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FINAL REPORT

NASA Grant NGR 05-007-273

Mariner Venus-Mercury Flyby Mission

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March 31, 1971

Background

The Institute of Geophysics and Planetary Physics of the University of California, Los Angeles, requested support for participation of the magnetometer instrument team on the Mariner Venus-Mercury Flyby Mission. The magnetometer team is directed by the principal investigator, Dr. Paul J. Coleman, Jr.

Progress During the Reporting Period

The magnetometer team held several meetings to prepare a final report on the magnetometer instrument. The final report was prepared and submitted to the Mariner Venus-Mercury office. During the reporting period, Dr. Coleman also attended the scheduled Mariner Venus-Mercury Science Steering Group meetings.

Included as part of this final report is one copy of the "Final Report of the Magnetometer Instrument Team for the 1973 Mercury-Venus Mission Design Study."

FINAL REPORT OF THE MAGNETOMETER INSTRUMENT TEAM for the 1973 MERCURY–VENUS MISSION DESIGN STUDY

National Aeronautics and Space Administration
Grant No. NGR 05–007–273

Publication No. 839

Institute of Geophysics and Planetary Physics
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Final Report of the Magnetometer Instrument Team for the 1973 Mercury-Venus Mission Design Study

National Aeronautics and Space Administration
Grant No. NGR 05-007-273

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I. INTRODUCTION

A. Objectives of the Magnetometer Team

The magnetometer team was selected by the National Aeronautics and Space Administration to participate in the planning of the Mariner Venus-Mercury 1973 (MVM 73) mission. The objectives of the team, as specified by NASA, were as follows:

1. To specify the scientific objectives of the experiment. In practice, there were two parts to this objective. The first was to assist in the development of the scientific objectives of the mission as a whole, and the second was to develop scientific objectives of the magnetic field experiment.
2. To generate the specifications for the instrumentation.
3. To recommend primary and alternate instrument mechanizations. In practice, the efforts of the team were directed toward specifying the least expensive instrument that would meet the scientific objectives. As a consequence, no alternatives are discussed.
4. To participate in spacecraft and mission tradeoff studies. In meeting this objective, we assisted project personnel in planning mission operations, selecting the trajectory, and designing the

spacecraft so that the magnetic field measurements would meet the scientific objectives.

B. Background

Early in the course of this work, it became apparent that the budget for the mission was too small either to accommodate a sophisticated magnetometer experiment or to support a stringent program to control the magnetic field of the spacecraft. Since that time, the goals of the magnetometer team have been a spacecraft and a mission that would provide the best magnetic field data obtainable with the available funds. Of course, the things that are best for any single experiment are not always best for the other experiments or for the project as a whole. Consequently, we, along with everyone else, have made a number of compromises.

To give two examples: The magnetometer that will be described here is a relatively simple instrument. There is no internal data processing other than output filters and there is no flipper for the sensor. Secondly, the magnetic field interference specifications are not as stringent as we had originally desired.

Because of the high data rates that will be available, we recommended the elimination of much of the onboard signal processing originally thought necessary. We eliminated the sensor flipper and relaxed the specifications on magnetic interference because 1) for the first time, a Mariner spacecraft will include a separate magnetometer boom (see Figure I.1); 2) because stronger fields should prevail in interplanetary space between the earth and Mercury; and 3) because techniques have been developed for using naturally occurring field rotations and spacecraft roll maneuvers to measure the total error field, i.e., the spacecraft field and magnetometer zero level error.

Although these are the main compromises, several others were made as well. In each instance, our recommendation was based primarily on cost advantages. However, no compromise was made that would, in our opinion, eliminate any of the stated scientific objectives of the experiment.

C. Remarks on the Contents of this Report

In this report, we will describe the simplest instrument that the team considers adequate to meet the scientific objectives, the magnetometer-spacecraft interface, and the requirements for the experiment. We will include a specification on the magnetic fields of spacecraft hardware and some discussion of this specification.

At the last meeting of the MVM 73 Science Steering Group (SSG), program personnel from NASA Headquarters described some of the procedures under which the proposals will be evaluated. In the final section of the report, we have included some of the reactions of the team to these changes and some recommendations to NASA on the subject of proposal evaluation. We have also summarized our technical recommendations.

