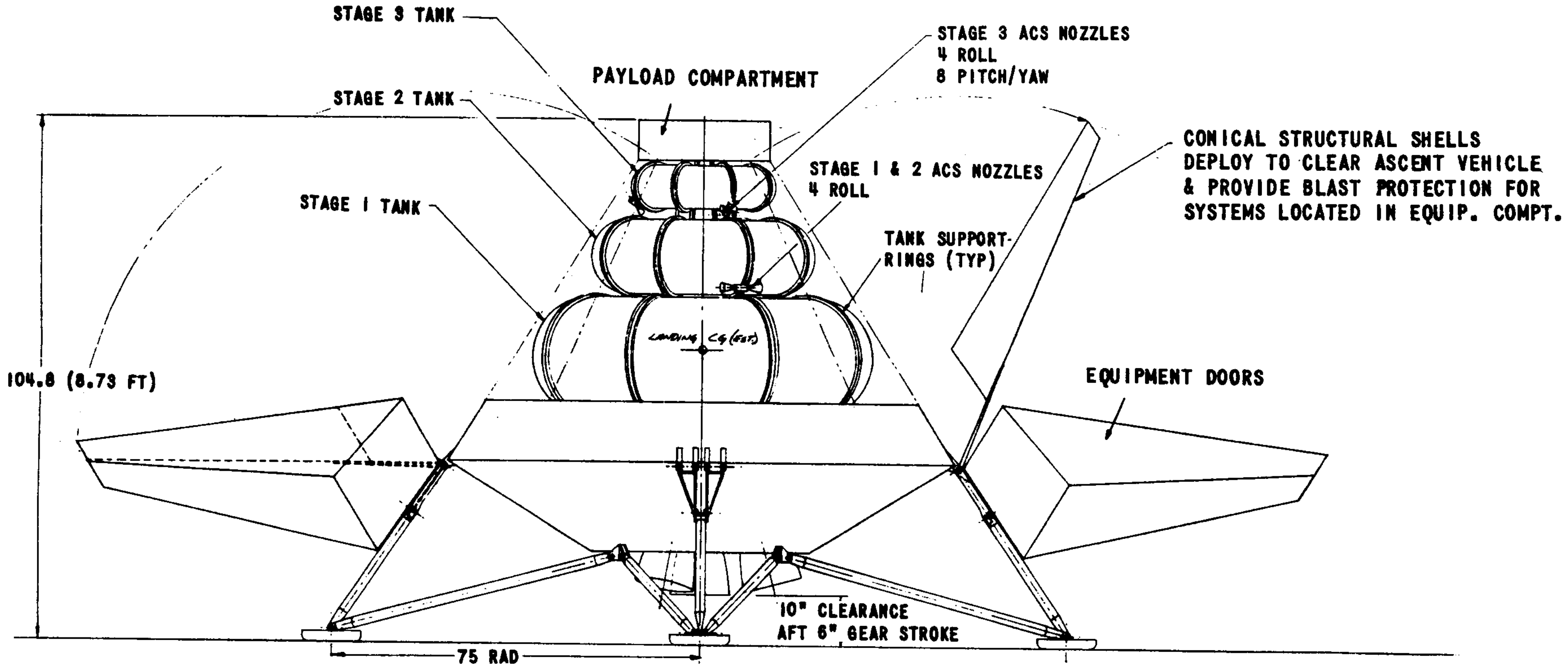

FIGURE D-2 - MSSR PROBE (LANDED CONFIGURATION)

