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MAGNETIC EFFECTS IN VENUS/SOLAR WIND INTERACTION

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SYNOPSIS

The overall objective of this research program is to obtain a better understand the interaction of a magnetized solar wind with the Venus atmosphere through the use of numerical solutions of the time-dependent, 2-D and 3-D magnetohydrodynamic (MHD) equations. Due to the more modest CPU requirements for the 2-D simulations, they were used for studies in which useful information not dependent on the third dimension could be obtained. The 2-D simulations served several purposes in addition to providing useful physical insight. They were used to determine the numerical parameters required in the 3-D studies, such as the grid spacing required to resolve particular features, and the damping that must be included to remove high-frequency oscillations. Among the specific studies performed with support from this grant that are discussed in this report are the following: (a) Comparison with other available models for purposes of testing the code and obtaining a baseline with which to evaluate the effects of aditional physical processes, (b) Effects of a finite planet conductivity, (c) Bow shock standoff distance, and (d) Formation of the magnetic barrier and slippage of the magnetic field around the planet. A brief description of the methodology is presented before discussing the results.

METHODOLOGY

The time-dependent, single-fluid MHD equations are solved in a spherical coordinate system centered on the planet and oriented such that the $\theta=0°$ pole is directed into the solar wind. One distinct advantage with this coordinate system is that a variable grid spacing in just one coordinate (radius) increases the numerical resolution where it is needed near the planet surface. In addition, the planet surface is at a fixed value of one coordinate thereby avoiding the complications of interpolating within the numerical grid as would be necessary in a Cartesian coordinate system. This capability is built into the code through the use of a coordinate transformation so the actual finite differencing is done on a uniformly spaced grid. For most of the computations the planet is treated as a solid, infinitely conducting sphere with both flow and magnetic field parallel to the surface. The assumption of an infinitely conducting sphere was relaxed for one of the studies discussed below. The numerical approach to obtaining a steady solution for the interaction is to start the computation with an initial state that is not in equilibrium. The MHD equations are then solved numerically until the solution relaxes to an equilibrium. Once this equilibrium has been reached, it can be perturbed by altering the solar wind conditions in order to study their effect on the steady state. A separate graphics code has also been developed to post-process the computed results and produce contour and streamline plots (in addition to other plots) that assist in understanding the physics of the interaction.

RESULTS

A. Comparison with Simpler Models

The results were compared with those from the earlier gas dynamic study of Spreiter and Stahara (*J. Geophys. Res.*, **85**, 7715, 1980). Spreiter and Stahara considered flow over a specified and fixed magneto/ionosphere boundary and, hence, did not compute the flow in the tail region. The present analysis computes the flow self-consistently in the entire region around the planet. For similar solar wind conditions the present solution and that by Spreiter and Stahara compared favorably in the region upstream of the terminator. The primary differences occured downsteam of the terminator where the current simulation predicts that the boundary assumed by Spreiter and Stahara should actually not flare outward as rapidly as they assume but should be more constricted toward the tail region.

B. Finite Planet Conductivity

A study was also carried out to investigate whether diffusion of the magnetic field through the planet may lead to the production of observed magnetic holes in the nightside ionosphere (Brace, et al., *J. Geophys. Res.*, **87**, 1982). When the planet is allowed to be diffusive, the magnetic field strength in the nightside is substantially higher than for an infinitely conducting planet, as would be expected for magnetic holes. However, the magnetic field does not tend to concentrate in high field regions adjacent to regions of lower field strength. As a result, some other physical mechanism not included in our model must be responsible for the observed bunching of the magnetic field. A typical simulation result for both an infinite and a finite conducting planet are shown in Figure 1.

C. Bow Shock Standoff Distance

A large effort was devoted to determining the standoff distance of the bow shock for different physical conditions in the solar wind. One part of this effort concerned a simulation of observed distant bow shocks and the other was a parametric study. The first study was motivated by a data analysis study by Russell and Zhang (*GRL, 19*, 833, 1992) who identified bow shocks in the PVO data at unusually large distances from Venus. These shocks occur when conditions in the solar wind are such that the magnetosonic Mach number is near unity and the plasma beta is small ($\beta \leq 1$). Based on experience with coronal mass ejections, it appeared that these solar wind conditions are such that either slow or intermediate MHD shocks may form along portions of the bow shock rather than the usual fast MHD shock (Steinolfson and Hundhausen, *JGR, 95*, 6389, 1990). This possibility was examined using solar wind conditions similar to those in the data when the bow shock was observed to be at large distances. As expected, the normal fast shock became an intermediate shock over a portion or the shock front, and the shock travelled outward to the observed large distances. These results have been published (Steinolfson and Cable, *GRL*, *20*, 755, 1993).