MARINER VENUS/MERCURY 1973

SPACECRAFT CONFIGURATION

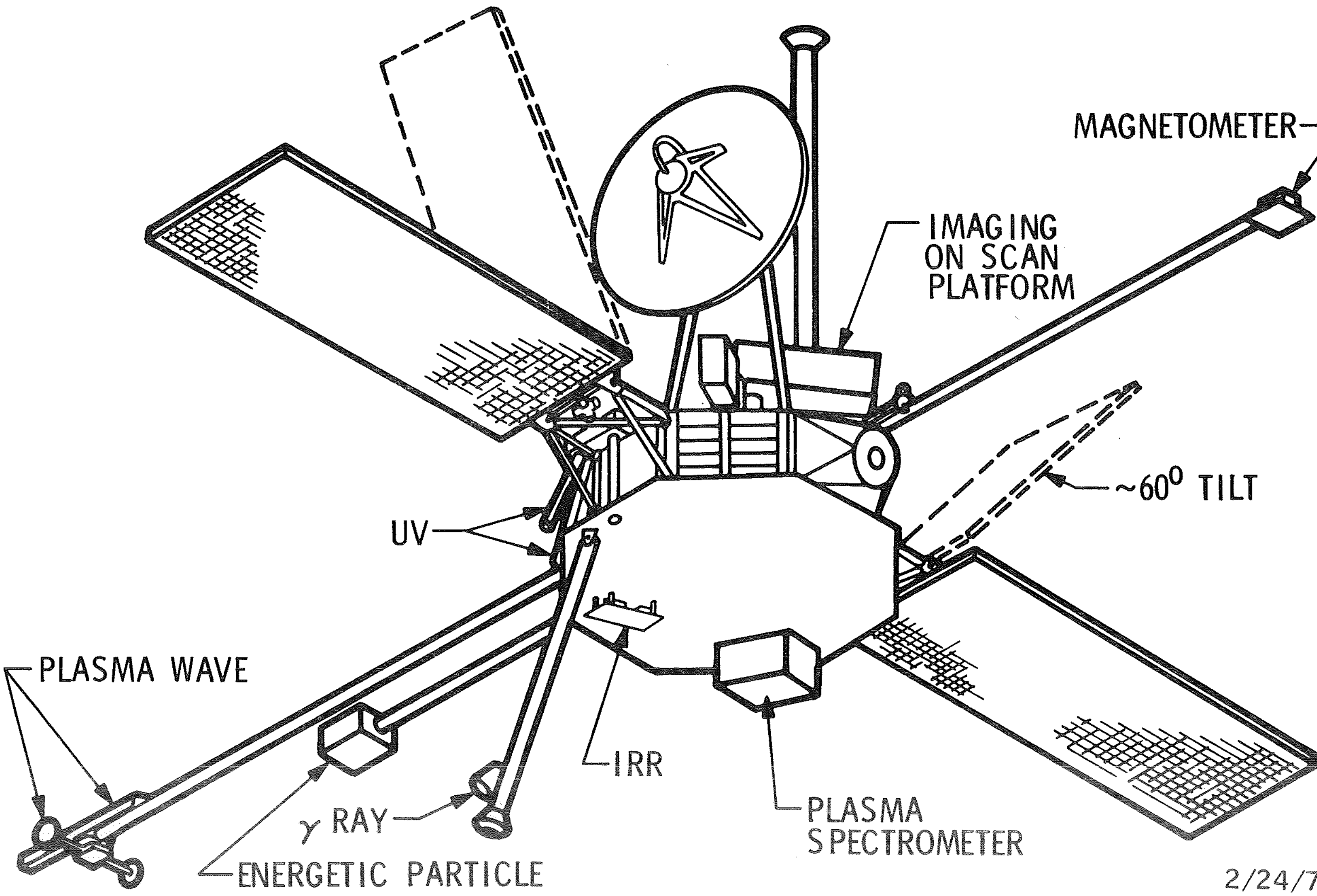

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Figure I.1

II. OBJECTIVES OF THE EXPERIMENT

A. Overall Scientific Objectives of the Mission (NASA)

The National Aeronautics and Space Administration (NASA) has established broad objectives of the MVM 73 mission, as follows: The primary mission objective is to conduct, during the 1973 opportunity, exploratory investigations of the planet Mercury's environment, atmosphere, surface and body characteristics and to obtain environmental and atmospheric data from Venus during the flyby of Venus. First priority is assigned to the Mercury investigations.

The secondary objectives are to perform interplanetary experiments while the spacecraft is enroute from earth to Mercury, and to obtain experience with a dual-planet gravity assist mission.

It is generally assumed that data obtained to satisfy Venus objectives would be obtained by using instruments primarily designed for use at Mercury.

B. Detailed Scientific Objectives of the Mission (SSG)

The Science Steering Group (SSG) recommended specific scientific objectives for the MVM 73 mission. No relative priority is implied in the following list of these objectives.

Mercury

1. Obtain imagery of the surface of the planet. This objective involves identification of gross planetary physiography, morphology of surface features,

determination of the photometric properties of local surface features and the determination of the shape and spin axis orientation of the planet.

2. Detect and measure an atmosphere and ionosphere, if present. This objective involves investigation of the interaction of a minimum atmosphere with the solar wind.
3. Characterize the surface thermal properties of Mercury. To satisfy this objective requires determination of thermal physical properties of the surface and anomalies in the temperature-phase relationship associated with physiographic features.
4. Determination of the plasma environment in the vicinity of Mercury. Development of this objective requires measurement of the characteristics of the solar wind interaction at the planet, quantitative measurements of any trapped radiation, and investigation of wave-particle interactions near the planet.
5. Determine the magnetic field environment in the vicinity of Mercury and relate the observed field to an intrinsic magnetic field of the planet or to the solar wind interaction with Mercury.
6. Obtain measurements which are directed toward establishingthe composition of the surface of the planet.
7. Obtain data which will improve the existing information relative to the gravitational potential, mass

and shape of Mercury and ephemeris of the planet.

Venus

1. Obtain data which will help to qualify the unknown parameters of the atmosphere, such as structure, circulation patterns, composition and distribution.
2. Extend existing knowledge regarding the interaction between the solar wind and Venus. Measurements should include plasma, plasma waves, magnetic fields, energetic particles and the composition of low energy ions.
3. Improve existing data relative to the mass, ephemeris and gravitational parameters of Venus.

Interplanetary Space

1. Study radial gradients of magnetic fields, plasma parameters, charged particle characteristics and plasma waves in interplanetary space.
2. Explore the plasma instabilities and collisionless interaction phenomena that must occur in the inner solar system and relate these to plasma characteristics observed near the earth.
3. Collect information relative to the dynamics of the solar system.
4. Seek data on energetic processes in the solar atmosphere during flares.
5. Obtain data on diffuse spectra which originate outside of the solar system.

Extended Mission

1. Collect data to determine relativity metric parameters.
2. Explore the solar corona by measuring electron content and magnetic fields.
3. Obtain data on the oblateness of the sun.
4. Maximize the possibility of re-encountering Mercury after reaching solar superior conjunction.

C. Objectives of the Magnetometer Experiment

The primary objective of the mission as defined by the NASA is the study of Mercury. Accordingly, the magnetometer team established objectives for the magnetometer experiment which, in order of priority, are as follows:

Mercury

1. To determine whether Mercury has a planetary magnetic field. If the spacecraft passes through a magnetic cavity produced by a field from Mercury, the experiment would yield at least a measurement of the dipole moment, both magnitude and direction.
2. To determine the magnetic properties of the interaction of the solar wind with Mercury. If the planetary field is not encountered directly, the data on this interaction will also put upper limits on the dipole moment of any planetary field.

Venus

1. To extend the measurements of the magnetic properties of the interaction of the solar wind with Venus. An important feature of the mission is a trajectory that passes through the regions of solar wind-planet interaction at three planets, the earth, Venus, and Mercury. The interpretation of the data from the particles and fields instruments at Mercury will therefore be

facilitated by the experience gained in the analysis of data obtained with the <u>same</u> instruments during the earlier encounters with the two other planets.

Interplanetary Space

1. To determine how the interplanetary magnetic field and the fluctuations in the field change with distance from the sun. An important aspect of the MVM mission is its simultaneity with the Pioneer Jupiter mission. The latter will provide measurements of the field and its fluctuations between 1.0 and 5.0 AU.

For a discussion of these objectives the reader is referred to the experiment proposal submitted by the team in May 1969 [*Colburn et al.*, 1969].

III. INSTRUMENTATION

A. Introduction

In recommending the simplest instrument consistent with our scientific objectives, we chose the fluxgate rather than the helium magnetometer as the basic magnetometer despite the fact that our tests show that the helium magnetometer is somewhat more stable. We also chose a sensor without a flipping device. Further, the simplified instrument includes no internal data processing circuitry other than the output filters. However, this last simplification will be compensated for partially by the rather high data rates that will be available for the mission. Thus, it will be possible to study field fluctuations at frequencies up to the proton gyrofrequency, which in the spacecraft reference frame may be doppler shifted to 10 times its value in the moving plasma.

As stated previously, these simplifications were recommended primarily as a means of reducing the cost of the experiment.

B. Technical Considerations

1. Type of Magnetometer. On the basis of the experience of the team members, the team concluded that either a helium or a fluxgate magnetometer could meet the scientific objectives for the MVM 73 mission. Tests have shown that the performance of the helium magnetometer is superior in some respects to that of the fluxgate. However, experience has shown that the

helium magnetometer is somewhat more expensive than the flux-gate. The overwhelming importance of budgetary considerations for this particular mission led the team to select a magnetometer of the fluxgate type as the best instrument for the MVM 73 mission.

