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Final Technical Report

Project Title: "Co-Investigator Participation in the Mars-94 Mission Studies of the Mars-Solar Wind Interaction: Topside Sounder and Magnetometer"
P.I.: Janet G. Luhmann, UCLA Institute of Geophysics and Planetary Physics
Period of Award: 2/01/91-1/31/96
Agency: NASA
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Summary of Accomplishments

The purpose of this investigation has been to provide U.S. co-investigator support toward the preparation of the Topside Ionospheric Sounder and Magnetometer experiments on the Russian Mars-96 (previously Mars-94) mission. The PI's main role has been to assist in the preparation of software tools that have allowed the optimum design of the investigations and evaluation of mission operations plans and orbits.

Throughout the period of this grant we have interacted with the PIs (T. Breus of IKI and K. Schwingenschuh of the University of Graz) as required to assist them in their efforts. In particular, we provided Topside Sounder PI T. Breus with our archive of Mariner and Viking mission radio occultation profiles of the Martian ionosphere for use in testing the software to be used for deconvolution of the electron density profiles obtained with the sounder on Mars-96. The first generation of the deconvolution software itself was developed at UCLA by postdoctoral researcher M. Zhang who spent a year working with us in 1992. We also presented several papers on behalf of the Sounder PI at international meetings (e.g. COSPAR) and supported her participation in the fall American Geophysical Union meeting in 1994. Our assistance was also requested and given in the Russian team's preparation and submittal of a proposal to CRDF (Civilian Research and Development Foundation), support from which is essential to the investigation's survival following the reduction in Soros Foundation funds. We provided magnetometer PI K. Schwingenschuh's group at Graz with some models of the plasma and field environment of Mars, and advised them on how to use them for evaluating Mars-96 orbits and estimating the values of the fields that they would be measuring. We expect to participate in the eventual use of these models for interpreting the data that are returned next year. We have also continually participated in coauthoring studies relating to the preparation for Mars exploration on Mars-96 with our team colleagues, as shown by the list of references below and described in the appended abstracts.

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Patents or Inventions Resulting

None.

ON THE COMPRESSIBILITY OF THE MAGNETIC TAILS OF MARS AND VENUS

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ABSTRACT

The compressibility of the Martian magnetic tail (the dependence of its diameter on the solar wind ram pressure) was first revealed by the Mars-5 spacecraft in 1975. Plasma and magnetic studies from the Phobos-2 spacecraft have provided the opportunity to investigate this dependence with good statistics. The observed dependence of the diameter on approximately the inverse one-sixth power of the solar wind dynamic pressure is similar to that expected for the location of a magnetopause of a planet with an intrinsic magnetic field. Until now, no one has examined the effect of solar wind dynamic pressure on the Venus tail with which to compare the Martian observations. In this paper we compare the compressibility of the Venus tail with that of Mars by using magnetic field signatures of the tail boundary as a proxy for high resolution plasma measurements.

INTRODUCTION

Recent results from analyses of the Phobos-2 TAUS experiment plasma data /1/ showed that the diameter of the Martian magnetotail responds to changes in solar wind pressure. The dependence of tail radius on the upstream dynamic pressure appears to be similar to the dependence that is expected for an intrinsic field magnetotail, even though the magnetic field polarities in the tail measured along the Phobos-2 orbit are consistent with an induced origin for the tail /2/. The Martian tail is also wider than the induced tail of Venus as was found in the earlier Mars-5 spacecraft measurements /3,4/. Both of these observations have been interpreted as evidence for an intrinsic field contribution to the Mars magnetotail.

In order to compare these results from Mars with a large sample of Venus tail data, we here use the Pioneer Venus Orbiter (PVO) observations to examine the dependence of the Venus tail diameter on solar wind pressure. The different orbit of the PVO, together with the different complement of instruments, make this comparison somewhat compromised. However, we consider that the results are worth presenting in view of the continuing debate over the nature of the Martian obstacle to the solar wind.