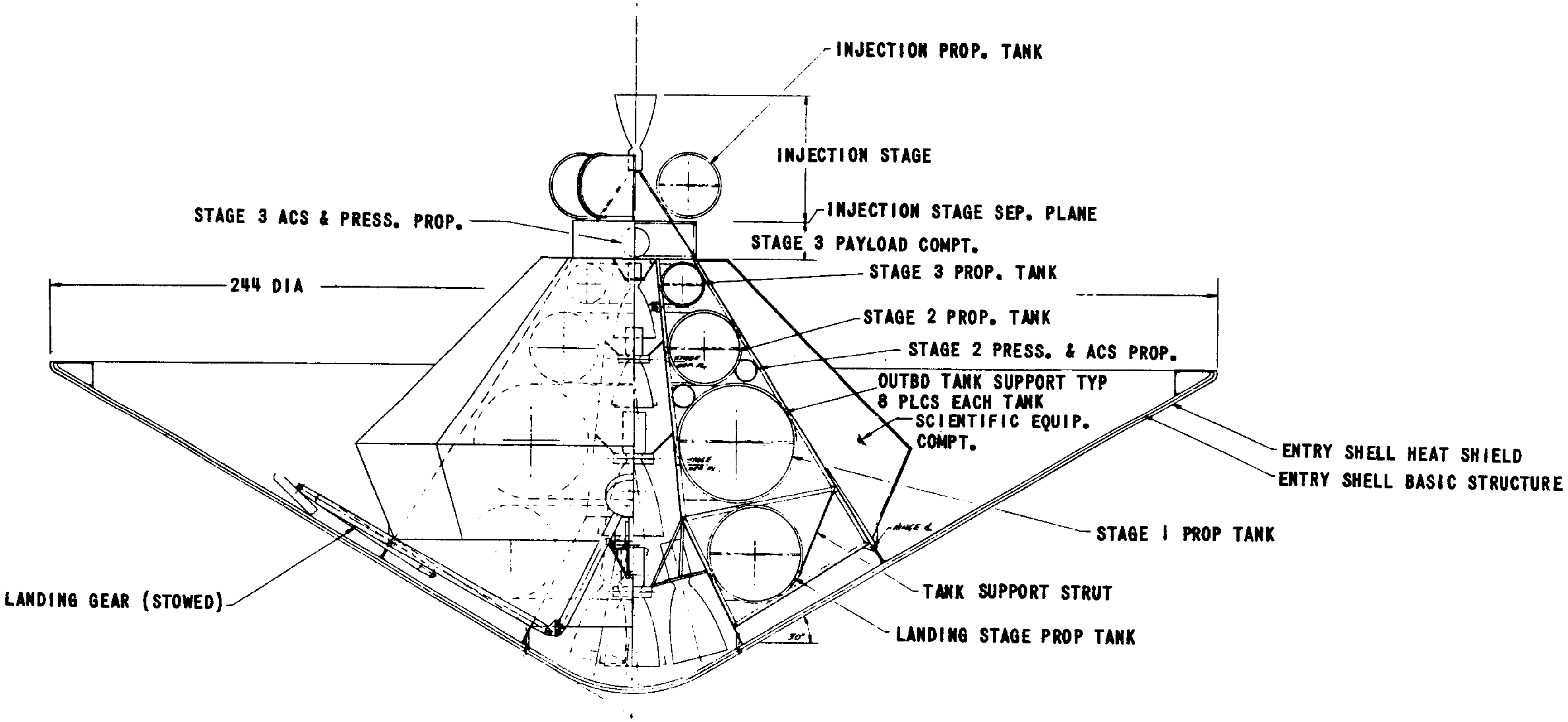

FIGURE D-3 - MSSR GENERAL ARRANGEMENT (FLIGHT CONFIGURATION)

APPENDIX E

LANDER PROBE

I. INTRODUCTION

The purpose of the lander probe is to emplace on the surface an atmospheric sounding rocket experiment and a long life geophysics laboratory. The lander probe is similar to the MSSR probe in several respects: the mission profiles are similar, both probes carry a geophysics laboratory and a rocket experiment as the payload, and many of the operational support subsystems are essentially the same. This appendix describes the mission profile, payload, and operational support subsystems of the lander probe.

II. LANDER PROBE MISSION PROFILE

The lander probe mission profile has three phases:

1. Deployment and space flight
2. Atmospheric entry and landing
3. Surface operations

Unlike the MSSR, the mission profile of the lander probe need not be closely synchronized with the flyby vehicle since the rocket experiment consists of unguided sounding rockets rather than a rendezvous vehicle. Figure E-1 shows the significant events in the mission profile.

The lander probe is deployed in a manner similar to the MSSR, and the injection propulsion subsystem is used to cause the probe to intercept the planet and land at the desired location. The combination of the shallow atmospheric entry angle and the trajectory of the probe in the atmosphere places the landing site roughly 90° away from the sub-Mission Module point.(1)(2) For the 1975 flyby mission the locus of acceptable landing sites is approximately a great circle passing through the poles of the planet. Very little injection velocity change is needed to target the probe to any place on this great circle, hence almost any latitude can be reached. To allow flexibility in longitude targeting, the time of arrival of the probe is adjusted. If the probe is launched seven days before M.M. periapsis passage, the nominal 1,000 fps capability of the injection propulsion subsystem allows about five hours adjustment in landing time corresponding to about 75° adjustment in landing longitude. About 40% of the planet can be reached with an injection propulsion velocity change capability of 1000 fps; 2500 fps would provide essentially full planet coverage.

The atmospheric entry and landing phase is the same as for the MSSR probe. Aerobraking reduces the relative velocity to about 2000 fps and the landing propulsion subsystem reduces the landing velocity to about 5 fps. The entry shell is jettisoned to save weight and to allow the landing gear to be extended. The lander probe has landing gears capable of leveling the spacecraft after landing to facilitate subsequent operations, particularly the sounding rocket launching. After landing, communications are established with the flyby vehicle using omnidirectional antennas on the landing probe.

Surface operations include launching the sounding rockets and operating the surface experiments. The sounding rockets are launched at intervals of about a month. Launch of the first sounding rocket might be timed so that the flyby vehicle is close enough to monitor the data being transmitted to the lander probe. The conical hatch and RTG radiators shown in Figure E-2 serve as blast deflectors to protect the equipment during launch. The sounding rocket ascends vertically to a height of 30 km in about two minutes, transmitting atmospheric data from omnidirectional antennas. Data are recorded by the lander probe for retransmission to Earth or the flyby vehicle.