2. Dynamic Range. The capability to accurately measure a dipolar field at Mercury, if the spacecraft penetrates a magnetosphere, requires a dynamic range at least several times 10^3 γ. For a solar wind of proton number density $n_p = 30$ cm^{-3} and velocity $v = 400$ km/sec, the stagnation pressure is roughly $9 \cdot 10^{-8}$ dynes cm^{-2}. If this pressure were balanced by magnetic pressure alone, the required field strength would be about 150 γ. The solar wind parameters used here are extrapolations to 0.4 AU, using Parker's solar wind model, of the values $n_p = 5$ cm^{-3} and $v = 400$ km/sec, which are typical of the solar wind near 1.0 AU. Since proton number densities as high as 80 cm^{-3} and velocities as high as 800 km/sec were observed during previous Mariner flights, the stagnation pressure can be as great as 64 times the value of $9 \cdot 10^{-8}$ dynes cm^{-2}. Thus, the stagnation field could be as large as 1200 γ. A dynamic range of four times this value, or 4800 γ, will therefore insure that, if the spacecraft encounters a planetary magnetic cavity, the magnetometer will not saturate before providing measurements adequate to determine the magnitude and orientation of the planetary dipole moment.

Intermediate sensitivities should be based on estimates of the disturbed fields in interplanetary space near 0.4 AU and the fields to be expected in the interaction regions (magnetosheaths) near the planets. Thus, intermediate dynamic ranges of $\pm 300\ \gamma$ and $\pm 1000\ \gamma$ should be adequate. A lowest range of $\pm 100\ \gamma$ would provide high sensitivity measurements of the interplanetary field, i.e. $0.2\ \gamma$ per bit. This sensitivity is compatible with our estimate of the magnetic noise from the spacecraft.

3. Frequency Response. To study field fluctuations that are likely to affect the thermal component of the positive ion velocity distributions, the magnetometer system should provide field measurements at frequencies up to 10 Hz. This upper limit exceeds the Doppler-shifted proton gyrofrequency. It is also the highest frequency at which the level of interplanetary field fluctuations near 0.4 AU is likely to exceed the noise level of the magnetometer system.

4. On-board Data Processing. In deciding how to obtain data on the field variations over the bandwidth from 0 to 10 Hz, one must choose between a low bit rate experiment which includes circuitry capable of performing on-board computations of spectral properties and a high bit rate experiment in which these computations are unnecessary. With a 40-bps data rate, the vector field could be sampled at a rate high enough to accommodate fluctuations in the band 0 to 0.5 Hz. The properties of the spectrum between 0.5 and 10 Hz could

then be measured with equipment on board and the results, probably, averages over relatively long intervals, could be telemetered by using only a small fraction of the data rate available for the magnetometer experiment. For a 1 kbps experiment the data rate would be high enough to accommodate vector field measurements with a bandwidth 0 to 10 Hz. The latter system, in which the waveforms of the three vector components are transmitted directly to the earth, is the best approach to a minimum experiment. The high data rate provides the information in its most useful form because once the data have been received they can be processed using the most sophisticated computational techniques available.

In recommending a minimum magnetometer experiment, the team has considered cost tradeoffs between sophisticated on-board signal processing and the simplified 1 kbps experiment with more extensive ground handling. The higher data rate results in the acquisition of more, high quality scientific data. Our conclusion that the high rate experiment is the least expensive is based on a comparison of the cost estimate for incorporating into the experiment 12 spectrum analyzers (4 per axis) and a waveform capture memory and the cost estimate for the acquisition of additional digital data tapes. In the opinion of the team, the simplified 1 kbps magnetometer experiment provides the most science for the dollar. Almost all the cost of the higher bit rate data is shifted to the acquisition and ground data handling. However, we made no attempt to estimate these costs, which will not affect the budget until 1973.

5. Sensor Flipper. The team gave serious consideration to including a sensor flipper in order to eliminate any uncertainty in the zero levels of the magnetometer sensors. However, on the basis of pre-flight tests and in-flight performance of the fluxgate magnetometers flown on Explorers 33 and 35, it was concluded that the long-term stability of such magnetometers is adequate to accommodate the scientific objectives of the mission without a flipper. The in-flight performance of the two sensors transverse to the spin axis of Explorer 35 exhibited zero level drifts from -.4 to +.6 gamma and -1.2 to 0.0 gamma during the first year of operation. For Explorer 33 the drifts were from +.4 to -.4 gamma and from -.6 to +1.5 gamma during the first year.

Other factors considered in arriving at this conclusion are essentially the same as those which led us to relax the specifications on the magnetic field from the spacecraft hardware, namely: stronger interplanetary fields between the earth and Mercury, the planned rolls of the spacecraft during several intervals in the flight, and the techniques for using naturally occurring field rotations for measuring the error field consisting of the spacecraft field and errors in the magnetometer zero levels.

C. Description of Minimal Instrument

A minimum experiment is one that is built from existing designs of proven flight quality and which includes only those circuits necessary to satisfy the principal scientific objectives of the mission. Throughout this study, the program office placed considerable emphasis on choosing a payload consisting of minimum instruments. Thus, in actuality, the task assigned to each experiment team was to recommend the best experiment that could be obtained under the specified budget.

In the case of the magnetometer experiment, the team considers that a valuable experiment can be performed with the minimal instrument provided that the requirements discussed below are fulfilled.

1. A 1000 bps data rate is available to the magnetometer experiment for most of the mission and especially during both encounters. A 1 kbps magnetometer data rate makes possible an extremely simple experiment consisting only of those elements common to any triaxial fluxgate instrument. The DC to 10 Hz triaxial waveforms would not be spectrum analyzed on the spacecraft, but rather transmitted to earth for laboratory analysis. However, this simple experiment will only be possible if the 1 kbps data rate is made available at both planetary encounters. The limited capacity for spacecraft data storage during earth

occultation may preclude this possibility, in which case either a limited amount of on-board spectrum analysis capability would be required in the experiment or the broadband DC to 10 Hz waveforms would be eliminated in favor of DC to 1 Hz waveforms during the data storage period. In either case, the amount of additional signal processing filters need not be very great, particularly for a favorable planetary encounter trajectory. For example, the $\theta = 21°$, 1000 km periapsis altitude trajectory for March 30, 1974 Mercury encounter would allow the spacecraft to pass through the optical shadow of the planet prior to earth occultation. Many, if not most, of the magnetometer experiment's principal scientific objectives could be satisfied using 1 kbps real-time data throughout this region. However, the important outbound shock front crossing may occur during the 15 minute earth occultation. In this case, a magnetometer data rate of 100 bps, which is perhaps more consistent with the spacecraft data storage capability, should provide the essential scientific information while necessitating as few as three additional filters.