DESCRIPTION OF THE PHOBOS-2 RESULTS FROM MARS

Verigin et al. /1/ defined the location of the Martian tail boundary crossing along the Phobos-2 orbit as the location in the wake where the solar wind plasma was no longer detected. They used 2 min resolution TAUS plasma analyzer data like that shown in Figure 1. These data were obtained with an instrument aperture of roughly 40° width pointing in the sunward direction. As seen in this example, there is a relatively sudden disappearance of the proton flux which is often followed by the appearance of oxygen ions in the heavy ion detector. These tail crossings, when normalized by fitting to typical obstacle shapes, and plotted against the solar wind dynamic pressure that was measured just outside of the closest bow shock crossing, exhibited the significant dependence shown

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A BALLOON-BORNE EXPERIMENT TO INVESTIGATE THE MARTIAN MAGNETIC FIELD

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ABSTRACT

The Space Research Institute of the Austrian Academy, of Sciences (Graz, Austria) in cooperation with MPE (Berlin, Germany), GFZ Potsdam (Obs. Niemegk, Germany) IZMIRAN/IOFAN (Moscow, Russian) and IGPP/UCLA (Los Angeles, USA) is designing the magnetic field experiment MAGIBAL (MAGnetic field experiment aboard a martian BALloon) to investigate the magnetic field on the surface of Mars. The dual sensor fluxgate magnetometer is part of the MARS-98/ MARS-TOGETHER balloon payload. During a ten days period the balloon will float over a distance of about 2000 km at altitudes between 0 and 4 km. Due to the limited power and telemetry allocation the magnetometer can transmit only one vector per ten seconds and spectral information in the frequency range from 2 - 25 Hz. The dynamic range is ± 2000 nT. The main scientific objectives of the experiment are:

- Determination of the magnetism of the Martian rocks
- Investigation of the leakage of the solar wind induced magnetosphere using the correlation between orbiter and balloon observations
- Measurement of the magnetic field profile between the orbiter and the surface of Mars during the descent phase of the balloon.

Terrestrial test flights with a hot air balloon were performed in order to test the original MAGIBAL equipment under balloon flight conditions.

SCIENTIFIC OBJECTIVES

Introduction. Even after the 1989 PHOBOS-2 mission, it is still controversial whether Mars has an intrinsic magnetic field or interacts with the solar wind nonmagnetically /1, 2/. Using the combination of orbiter and surface magnetometers the following parts of the Martian magnetic field can be investigated:

- The main field with the source in the core mantle region (active dynamo?)
- The external field generated by the interaction of the solar wind with the upper atmosphere
- The magnetic field of the crustal anomalies
- The magnetic field of the 'telluric' currents induced by the external field.

Mission Scenario. After the injection of the MARS-98 probe into the Martian orbit a descent module including a balloon (fig. 1) will be released. During the descent phase the profile of the magnetic field will be measured. After landing the balloon (42 m high, 5500 m^3) will be inflated. The balloon moves during day time horizontally with the prevailing winds at an altitude of about 3 km. In the afternoon the gas cools

ON THE VENUS ION MAGNETOTAIL STRUCTURE

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ABSTRACT

The magnetic field data obtained by PVO in the low altitude Venusian magnetotail are reexamined for the study of peculiarities of its formation and its connection with the IMF. Although the general induced nature of the Venusian magnetotail lobes with their characteristic control by the IMF orientation is clear, some features are not in line with the simplest magnetic field draping model. Perpendicular or transverse magnetic field components reversed from the IMF direction often occur in the tail. These observations are discussed in terms of possible magnetotail field reconnection and twisting.

INTRODUCTION

The generally accepted model of the induced magnetotail of Venus is that of draped magnetosheath field lines that sink into the wake as shown in Figure 1. An implicit assumption of this model is that the cross-tail or transverse field is everywhere parallel to the prevailing transverse interplanetary magnetic field (IMF). In this paper we examine some low altitude magnetotail data obtained on the Pioneer Venus Orbiter (PVO) during a period when periapsis rose above the nightside ionosphere. We restrict ourselves to cases when a clear draped magnetosheath and tail lobe structure is present, indicating the presence of fairly steady solar wind and IMF conditions. Out aim is to determine how consistent these tail observations are with the standard induced tail picture.