The nine geophysics experiments are deployed and communication is established with the flyby vehicle using the articulated high gain antenna. When the flyby vehicle reaches the cross-over range, the lander probe high gain antenna acquires the Earth and communicates directly for the remainder of the mission.

III. LANDER PROBE PAYLOAD SUBSYSTEMS

The lander probe payload consists of two subsystems: the sounding rocket experiment and the geophysics laboratory. The sounding rocket has the mission of making repeated measurements of properties of the lower atmosphere; the geophysics laboratory conducts long term experiments on the planet surface.

The sounding rocket experiment consists of ten small sounding rockets, the launcher, and associated electronics. Each sounding rocket has a total payload of 5 pounds including temperature and pressure instrumentation, communications, batteries, and structure. A two pound solid rocket motor is sufficient to boost this payload to 30 km. Total weight of the ten rockets is 70 pounds.

The rockets are launched from a tubular launcher which weighs about twenty pounds. An electronic timer is used to provide timing signals which are combined with the data prior to storage. These timing signals enable the altitude of the sounding rocket to be determined from the predicted trajectory. The rocket motor temperature is measured prior to launch to aid in predicting the trajectory. The timer, temperature instrumentation, firing circuits, and experiment programmer are estimated to weigh an additional 10 pounds. This brings the weight of the static portion of the experiment to 30 pounds, and the total weight of the sounding rocket experiment to 100 pounds.

The geophysics laboratory is essentially the same as that on the MSSR and weighs 180 pounds. The total payload weight of the lander probe payload is 280 pounds.

IV. LANDER PROBE OPERATIONAL SUPPORT SUBSYSTEMS

Many of the lander probe operational support subsystems are very similar to the MSSR probe operational support subsystems; these were discussed in Appendix D which describes the MSSR. Weight estimates of these subsystems were based on the Surveyor and Voyager 1975 landing vehicles and are summarized in Table IV of Appendix D.

The lander probe spaceframe subsystem differs considerably from the MSSR spaceframe, being more similar to Surveyor and Voyager. It consists of a hexagonal horizontal framework to which the landing gear, landing rockets, and most of the other operational support subsystems are attached. The rocket launcher tube is fixed vertically in the center of the hexagonal framework and braced by struts at both ends. The injection propulsion subsystem is attached to the upper end of the rocket launch tube. The entry shell is supported near the periphery by the hexagonal framework and at the center by the bottoming pad attached to the lower end of the rocket launcher tube. The conical afterbody is divided radially into thirds by the three upper struts. The radiators of the two radioisotope thermoelectric generators occupy two-thirds of the afterbody; the remaining third is a hatch which swings down to allow the high gain antenna and other equipment to be deployed.

Figure E-3 shows an arrangement of the larger subsystems within the sterilization cannister. Packaging density is about 15 pounds per cubic foot.

REFERENCE

(1) James, D. B., "Probe Targeting and Probe Guidance Near Mars," Bellcomm Memorandum for File, October 7, 1966.

(2) Schoch, J. J., "1975 Mars Flyby Mission - Trajectories of Probes from Manned Spacecraft," Bellcomm Memorandum for File, July 6, 1966.