2. The magnetometer sensor is boom mounted at a distance that will keep the total change in spacecraft magnetic field within acceptable limits (see Section V). The

presence of large, variable spacecraft magnetic fields causes data processing costs to soar while diminishing the amount of useful scientific information. A compromise is possible between the costs of imposing rigid magnetic constraints on the spacecraft hardware and those associated with a long boom. In the case of MVM 73, many subsystems have already been designed without regard to their magnetic properties. Consequently, the long experiment boom becomes an attractive practical alternative. It is not customary to consider the boom as part of the experiment, but rather as part of the spacecraft. The magnetometer team considers magnetic contamination to be a spacecraft interference problem which should be resolved in a manner similar to other incompatibilities between experiments and the spacecraft (e.g., EMI, optical viewing).

With an isolating boom available, a magnetometer system which is suitable for the MVM 73 mission should consist of a boom mounted sensor unit and a body mounted electronics assembly. The sensor unit must be capable of driving signals down the long boom cable to the electronics assembly without appreciable degradation. The recommended bandwidth for the instrument is 0 to 10 Hz. The electronics unit must include additional low pass filters to reduce the pass band, as required, to compensate for any reduction in the sampling rate below that consistent with the 0 to 10 Hz pass band.

D. Effects of Midcourse Motor Exhaust

The boom presently planned for the magnetometer sensor will place the sensor directly in the exhaust cone of the midcourse motor, as shown in Figure I.1. The effects of this exhaust on the temperature of the sensor and the thermal properties of the surface of the sensor unit have not yet been accurately assessed. However, the following material has been included to alert potential experimenters to the problem and to provide the information pertaining to the problem that is available to the team.

The midcourse rocket motor fires outward along the magnetometer boom toward the fluxgate sensor. For the present at least, it is the baseline configuration. It may well become the final configuration because the navigational aspects of the mission are simplified when the thrust vector is directed along one of the principal axes of inertia. The plume of the exhaust will extend well beyond the end of the boom. To aid in the calculation of the thermal insulation required at the sensor, we have included data on the plume heat per unit area per unit time, both along the axis of a cylindrically symmetric plume and also at points off axis, Figure III.1. More specifically, Figure III.1 [Sola, 1970] is a graph depicting a calculated exhaust plume profile for an idealized (i.e., no jet vane or support ring interaction) case using the 50 lbf MM'69 monopropellant engine. Lines of constant Mach number, M,

EXHAUST PLUME PROFILE

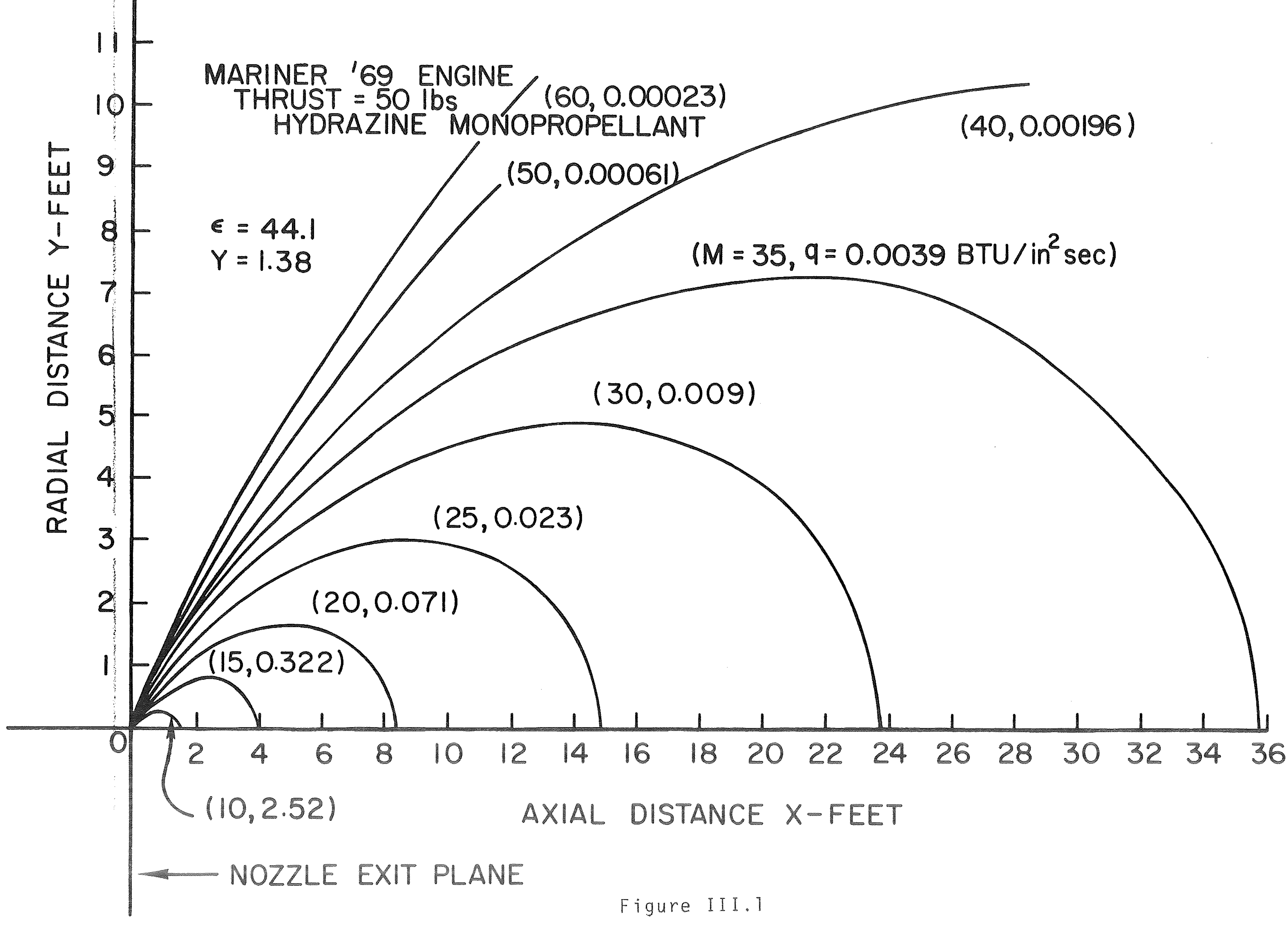

Figure III.1

and heat flux, q, are shown as functions of radial and axial distances. Axial distance, X, is measured from the nozzle exit plane and radial distance, Y, from the nozzle centerline.

The heat flux values are conservative since they are based on complete recovery of the energy in the exhaust stream. The effect of the jet vanes in deflecting the plume is complex and unknown at this time.