The analytic gasdynamic model for the bow shock standoff distance is based on the assumption that the standoff distance is linearly proportional to the jump in density across the bow shock (e.g., Spreiter et al., *Planet. Space Sci. 14*, 223,1966). For no magnetic field our simulated values agree almost exactly with the predictions of this relatively simple model. This gasdynamic result should remain unchanged for the case of a flow-aligned magnetic field since in this case the magnetic field has no role in the shock jump conditions. Our simulations confirm this to be true providing the plasma beta (β, the ratio of thermal pressure to magnetic pressure) in the solar wind is much larger than unity. When β is on the order of one or smaller, the agreement with the gasdynamic model is still quite good at large Mach numbers, but it becomes worse with decreasing β at smaller Mach numbers. This is illustrated in Figure 2 where the bow shock standoff distance is plotted against the sound Mach number for β=2. The gasdynamic model result is shown as the dashed line, and the simulation results are the solid triangles connected with the solid line. The large deviation at low Mach numbers is due to the formation of an intermediate shock along the central portion of the shock front. A typical shock front containing an intermediate shock along part of the shock front is shown in Figure 3. These results are currently being written up for submission to the Journal for Geophysical Research.

D. The Magnetic Barrier and Slippage of the Magnetic Field Around the Planet

The pile-up of the magnetic field on the dayside of Venus to form what has been referred to as a magnetic barrier is well-observed (e.g., Zhang et al., *J. Geophys. Res., 96*, 11,245, 1991). The magnetic pressure dominates all other pressure contributions within the magnetic barrier. The magnetic field cannot pile-up indefinitely, however, and it eventually slips around the planet. These phenomena have been simulated for the case of a magnetic field perpendicular to the solar wind velocity, and a representative result for the magnetic field lines is shown in Figure 4. There is an obvious pile-up of field lines on the dayside, and the speed of the field lines around the planet near the surface (the lines indicated in the figure) is much greater than that at larger distances from the planet. These results are being written up for submission to the Journal for Geophysical Research.

PRESENTATIONS AND PAPERS

Steinolfson, R.S., Global MHD simulations of the interaction of the solar wind with the Venus atmosphere, *EOS, 73*, 189, 1992.

Cable, S., and R. S. Steinolfson, Venus bow shocks at large distances from the planet, *EOS, 73*, 334, 1992.

Cable, S., and R. S. Steinolfson, MHD simulations of the solar wind interaction with Venus, *EOS, 74*, 254, 1993.

Steinolfson, R.S., and S. Cable, Venus bow shocks at unusually large distances from the planet, *Geophys. Res. Lett., 20*, 755-758 , 1993.

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Cable, S., and R. S. Steinolfson, MHD simulations of the Venus bow shock, *EOS, 74*, 380, 1993.

Steinolfson, R. S., and S. Cable, Parametric study of the standoff distance for the Venus bow shock, *J. Geophys. Res.*, in preparation, 1993.

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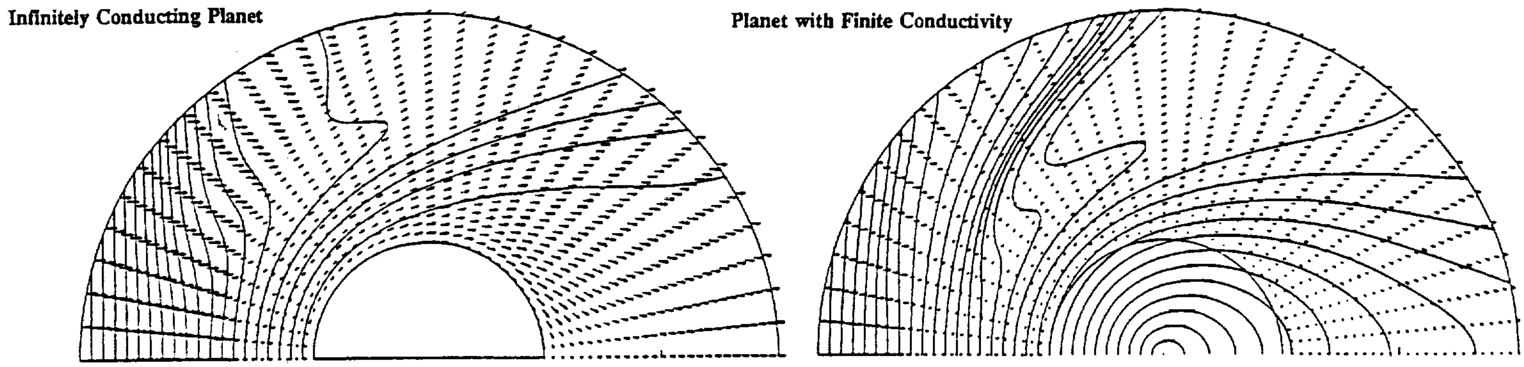