OBSERVATIONS

Figure 2 shows the time series of the PVO magnetometer data that were selected for this study. In all cases the tail lobes have polarities in the x (Venus-sun) direction that are parallel to those in the adjacent magnetosheath in accord with the standard model. The orientation of the transverse field component throughout the tail and magnetosheath is most easily seen in vector projections of the magnetic field along the PVO orbit track. Figure 3 shows two orthogonal views of the field vector projection for each tail crossing. The x-z view is the noon-midnight projection, and the y-z view is the view through the planet from the sun. The second of these is most relevant here because it shows the transverse fields, while the first illustrates the degree to which the draped magnetosheath and induced tail fields are related. The y-z (transverse field) views in Figure 3 appear to exhibit two types of behavior. In two of the examples (orbits 2325 and 1643), the transverse fields in the upstream, magnetosheath, and tail regions are roughly parallel, consistent with Figure 1. However, in the remaining cases there is an apparent reversal in the transverse field component in the tail at about the halfway point.

POSSIBLE INTERPRETATIONS

One way of producing transverse field reversal in the induced tail is by réconnection of the lobe

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The flaring of the Martian magnetotail observed by the Phobos 2 spacecraft

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Abstract. Spacecraft observations from the Earth's magnetotail show that the flaring angle depends on the downtail distance, the upstream solar wind dynamic pressure and the B_z component of the interplanetary magnetic field [*Petrinec and Russell*, 1993]. Measurements from the Phobos 2 spacecraft along a circular orbit at 2.8 Mars radii allow a similar study of the Mars magnetotail. Under the assumption that the magnetic pressure in the Martian tail lobes is much greater than the plasma pressure in the lobe, we use the pressure balance condition between the tail lobe magnetic pressure and the normal component of the solar wind pressure to infer the angle at which the tail magnetopause flares. As in the case of the terrestrial magnetotail, the flaring angle of Mars tail depends on the solar wind dynamic pressure, but this angle (at 2.5 R_M) is about one half the terrestrial value (at 17 R_E). The median inferred flaring angle is about 13°.

Introduction

Initial observations with the magnetometers on the Phobos mission showed the principally induced nature of the Martian magnetotail [*Yeroshenko et al.*, 1990] although there is still some uncertainty as to the strength of any intrinsic component of the tail field [*Mohlmann et al.*, 1991; *Dubinin et al.*, 1994]. The induced magnetotail forms as a result of the atmospheric mass loading and subsequent draping of passing magnetosheath flux tubes that sink into the wake. In general, planetary bodies without intrinsic magnetic fields, but with substantial atmospheres, are known to possess such cometlike induced magnetotails. Figure 1 shows the schematic illustration of the formation of an induced magnetotail from draped interplanetary field. To describe the configuration of the magnetotail, we will use the local draping angle and the flaring angle. The local draping angle is the angle between the tail magnetic field (solid lines) and the flow axis, X. The flaring angle is the angle of inclination between the solar wind flow direction and the tail surface (dashed lines).

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In the case of the magnetized planets, the magnetotail is formed by the tangential stresses of the interaction of the solar wind on an intrinsic magnetic field. However, the strength of the field in the tail, the tail radius and the increase of this radius with distance are governed by the balance between the solar wind pressure on the flaring tail boundary and the mainly magnetic pressure of the tail lobe as originally formulated by *Coroniti and Kennel* [1972]. *Petrinec and Russell* [1993] recently studied the near-earth magnetotail, in the region of $-22.5\ R_E \leq X \leq -10R_E$ which, when scaled by the size of the obstacles at Earth (10 R_E) and Mars, (1.2 R_M) is similar to the location of Phobos observations (2.5 R_M) in the Martian tail which, when scaled by the ratio of the obstacle radii, would be equivalent to 21 R_E. *Petrinec and Russell* [1993] showed that the flaring angle of the Earth's tail depends on the distance downtail, X, upstream solar wind dynamic pressure, ρv^2_{sw}, and the B_z component of the interplanetary magnetic field.