The baseline spacecraft has the fluxgate sensor 12 feet out from the exhaust nozzle and essentially on the plume axis. The graph shows that this arrangement will result in 0.04 to 0.05 btu/in^2-sec at the magnetometer sensor. This becomes 4 to 5 btu per square inch after the longest possible MVM 73 motor burn (90 seconds). In designing the sensor thermal blanket an experimenter should keep in mind that the subsystem test requirements on this project will specify that the experimenter perform his own temperature testing. JPL will not do any subsystem thermal testing on experiments. Thus, the experimenter must qualify the magnetometer sensor at a temperature 20°C higher than the highest operating temperature he calculates as a result of his thermal design. The project has no specific test temperature, but of course the magnetometer sensor thermal blanket must be designed to at least accommodate the continuous 140 milliwatt/cm^2 (0.00086 btu/in^2 sec) solar radiation at 1 AU and about 6-1/2 times that amount (0.0056 btu/in^2 sec) at 0.39 AU. By comparing these numbers with the rocket exhaust graph, one sees that the rate of heat flow per unit area at 12 feet back from the rocket nozzle will be about seven to nine times the amount due to the solar intensity at 0.39 AU. About 10% of the incident energy is likely to be deposited as heat in the sensor unit. A system of conical shields mounted at various positions along the boom and coaxial with it might shield the sensor significantly.

There may be four, possibly five, motor burns on this mission since it is entirely possible that the spacecraft may encounter Mercury a second time--176 days after the first encounter. The project now considers the second encounter feasible, in which case one or two of the burns would take place near 0.4 AU. The spacecraft is always reoriented during these maneuvers but the magnetometer sensor will probably still be exposed to the sun during the motor burn. Therefore, the combination of a high solar intensity and a long motor burn are likely to occur simultaneously.

At the other extreme, we are told that the surface temperature of a one half pound magnetometer sensor package can be expected to decrease by 150°F as the spacecraft experiences an eight minute solar occultation at Mercury. This estimate assumes a surface emissivity of 0.8. If an alternate Mercury encounter trajectory is chosen, that is, one which does not involve solar occultation, then planetary albedo may become an important consideration in thermal design.

Within the main body of the spacecraft, the project anticipates that experimenters will qualify their flightworthy prototype units at 75°C and acceptance test the flight units at 55°C--the highest expected operating temperature. The nominal temperature within the spacecraft bus is expected to be in the 10°C to 32°C range.

E. Summary Description of Minimal Magnetometer System

Magnetometer

Type:	Three-axis fluxgate
Sensors:	Example: low-noise, stable perm, NOL, ring cores used by NASA ARC.
Dynamic Ranges (γ):	±100, ±300, ±1000, ±5000, selected automatically
Corresponding Sensitivities (γ/bit):	0.3, 0.6, 3.0, 10.0, using 10-bit A/D conversion
Output Bandwidth:	0-10 Hz(before data processing)

Data Processor

High-Frequency Waveform

Bandwidth of Output Filters:	0-10.0 Hz	
Output Data:	B_x	10 bits
	B_y	10
	B_z	10
	Sensitivity State	2
Total Data:	32 bits per vector-field sample	
Readout Rate:	25 per second at 1000 bit/sec magnetometer readout rate	

Low-Frequency Waveform (If required during earth occultation)

Bandwidth of Output Filters:	0-0.5 Hz
Output Data:	Same as HF waveform
Total Data:	32 bits per vector-field sample
Readout Rate:	1 per sec at 40-bit/sec magnetometer data rate

Subcommutated Data (Spacecraft Subcommutator)

Temperatures, selected instrument parameters, instrument status

Power Consumption

Magnetometer:	4.0 w, exclusive of power for temperature control

Weight

Magnetometer Electronics:	3.0 lbs.
Sensor:	1.0
Total	4.0 lbs.

Volume

Magnetometer Electronics:	180 in^3
Sensor	27
Total	207 in^3 (assuming A to D conversion by spacecraft FDS)

Temperature Limits (Operating)**

Electronics:	-30 to +40° C
Sensor:	-30 to +40° C

Changes in Data Rate

To accommodate changes in the data rate in flight, the filters on the outputs will be changed automatically.

Spacecraft Fields at Magnetometer Sensor*(Desired)

Permanent and DC:	<10 γ
Fluctuating:	<0.1 γ rms (0-10 Hz)

*See Section V.

**See Part D of this section.

IV. MISSION REQUIREMENTS OF THE EXPERIMENT

A. Trajectory

The Science Steering Group concluded that a trajectory that includes both sun and earth occultation at Mercury is scientifically the most desirable of those of the possible trajectories for the Venus-Mercury mission. The group recognized the fact that this trajectory imposes a serious limitation upon the imaging experiment. However, if the budget permits, this limitation may be compensated for by the imaging instrumentation.

The following arguments led the magnetometer team to the conclusion that the dual occultation trajectory was the best of those available, at least insofar as the magnetic field measurements are concerned.

A flyby magnetometer experiment can best determine the electrical and magnetic properties of a planet by making measurements in the wake cavity which is created as the streaming solar wind interacts with the planetary body. The interactions are complex and extend far back into space. For the rapid flyby anticipated at Mercury, a solar occultation trajectory through the wake cavity will enable a high rate magnetometer experiment to obtain an ample number of samples in the interacting regions. With these samples, plus a knowledge of the solar wind properties obtained during the cruise phase of the mission, the magnetometer experiment team can identify the type of interaction taking place at Mercury and infer some of the physical properties of the planet. The team therefore favors a March 30, 1974, arrival at Mercury with a B plane angle of $\theta = 21°$ and a periapsis altitude of 1000 km.

This trajectory also provides an earth occultation shortly after the end of sun occultation. The earth occultation is of no value to the magnetometer experiment; in fact, it creates the necessity for storing data while the spacecraft is out of sight of earth. Nevertheless, the team endorses this trajectory as a compromise with the requirements of the spacecraft radio science experiment.

In some models of the solar wind-Mercury interaction, alternate trajectories which do not involve solar occultation do penetrate the outermost regions of the wake cavity. However, in other models they do not. Other things being equal, the closer the trajectory approaches the sun occultation region, the better are the magnetic field measurements. The closest approach to the sun occultation region should be as close to the planet as possible.

In general, this criterion applies to the Venus flyby, also. However, for a given arrival at Mercury, the Venus flyby trajectory is primarily determined by the earth launch date chosen. Further, of all the near-Venus trajectories which are possible for this gravity-assisted mission to Mercury, none will involve solar occultation at Venus. Consequently, the magnetometer team favors a Venus pass with a low periapsis altitude and which penetrates at least to the outer regions of the planet's wake cavity. This type of Venus encounter trajectory results from choosing a late launch date, say in November 1973. A November launch date is favored by the team because it also opens up the possibility of a second encounter of Mercury during the fall of 1974.

B. Data Rates and Data Storage

A magnetometer experiment will require data coverage for a substantial fraction of the six month mission. Significant information at the two planetary encounters will be supplemented by new data on the unexplored interplanetary region between earth and Mercury. Effective testing of theoretical models of the solar wind in the inner solar system requires nearly continuous measurements of fields and low energy plasma particles during the cruise phase of the mission. Since the Pioneer Jupiter spacecraft will be simultaneously traveling out toward Jupiter, the comparison of measurements of the interplanetary field taken with MVM 73 and Pioneer Jupiter will provide essential data on the physics of the interplanetary plasma.