Figure 1. Magnetic field lines and velocity vectors.

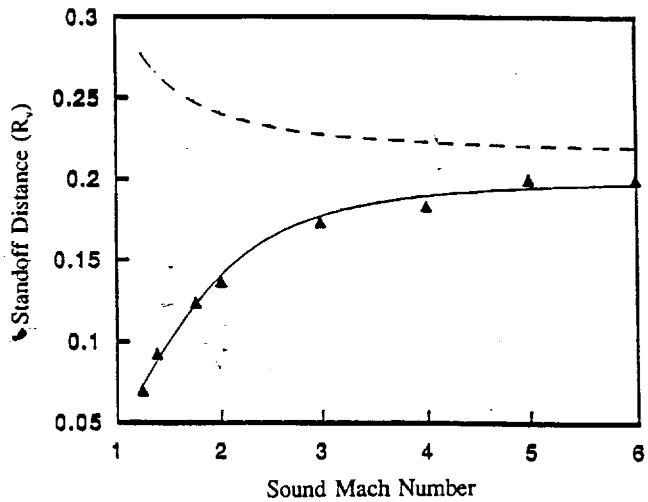

Figure 2.

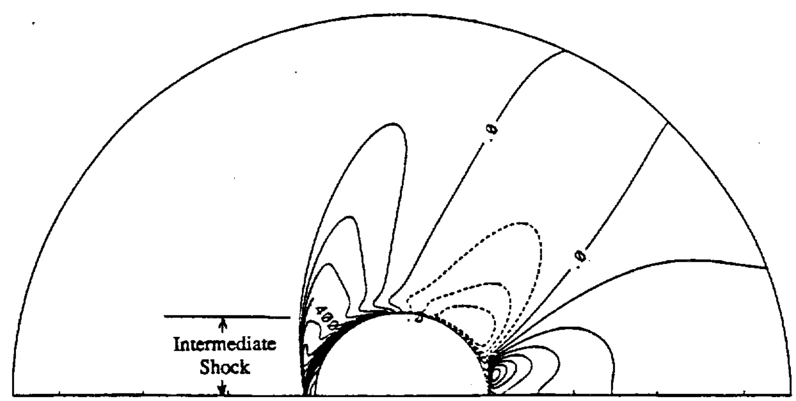

Figure 3. Density contours.

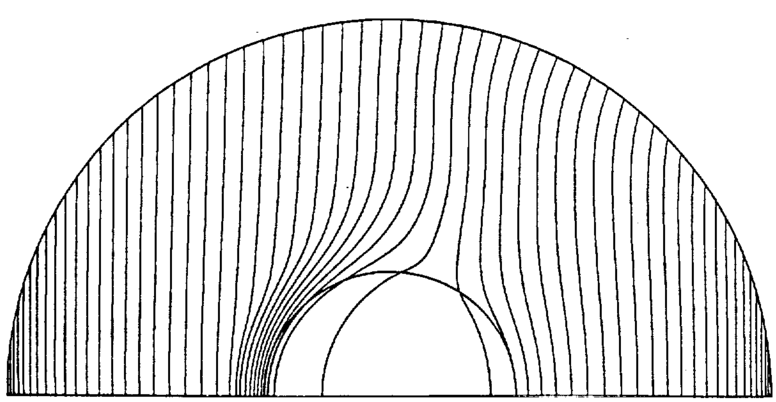

Figure 4. Magnetic field lines.