Measurements from the Phobos 2 spacecraft along the circular orbit at 2.8 Mars radii allow us to study the properties of the Mars tail. Previous work includes that of *Luhmann et al.* [1991] who have conducted a comparative study of the induced magnetotails of Venus, Mars, and Titan. This work indicated that tails of Venus and Mars were similar in their dependence on the IMF strength but that the Mars tail was comparatively wider than that of Venus. More recently *Verigin et al.* [1993] examined the compressibilities of the magnetotail boundary.

In this study, we examine the properties of the Martian magnetotail in comparison with the properties of the Earth's tail as studied by *Petrinec and Russell* [1993]. We investigate the dependence of the local draping angle of the

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STUDIES OF THE DRAPING AND FLARING ANGLES OF THE MARS AND EARTH MAGNETOTAILS

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ABSTRACT

Observations of the Mars tail by the Phobos spacecraft have been used to estimate the draping angle of the magnetic field within the tail and the boundary flaring angle. The boundary of the tail is defined by the sudden disappearance of the proton flux as measured by the TAUS ion spectrometer. Solar wind measurements by the TAUS instrument are used to calculate the approximate solar wind dynamic pressure when the spacecraft is within the tail boundary. The average draping angle (Arcsin($\sqrt{B_y^2 + B_z^2/B_T}$)) is found to be 27.2° ± 1.4°. The draping angle magnitude depends on the solar wind dynamic pressure, but is quite variable. The flaring angle of the tail boundary at $X = -2.5R_M$ has also been calculated from the balance of pressure between the lobe of the Martian tail and the component pressures of the solar wind. The flaring angle depends strongly on the solar wind dynamic pressure, and this dependence is identical to that obtained at the Earth by Petrinec and Russell /1/. However, the magnitude of the flaring angle at Mars at $X = -2.5R_M$ is one-half the value obtained at Earth for $-22.5R_E \leq X - 10R_E$.

INTRODUCTION

Initial observations with the magnetometers on the Phobos mission showed the principally induced nature of the Martian magnetotail /2/ although there is still some uncertainty as to the strength of any intrinsic component of the tail field /3/,/4/. The induced magnetotail forms as a result of the atmospheric mass loading and subsequent draping of passing magnetosheath flux tubes that sink into the wake. In general, planetary bodies without intrinsic magnetic fields, but with substantial atmospheres, are known to possess such cometlike induced magnetotails. To describe the configuration of the magnetotail, we will use the local draping angle and the flaring angle. The local draping angle is the angle between the tail magnetic field and the flow axis X. The flaring angle is the angle between the solar wind flow direction and the tail surface.

In the case of the magnetized planets, the magnetotail is formed due to the tangential stresses of the interaction of the solar wind on an intrinsic magnetic field. However, the strength of the field in the tail, the tail radius and the increase of this radius with distance are governed by the balance between the solar wind pressure on the flaring tail boundary and the mainly magnetic pressure of the tail lobe as originally formulated by Coroniti and Kennel /5/. Petrinec and Russell /1/ showed that the flaring angle of the Earth's tail depends on the distance downtail, X, upstream solar wind dynamic pressure, ρv_{SW}^2, and the B_Z component of the interplanetary magnetic field.

Measurements from the Phobos 2 spacecraft along the circular orbit at 2.8 Mars radii allow us to study the properties of the Mars tail. Previous work includes that of Luhmann et al. /6/ who have conducted a comparative study of the induced magnetotails of Venus, Mars, and Titan. This work indicated that tails of Venus and Mars were similar in their dependence on the IMF strength but that the Mars tail was comparatively wider than that of Venus. More recently Verigin et al. /7/ revealed the compressibilities of the magnetotail boundary.

In this study, we examine the properties of the Martian magnetotail in contrast with the properties of the Earth's tail as studied by Petrinec and Russell /1/. We investigate the dependence of the local draping angle of the tail magnetic field on the upstream solar wind dynamic pressure. We