The magnetometer can effectively utilize 1000 bps whenever the total spacecraft data rate is high enough to provide this allotment for the experiment. If circumstances dictate a lower data rate, say 100 bps, at various intervals during the flight, switchable filters can be included within the electronics unit to accommodate the lower rate. The sacrifice in scientific information will be acceptable so long as high rate data are acquired most of the time, i.e., for perhaps two-thirds of the cruise phase.

One approach that is attractive because of its simplicity is to design the experiment to operate at the same data rate during the low-rate cruise mode and during the data storage mode when Mercury occults the earth. We suggest that the project consider sizing the data storage to accommodate 15 minutes of science data at the lowest anticipated cruise telemetry rate. With this simplification in mind, the magnetometer data requirements can be stated as follows:

1. 1000 bps during high rate cruise mode and at the planetary encounters except during earth occultation.
2. 100 to 300 bps during low rate cruise mode and during earth occultation data storage mode.

The 100 bps rate corresponds to 90 K bits of data during a 15 minute occultation which might be accommodated by a quarter million bit science data storage buffer. Higher bit rates would probably require that science data be stored on spacecraft tape recorder.

The SSG made no attempt to establish or recommend a specific integrated operational profile for the payload. The magnetometer team feels that a preliminary operational profile should have been recommended by the SSG. Accordingly, we recommend that the project office give some consideration to developing such a profile as soon as possible.

C. Interplanetary Roll Maneuvers

The team recommends that the mission operations plan include at least two interplanetary roll maneuvers, one for each extreme in solar panel position. Additional roll maneuvers, e.g., one each month, would be very beneficial. The purpose of the spacecraft roll maneuver is to separate, on a statistical basis, spacecraft caused contributions to the magnetometer readings from those of natural origin. Each maneuver should consist of approximately 50 slow rolls about the spacecraft-sun line with a roll period of approximately 30 minutes per revolution.

D. Data on Mode Changes

Changes in the mode of operation of the spacecraft may cause small changes in the magnetic field at the sensor unit. Accordingly, the data tapes prepared for magnetometer experimenters should contain the specifics of any change in the mode of operation, for example, the mode of operation prior to the change, the mode of operation after the change, and the time at which the mode change occurred.

The term "mode" is used here to denote an operational state of the spacecraft. With regard to the magnetic field measurements, only those changes of state which are accompanied by changes in the magnetic field from the spacecraft are of interest. However, since the very small changes will be difficult to measure during pre-flight tests, it is desirable that data on any mode change be included as just outlined.

E. Data on Currents and Movable Apparatus

The data tapes provided to the magnetometer experimenters should also include data on the solar panel currents and the positions of any movable apparatus on the spacecraft. It would be desirable to telemeter the solar panel currents with an accuracy of 1 per cent. As a minimum, the current measurements should be provided before and after each mode change and once a day or perhaps once every few days during intervals during which no mode change occurs. Alternatively, the current could be measured periodically, say once a day during cruise and more often during encounter.

The positions of movable parts are also important. It is presently planned that the solar panels and the antenna will change orientation during the flight. These changes may be accompanied by small changes in the magnetic field at the sensor unit. Measurements of changes in the location (position) and orientation of the movable parts will be particularly important if they occur during either encounter.

If a choice is possible, incremental, rather than continuous, changes of movable parts are preferred. For example, two or three large changes in the orientation of the solar panels during the flight are preferable to a continuous and gradual change in orientation.

V. MAGNETIC-FIELD INTERFERENCE SPECIFICATIONS

A. Background

The team is confident that the spacecraft magnetic fields at the magnetometer sensor can be kept low enough to satisfy the requirements of the scientific investigation. Our confidence is based on experience with Mariners 4 and 5, where the permanent fields were 30 and 10 γ, respectively, at the magnetometer sensors. These fields were nearly constant throughout both flights. The fields due to DC electrical currents were small and constant and the magnetic noise due to varying currents and moving parts was generally below the magnetometer noise level. Furthermore, a procedure to determine accurately all three components of the spacecraft field with the spacecraft completely stabilized [Davis et al., 1968] has now been developed. This technique involves the use of the frequently-occurring rotations in the interplanetary magnetic field. These jumps are associated with contact surfaces that separate regions of distinctly different solar wind plasma. An accumulation of approximately one month's interplanetary data should provide a value of the spacecraft field components and the magnetometer error field accurate to better than 1/2 γ.

The same diagnostic procedures, and the preventive and corrective measures used on previous Mariners and OGO's to reduce the stray fields to tolerable levels, should prove effective on this mission. The techniques developed to measure the spacecraft magnetic fields by rotation about two axes in the earth's field can be used to verify, prior to launch, the adequacy of the magnetic control procedures. Demagnetization of the spacecraft prior to launch has been used successfully on several missions to reduce stray fields.

In discussing the advantages of a magnetometer boom, a distinction must be drawn between the absolute accuracy imposed on the magnetometer experiment by the scientific objectives of the mission and that which can be attained in the presence of a spacecraft-caused magnetic field. If the major interplanetary objectives of the Venus-Mercury experiment are to be satisfied, the magnetometer experiment must achieve an absolute accuracy of somewhat better than 1 γ.

Magnetometer experimenters are sometimes asked, "What is the largest spacecraft-caused magnetic field that can be tolerated before it becomes meaningless to fly the experiment?" The question is unanswerable in any precise sense, particularly in the early planning stages of a mission because field stability rather than field magnitude is the important parameter. However, in an attempt to address themselves to the legitimate intent behind such a question, the experiment team considers a 10 γ field to be the largest that can be tolerated with a <u>reasonable chance</u> of meeting the scientific objectives. This estimate, based in part on past experience with Mariner spacecraft, assumes the spacecraft magnetic fields will be stable to approximately 10%. It is obvious, however, that there are some risks to the success of the experiment in setting this criterion. The 10 γ figure is considered an upper limit (assuming the 10% rule-of-thumb holds). The increased size and general complexity of the Mariner spacecraft suggests it may be <u>difficult</u> to achieve the degree of magnetic cleanliness of previous missions. If the magnetometer were to be located at the end of the omnidirectional antenna, a field of 10 γ or less might not be attained. Furthermore, it is conceivable that system design changes could result in a field instability of, say, 50%, in which case a 10 γ spacecraft field would result in variations of 5 γ or so during the life of the mission. This would have a deleterious effect on the magnetometer measurements.

If the spacecraft long-term field variations equal or exceed the 1 γ limit imposed by the scientific objectives of the magnetometer experiment, complicated data reduction and analysis techniques must be employed to separate naturally occurring phenomena from drifts in the spacecraft field. For example, on Mariner 4 it was necessary to remove from the data a small field contributed by the solar vanes whose positions changed slowly during the mission. A considerable analysis effort was required in order to do this successfully. Careful removal of spacecraft fields requires the expenditure of inordinate amounts of both time and money. On earlier Mariner missions, by committing the necessary resources, it has been possible to carry out interplanetary field measurements on spacecraft having steady state fields in the 10 to 30 γ range. However, this placed the Mariner magnetometer experimenters in a compromising situation with some elements of the scientific community insofar as they might have been expected to demand essentially zero spacecraft fields. Nevertheless, we, along with a substantial fraction of the scientific community, are now convinced that sufficiently accurate measurements of field magnitudes and directions can be made in spite of difficulties associated with such spacecraft fields. Thus, our position remains as follows with regard to the Mariner Venus-Mercury mission: While a near-zero spacecraft magnetic field would make for ready acceptance of the scientific results, it is not an absolute requirement; however, <u>magnetic stability to less than 1 γ is a requirement</u> if data reduction costs are to be held down.