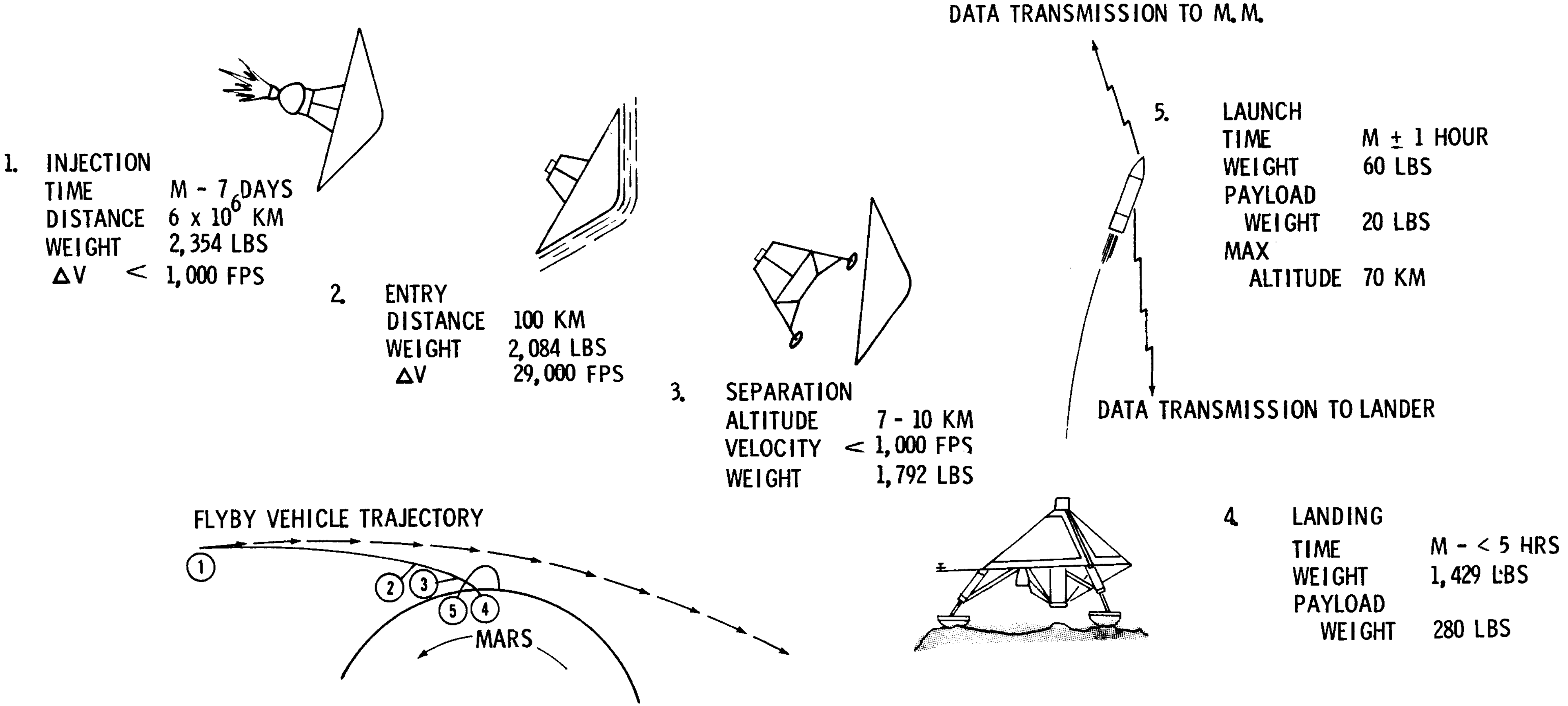

FIGURE E-1 LANDER PROBE MISSION PROFILE

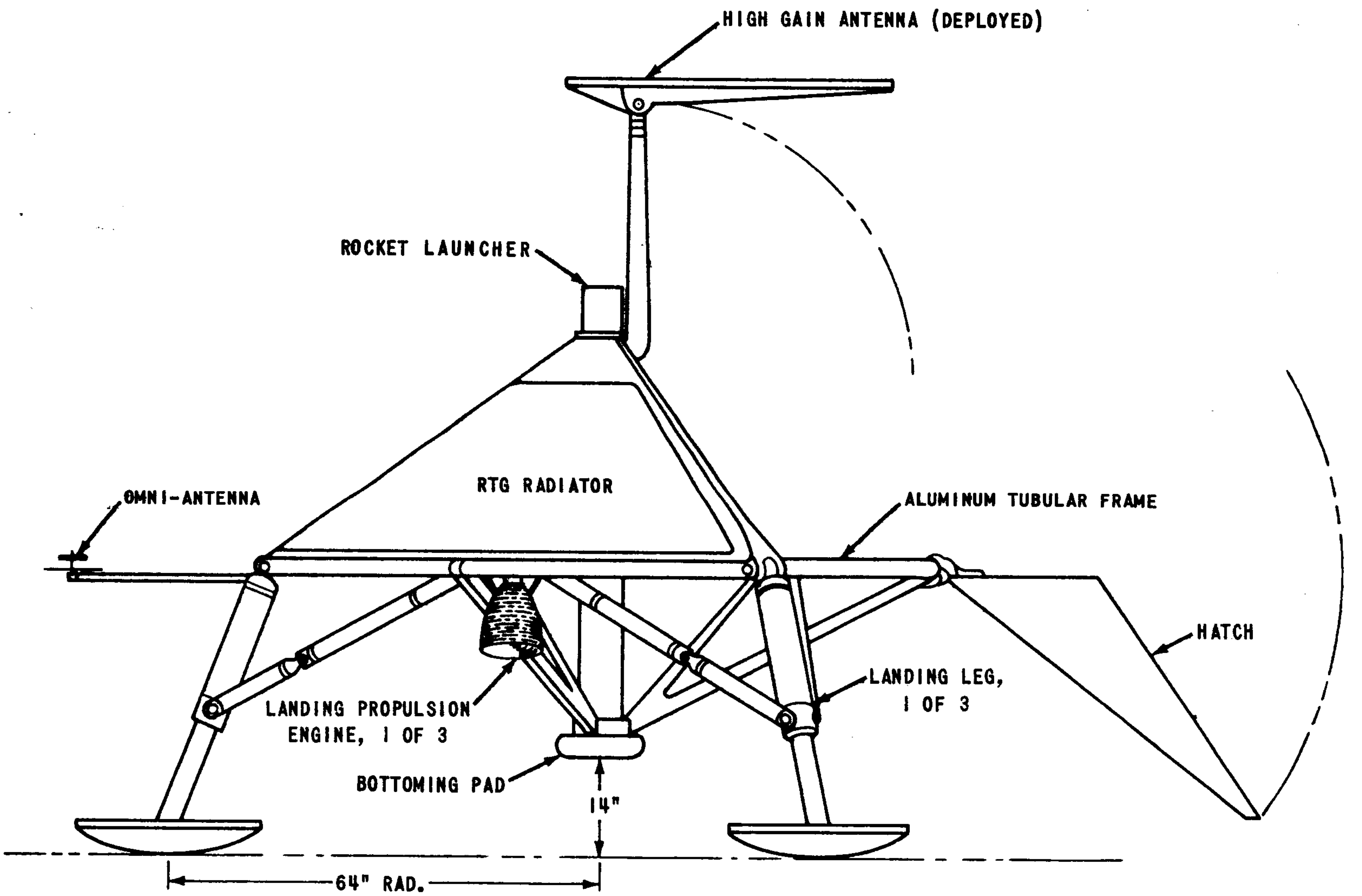

FIGURE E-2 LANDER PROBE (LANDED CONFIGURATION)

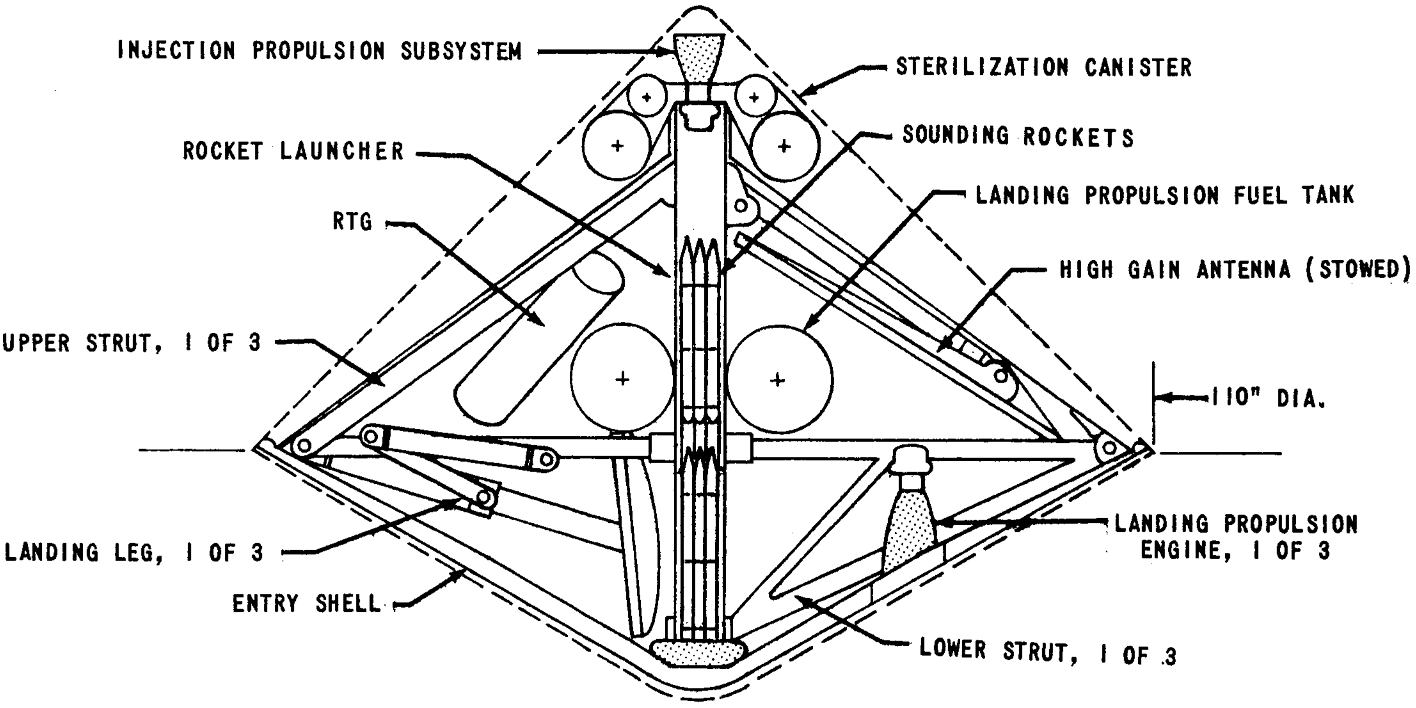

FIGURE E-3 LANDER PROBE GENERAL ARRANGEMENT (FLIGHT CONFIGURATION)

APPENDIX F

EN ROUTE EXPERIMENTS FOR MANNED MARS FLYBY

One important phase of the 700 day manned Mars flyby mission currently being considered as a possible space goal for 1975 is the program of scientific experiments to be carried out en route. While the Mars observations themselves are, of course, the principal goal of the mission, these additional experiments can add tremendously to our total present knowledge in important areas of astronomy, physics, and biology. The availability of a large, manned, well-equipped space station, stably oriented in space far from Earth for over 600 days of prime space observation time, represents a great opportunity for the advancement of space science.