One advantage of the magnetometer boom is to provide adequate separation between the magnetometer experiment and the spacecraft-caused sources of DC and slowly varying magnetic fields. Since the dominant magnetic sources are dipoles, the inverse cube relation implies that doubling the separation reduces the effect by a factor of eight. The resulting benefits which accrue to the magnetometer experiment are:

1. The risks to the success of the magnetometer experiment are reduced.

2. The data reduction costs are reduced.

3. The scientific results will be more readily accepted by the scientific community.

There are additional arguments which favor a magnetometer boom on this particular mission and which did not apply to previous Mariners. The experiment proposed for the Venus-Mercury mission should study naturally occurring field variations at frequencies up to 10 Hz. Earlier Mariner magnetometers were essentially DC to 1 Hz instruments. The Mariners have never been tested for spacecraft magnetic field variations above 1 Hz and it is difficult to predict what difficulties reside in the next frequency decade.

In the same vein, the requirements for the plasma wave experiment proposed for the Venus-Mercury mission are even more stringent. The plasma wave experiment is intended to measure both electric and magnetic time varying fields with frequency components up to tens of kilohertz. Essentially nothing is known regarding the Mariner fields at these high frequencies. At some frequencies the plasma wave experiment has a threshold sensitivity 30 times greater than the magnetometer. Past experience with search coil magnetometers makes it seem extremely unlikely that one could hope to satisfy the requirements of the plasma wave experiment without placing the sensors at the end of a long boom. <u>The best way to meet the requirements of both experiments would be to use a long boom</u>. Ideally, the experimenters would prefer separate booms to avoid potential mutual interference problems. Furthermore, the symmetrical deployment of two booms on opposite sides of the spacecraft is attractive from the viewpoint of spacecraft dynamics.

Finally, it should be mentioned that on other projects, the magnetic requirements have been met by a combination of two tactics. Rather severe magnetic constraints were imposed on the experiments and spacecraft subsystems and an appropriate length boom was then used to reduce the field at the magnetometer sensor to a tolerable level. A long boom should result in a smaller spacecraft field at the magnetometer sensor and facilitate a reduction of the magnetic constraints imposed on the various subsystems.

B. Magnetic-Field Interference Specifications*

Mariner Venus-Mercury 73 equipment of a new design, or that which is modified, shall be compatible with the magnetic requirements as specified herein. Adherence to both the maximum magnetic field strength and field stability shall be required. The requirements are as follows, and as shown in Figure V.1:**

Permanent or Remnant Fields Due to Magnetic Materials

- Maximum radial field shall be within the limits shown in Figure V.1.
- The maximum radial field shall be stable to a value less than, or equal to, that shown in Figure V.1 under the following conditions:
  - After exposure to a 25 Gauss field, followed by demagnetization in zero field.
  - After movement or repositioning of magnetic materials (e.g., solenoids, stepping motor, scan platform, etc.)

Fields Due to Current Loops (DC to 0.01 Hz)

- The maximum radial field shall be within the limits shown in Figure V.1.
- Changes in the current loop field shall be within the limits shown in Figure V.1 under both of the following conditions:

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*Specifications set by project office [Swenson, 1970].
**Figure V.1 is derived from the specifications given in Table V.1.

- Any changes to the equipment operating mode or state.
- Long-term changes resulting from varying operational or mission parameters (e.g., solar panel currents, etc.).

Equipment as defined herein is spacecraft subsystem/assemblies which are carried as provisional spares and are delivered to SAF as a complete unit (e.g., CC&S, Canopus Sensor, RFS, etc.).

AC Magnetic Fields (0.01 Hz to 10 Hz)

AC magnetic fields shall be less than 0.1 gamma (rms) at a distance of three feet from the equipment. These requirements shall be exclusive of turn-on or turn-off transients.

Demonstration of adherence to the above may be required through the implementation of a magnetics control/evaluation program.

TABLE V.1

MVM '73 Magnetometer Team recommendations for magnetic constraints on entire spacecraft, expressed in terms of maximum allowable field or field change at the magnetometer sensor location (15' from center of bus).

Source of Magnetic Field	Maximum Allowable Field at Sensor	Maximum Allowable Change in Field	Comments Regarding Field Changes
Perm (remnant) magnetic fields due to ferro-magnetic materials	3γ	0.3γ	0.3γ perm field stability can be measured by 25Γ exposure followed by demagnetization in zero field (on a selective basis).
		0.2γ	Due to moving ferromagnetic material, solenoids, or stepping motors.
DC current loop fields	3γ	0.2γ/month	Measure steady state current loop field at each subsystem turn-on. Check all operating modes.
		0.1γ/month	Due to changes in solar panel currents as panel voltage varies. Request solar panel currents to be telemetered to 6 bits.
		0.3γ	DC step function due to change in operating mode (when the change in mode is documented in engineering telemetry).
		0.1γ	DC step that is due to change in operating mode that is not recorded in engineering telemetry
Field variations in the frequency range 0.01 Hz to 10 Hz due to AC currents		0.1γ rms	Exclusive of turn on transients.