These en route experiments can be considered in two groups. Part I of Appendix F describes experiments that are particularly attractive because of the actual geometry of the orbit - out beyond Mars to a distance of 2.2 A.U. on the opposite side of the sun from the Earth and back. In Part II are experiments that could also be done from Earth orbit but which, because of their importance, should be included in any early 700 day space mission. A summary of the equipment needed for the en route experiments is given at the end of this section in Table F-1. Rough estimates of crew-time needed for these experiments, plus Mars data taking and analysis indicate that a four-man crew will be kept occupied for the entire mission.

PART I

The following experiments are particularly attractive because of the proposed Mars mission orbit geometry.

1. Solar Observations

Solar observations made possible by this mission promise a particularly rich scientific return. The one meter telescope should be used to study solar phenomena.* An Earth orbital manned station equipped with a telescope of the same or greater capabilities is needed to optimize these observations. For the first time simultaneous manned telescopic observations

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*It appears at this time that, with proper emphasis on thermal design problems, the same telescope used for planetary and stellar observation can be used for solar observation without compromising either goal.

of the sun will be possible from two points widely separated in the angle subtended at the sun. Stereo views will make possible three dimensional reconstruction of flares, spots, and surface structure at a resolution of about 250 km - smaller than ever yet attained from Earth. Particularly useful for the elucidation of plasma-magnetic interactions will be such stereo views of the fine structure of the photosphere and fine resolution of the luminous manifestations of magnetic field structures, both general and spot-associated. Stereo views of the fine structure of the chromosphere in H_2 and calcium K line can be made with appropriate filters. By synchronizing exposures at the two telescopes and taking timed sequences, velocity of motion of all parts of the field can be determined. UV and IR photographs and spectrograms can be taken of the entire disk through the telescope. The accessory equipment required for the telescope is shown in Table F-I. By observing the sun from opposite sides, as will be possible during the midpoint of the mission, spot development lasting several 26-day solar rotations can be followed continuously. To obtain high resolution white light coronographs, external occulting disks, possibly with internal optical baffles, will be used on the one meter telescope.

A Bragg crystal X-ray telescope will be needed for scanning the solar disk with moderate angular resolution (about 5' arc) in the range 1 Å to 20 Å. A grazing incidence imaging telescope will be needed to cover the soft X-ray and far UV range 20 to 300 Å.

The total solar observation equipment will thus consist of the one meter telescope with accessories, plus a much smaller and lighter group of X-ray, UV, and cosmic ray telescopes also pointed toward the sun.

The large telescope could profitably be used about one-half of the entire mission making solar photographs. This must be scheduled early in the outbound phase or on the return phase so as not to interfere with required Mars observations. For optimum coverage flare activity should be monitored by means of Hα emission on a regular basis, and when activity occurs, rapid photographic coverage (up to six frames per minute) will be needed. The total solar information stored, about 10^{14} bits, will require about 500 lbs of film. The smaller solar telescopes will operate automatically except for scale range and data rate changes commanded by the astronauts and will represent far lower data storage. (See Table F-I).

For correlation with these telescopic observations, a complete set of data on other solar emissions will be needed. These will include a plasma probe to monitor energy, flux and direction of low energy solar protons and electrons in the solar wind, and a solar cosmic ray telescope to detect high energy particles during flare events.

By comparing the high energy emissions reaching the Mars module and the Earth orbiting station, far better separation of the spatial and time variations can be made than is possible from the Earth alone. Thus, for example, highly directional flares may show up at one station but not the other.

A three-axis magnetometer is also required to monitor the strength and direction of the interplanetary magnetic field throughout the mission, both for its intrinsic interest and because this has an important bearing on all charged particle radiation detected at the spacecraft. The interaction of this magnetic field with the solar wind is of particular importance both in space and near Earth, Mars, and Venus.

Valuable information on electron density in the sun's corona can be obtained during the solar occultation of radio waves emitted by an Earth transmitter and received at the spacecraft. The change in effective path length is proportional to electron density and inversely proportional to the frequency squared. Hence, by using two frequencies such as 400 Mc and 50 Mc the measurement is self-calibrating and permits separation of the electron density effect from the relativistic change in path length due to the sun's gravitational field.

2. Astronomy (Using a One Meter Telescope)

One of the principal items of astronomical interest in this mission will be the telescopic observation of the moons of Mars - Phobos and Deimos. The spacecraft will pass well within 10,000 km of each, the exact proximity depending on their phase at time of encounter. Other bodies passing close to the orbit will be certain known asteroids (see chart below) and other unknown asteroids or comets whose characteristics and orbits can be determined on the mission. No great advantage exists in photography of the other planets for this mission.

Photography and polarimetric observation of Zodiacal light at various points in the solar system and of the libration regions of Earth, Mars, and Venus will be of great interest. Photographic and spectrographic information on airglow in the Martian atmosphere during passage on the night side of the planet should be sought.