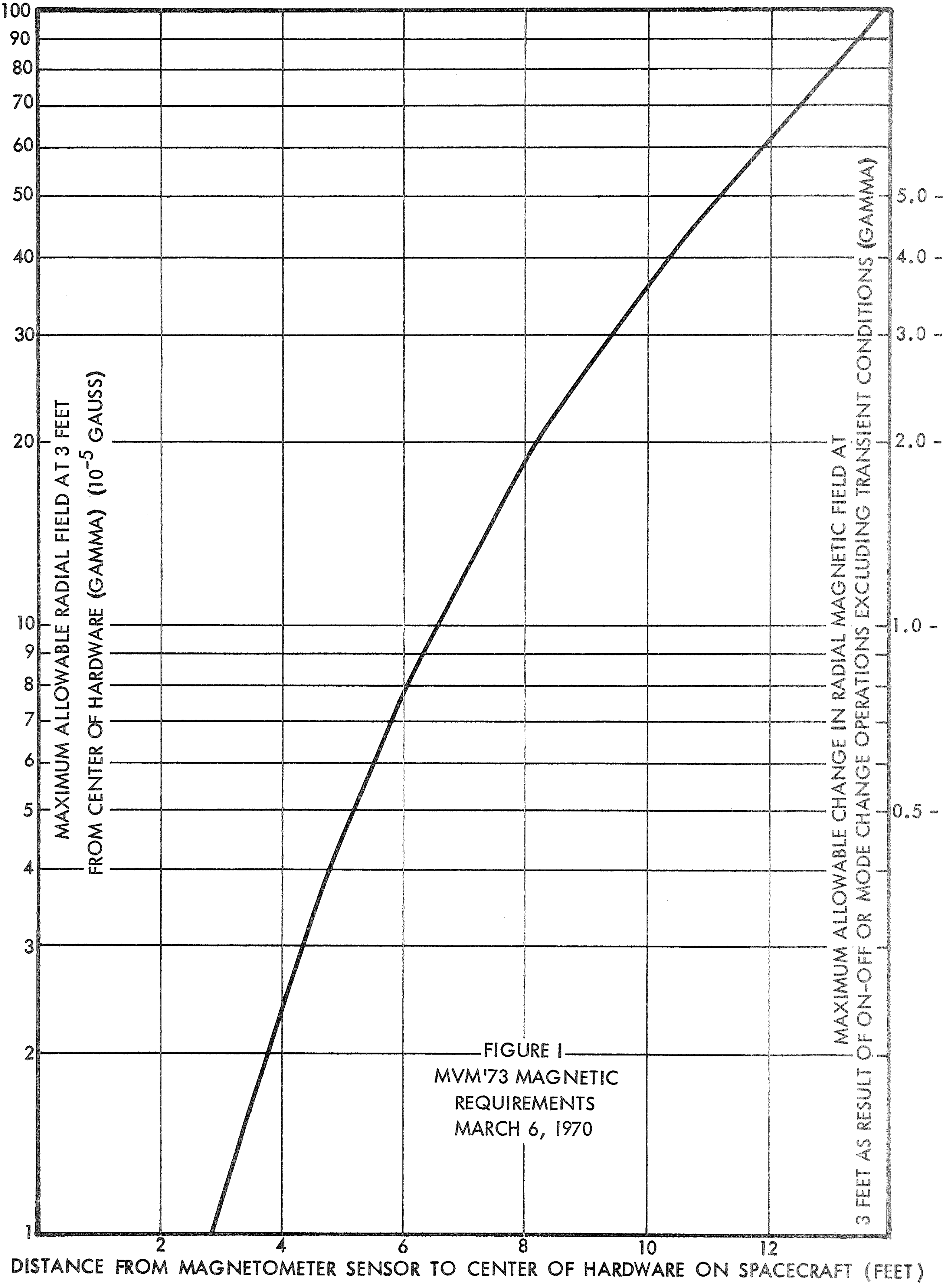

FIGURE I
MVM'73 MAGNETIC
REQUIREMENTS
MARCH 6, 1970

C. Procedures for Magnetic Interference Tests

In order to relax the specifications on the magnetic fields from spacecraft hardware, it is necessary to perform an adequate series of pre-flight tests. The difficulty here is that a thoroughgoing test procedure can be extremely expensive. Of course, regardless of how elaborate such tests become, they would still be considerably less expensive than the production of magnetically clean spacecraft. Nevertheless, the team recognizes that even with all the other concessions involved in our assignment of the specifications, there may not be sufficient funds to support a really thorough evaluation of the magnetic fields from the spacecraft. Accordingly, we outline here what we consider to be a minimum test procedure.

The subsystems and the complete spacecraft should be mapped in the earth's field using a technique similar to that used on Mariners 4 and 5. The magnetic fields produced by the electric currents in the subsystems and the spacecraft should be determined again using procedures similar to those used on earlier Mariners. It will also be necessary to make every effort to measure changes in the spacecraft magnetic field produced by changes in the positions or orientations of movable machinery on board. The change produced in the magnetic field at the sensor by each change in the mode of operation of the spacecraft should also be measured before the flight.

Many of these fields can be checked in-flight. However, it is most important to perform such tests with the complete system in order to be sure that there is no mode of normal operation that can degrade the measurements of the magnetic fields to intolerable levels.

D. Remarks on Magnetic Interference Specifications

The interference specifications in Section V.B are those proposed by the project office. They were derived from the material in Table V.1. This material was provided by the magnetometer team. Nevertheless, the team members feels that the specifications are inadequate in several respects. First, there is no provision for testing or re-testing equipment other than that which is of a new or modified design. Second, there is as yet no responsibility for the tests. Third, there is as yet no indication of the scheduling of the tests. It is essential that these tests be performed early enough to permit any corrective action that may be indicated.

VI. REMARKS ON THE PROPOSAL SELECTION PROCESS

In this section we discuss various aspects of the procedures that will be used to evaluate proposals for the MVM 73 experiments.

A. Cost Information

A severe budgetary constraint on the project requires that the cost of any proposed experiment be considered in the proposal evaluation. This requirement raises several questions:

1. How will costs of an experiment proposed by a group within a government agency be compared to those of an experiment proposed by a group at a university or industrial concern? Because of present cost accounting procedures within the government, an experiment proposed by a research center of either NASA or another government agency can be performed at less cost to the project than the same experiment proposed by a non-government organization. However, the actual cost to the government of the in-house experiment may be equal to or greater than that of the others. Further, it is more difficult for those who evaluate the proposals to estimate the cost of an experiment carried out at a government center than it is to estimate the costs of one performed by a university or industrial group. A procedure for such comparisons should be established.

2. The proposals are to contain the cost history of the proposed instrument or its previous versions. How will these histories be evaluated? We feel that the cost of particular

(identical) instruments would differ considerably from one project to another. Thus, for example, OGO hardware appears to us to have been much less expensive than either Mariner or Pioneer hardware.

3. How will the cost of reliability and quality assurance be estimated? Project personnel have stated that they will pretty much leave it to the proposing experimenter to establish his QA specifications. However, we have found no unanimity within the project as to the comparative costs of the various QA programs that have been used in the past. How, then, will the proposal evaluators assess the accuracy of cost estimates even when the proposer describes his approach to QA?

B. The Composite Subcommittee

At the final meeting of the SSG, program personnel from NASA Headquarters described NASA's plan to form a composite subcommittee for evaluating the MVM 73 proposals. The subcommittee would consist of one member from each standing, discipline-oriented subcommittees of the Space Sciences Steering Committee.

The SSG felt that the idea of forming a composite subcommittee was a good one but that the procedures needed clarification. It appeared that the purpose of the composite subcommittee, i.e., to eliminate conflicts of interest that would exist under the usual procedures, could be defeated by the rule that the representative of a discipline subcommittee was to act as instructed by his subcommittee. Accordingly, the following resolution was passed by the Science Steering Group:

a. That each member of the Venus-Mercury composite subcommittee give due consideration to the ratings assigned by his discipline subcommittee, but that he act autonomously.

b. That the composite subcommittee <u>not</u> assign priorities to competing proposals within a given discipline.

The magnetometer team further suggests that the function of the discipline subcommittees be limited to categorizing the proposals in accordance with previous rules and that they assign no priorities among the experiments that they have put in a particular category.

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