ASTRONOMICAL OBJECTS

		Time in Mission	Closest Approach	Least Distance From Earth
PLANETS:	Jupiter	30 Days	4.16 A.U.	4.2 A.U.
	Saturn	220 Days	7.64 A.U.	8.54 A.U.
MARS MOONS	Phobos & Deimos	147 Days	<10,000 km	0.5 A.U.
ASTEROIDS:	Medusa	300 Days	0.2 A.U.	1.03 A.U.
	Xanthippe	450 Days	0.14 A.U.	1.11 A.U.

3. Micrometeoroid Collection

Since the flux of micrometeoroids is expected to change considerably along the spacecraft's path from Earth to beyond Mars, it will be important to have two or more experiments designed to record, collect, and analyze such particles over a large range in size and velocity. The direction of incidence will be an important parameter to measure throughout the mission, but particularly beyond Mars, where it is expected to find particles in definite orbits near the asteroid belts. The elemental composition of these particles is of great interest, since they may date back to very early epochs. Hence, an analyzer that traps some of these, allows them to impact and vaporize on a clean surface, ionizes them, and then analyzes them in a mass spectrometer is proposed.

4. Galactic Cosmic Radiation

This should be monitored during the entire trip for flux intensity, energy level, and directionality. Variation in these parameters with position in the solar system and possible fluctuation in time are of interest. Simultaneous monitoring of the same kind on Earth will be needed for control.

5. Accurate Solar System Measurements

The spacecraft's range and velocity relative to Earth will be determined throughout the mission by the time delay and frequency shift of signals transmitted from Earth to spacecraft and returned by a spacecraft phase coherent transponder. This method, already used on Ranger and Surveyor, is in principle capable of a range accuracy of one or two wavelengths, though absolute range accuracy is much lower due to uncertainty in the velocity of light and in the gaseous and electron content of interplanetary space.

This mission possesses the attractive feature that the spacecraft will be able to determine its position very accurately relative to Mars or Venus at close encounter by use of telescopic position fixes against known star backgrounds. The time of observation will be precisely determined by the spacecraft clock. This position together with the accurate range data will give the distance between Earth and Venus or Earth and Mars to an accuracy essentially equal to the high accuracy of the Earth-spacecraft range.

The present standard of solar system distance is based upon the Earth-Venus distance measured by non-coherent radar reflection in 1961 where the error was about ±150 km, giving an error in the A.U. of about 2 in 10^6. It is accepted that this error could have been reduced by reflection from a phase coherent transponder by perhaps a factor of as high as 10. We conclude then that the present mission should permit an improvement in the accuracy of the astronomical unit through measurements to Mars or Venus by a factor of over two. The limitation in accuracy will then certainly be that in the accuracy of the velocity of light, which in turn may be expected to improve steadily.

6. Relativity Experiments

If an atomic clock, now available accurate to one part in 10^{11} over many months, is carried on the spacecraft, the time contraction due both to the spacecraft's velocity relative to the Earth and to its operation in a markedly different gravitational field from that of the Earth should be measurable over the long duration of the flight or as it passes the sun. The velocity contraction should be on the order of one in 10^9 and therefore observable to about 1% accuracy by the atomic clock standard.

A further check on the general theory of relativity can be carried out by measuring the change in transmission time of a radar beam sent from Earth to spacecraft and reflected to Earth past the sun at solar occultation. A phase coherent transponder system should permit an improvement of a factor of two to 10 over the experiment presently proposed by Shapiro (M.I.T. Lincoln Laboratory) to reflect the radar beam from Venus as it is occulted by the sun.

7. Bistatic Radar Observations

Bistatic radar experiments with the source on the Earth and the receiver on the flyby vehicle will increase our knowledge of planetary surface characteristics compared to what we have learned from strictly backscatter measurements with both source and receiver on Earth. Attention should be devoted to Venus and Mars.

8. Radio Astronomy

Monitoring of radio noise intensity in the low frequency range - 100 kc to 10 Mc - will be of particular interest at points in the mission far from the Earth which is itself an active radio noise source. Depending on the type of large antenna that can be deployed, directional information on the radio sources may be obtained and would be of great interest.

PART II

In this section we list experiments that could also be done from Earth orbit, but which should be strongly considered for an early long duration mission such as this.

1. Optical Astronomy

Measurements above the Earth's atmosphere will allow observations at UV(down to 912 Å) and IR wavelengths. These data can be used to determine the spatial distribution of H_2, which may be a large part of the mass of our galaxy. Improvements in resolution by elimination of atmospheric distortion should allow extended measurements of the cosmic distance scale (assuming a one meter diffraction limited telescope) by measuring the angular diameter of the hydrogen emission region surrounding early-type stars. In addition, high resolution photographs at several wavelengths should be taken of star clusters, nebulae, and galaxies.

2. X-Ray Astronomy

One of the most exciting new fields in space physics is X-ray astronomy. Rocket measurements have identified about a dozen discrete X-ray sources, all of which are concentrated toward the galactic plane. To date only one source, the Crab Nebula, has also been identified with an optical or radio source. Higher resolution detectors, such as those already described for solar observation, based at stable space platforms should be able to resolve many more sources, and in addition study the internal structure of individual sources. Spectral measurements and polarization studies will supply additional information on the nature of X-ray sources.

Hopefully X-ray astronomy will develop into a powerful tool for studying problems of cosmological interest such as the origin of cosmic rays, the strength of galactic and intergalactic magnetic fields, and the composition and density of galactic and intergalactic matter.

3. Physics

In addition to the relativity experiments in Part I, experimental investigations of the general theory of relativity could be carried out by measuring the gravitational bending of star light during the occultations by a planet. The measurement could also be carried out for the case of the sun by using a coronograph so that the star could be observed through the solar atmosphere. While this measurement has been made on the Earth, a much better determination could be made in the absence of atmospheric distortion.

4. Biology

There will be a prime opportunity for biological experimentation under zero-g conditions for a continuous period of over 600 days in a large space capsule already well provided with biological apparatus for study of the Mars samples. Earth-based life systems may be used as controls for Mars samples. The presence of an astronaut trained as a biologist in microscope techniques would greatly enhance the returns. Precautions would have to be taken, of course, to avoid contaminating instruments sterilized for Mars sample analysis with Earth life forms.

TABLE F-I - EN ROUTE EXPERIMENTS (1)

INSTRUMENT	CHARACTERISTICS	MEASUREMENTS	TOTAL BITS	WEIGHT LBS
One meter diffraction limited telescope and film.	Cassagrain optics, focal length 5 to 20 meters. From 800 Å to 100 μ. Tethered mode.	Rapid sequence photography of flare activity; single frame exposures of planets, stars, etc., at 10 min intervals.	$5x10^{13}$	3500
Telescope accessories: IR spectroscope and detectors	1 μ to 100 μ	Magnetograms of sun (Zeeman lines). IR spectrograms and photographs of sun and stars.		50
UV spectroscope and detector	800 Å to 3000 Å	UV spectra and photographs of sun and stars		50
Lyot filters for H_2 and calcium K line		Observations of chromosphere		10
External occultating disk on boom		White light coronagraphs		50
Image intensifier for dim light photography		Libration region and Zodiacal light photography		10
Solar wind plasma probe	Hemispherical energy analyzers. Protons from 100eV to 15 KeV. Electrons from 5eV to 1 KeV	Monitor flux and direction of solar wind		10
Phase coherent radio transponder at 400 Mc, 50 Mc	Antennae on spacecraft	Measure solar coronal electron content at occultation by frequency shift		50

TABLE F-I - EN ROUTE EXPERIMENTS (2) CONT'D

INSTRUMENT	CHARACTERISTICS	MEASUREMENTS	TOTAL BITS	WEIGHT LBS
X-ray telescope and detector	1 to 20 Å, Bragg Crystal Type 0.1° collimation	X-ray map of solar disk, activity during flares; search for new X-ray sources	10^8	30
Soft X-ray - Far UV telescope and detector	20 Å to 100 Å Grazing incidence imaging type	Solar disk X-ray map	10^8	50
UV spectrograph	100 Å to 800 Å	Solar disk spectroscopy	10^6	20
Cosmic ray telescope	Protons 10 to 200 MeV	Solar and galactic cosmic particles	10^6	100
Gamma ray telescope	10 to 200 MeV	Search for cosmic gamma sources	10^6	200
Magnetometer	3-axis, 0.1 gamma	Continuous monitor of interplanetary magnetic field	10^8	10
Trapped electron and proton detectors	Protons 1 to 100 MeV; electrons 0.1 to 5 MeV Solid state detectors	Search for high energy trapped particle belts near Mars and Venus	10^6	20

TABLE F-I - EN ROUTE EXPERIMENTS (3) CONT'D

INSTRUMENT	CHARACTERISTICS	MEASUREMENTS	TOTAL BITS	WEIGHT LBS
Micrometeoroid Detectors	Thin film capacitors in banks.	Flux, energy, and direction of particles	10^8	20
	Microphone type	Flux and energy		20
Micrometeoroid analyzer	Traps particles on clean surface, ionizes them, and does mass-spectrometer analysis	Chemical composition of particles		50
Coherent S-band radar transponder	Communication channel as well as ranging	Range and range rate measurements to nearest wavelength.		100
Atomic clock	Cesium vapor; stable to 1 in 10^{11} for several months	Time synchronization S/C to Earth. Relativistic time shift on spacecraft		65
Biological apparatus, including microscopes, spectrometers, chromatography equipment, culture media, nutrients, and control plants and animals.		Used both for Earth life control experiments and Mars sample studies		300
Biomedical analysis and conditioning equipment		Determine and maintain crew health.		100
		Total Instruments		1315
		Telescope and Film		3500
		Total En Route Instruments		4815

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