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THE EFFECT OF THE HOT OXYGEN CORONA ON THE INTERACTION OF THE SOLAR WIND WITH VENUS

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Abstract. A numerical gas dynamic model, which includes the effects of mass loading of the shocked solar wind, was used to calculate the density and magnetic field variations in the magnetosheath of Venus. These calculations were carried out for conditions corresponding to a specific orbit of the Pioneer Venus Orbiter (PVO orbit 582). A comparison of the model predictions and the measured shock position, density and magnetic field values showed a reasonable agreement, indicating that a gas dynamic model that includes the effects of mass loading can be used to predict these parameters.

Introduction

Studies of the interaction of the solar wind with planets have shown that gas dynamic models (e.g. Spreiter et al., 1966 and Spreiter et al., 1970) reproduce reasonably well the observed main properties of this interaction with planets having strong intrinsic magnetic fields. On the other hand the solar wind interaction with a planet having effectively no intrinsic magnetic field, but only a dense plasma shell, such as Venus, is not described well by traditional gas dynamic models. Recent studies which attempt to match observed and modelled parameters such as specific heat ratios, the shape of the obstacle and Mach numbers for Venus (Mihalov et al., 1982; Tátrallyay et al., 1983; Tátrallyay et al., 1984) have not been very successful, especially if a number of different parameters must be fit simultaneously.

Some of the results of the plasma measurements near Mars (Vaisberg et al., 1973; Bogdanov et al., 1975a, b) and Venus (Vaisberg and Bogdanov, 1974; Romanov et al., 1978; Mihalov et al., 1980) have pointed to the presence of cold planetary O^+ ions mixed with the solar wind protons. Zeleny and Vaisberg (1984) pointed out that O^+ creation due to the photoionization of the cold neutral atmosphere would have only very small effects. However, there have been suggestions that the existence of an extensive hot hydrogen corona (Barth et al., 1967; Bertaux et al., 1981) and the more recently postulated and measured hot oxygen corona at Venus (Nagy et al., 1981) are going to have significant impact on the solar wind interaction processes (e.g. Wallis,1982). The absorption and momentum losses of the solar wind due to charge exchange with the hot hydrogen and oxygen corona of Venus and Mars have been estimated (Gombosi et al., 1980; Gombosi et al., 1981; Russell et al., 1983). These studies did not address the problem of the actual interaction parameters directly. Quantitative analyses of the processes associated with the mass loaded solar wind were carried out by Breus and Krymskii (1987) and Breus et al. (1987), who indicated that their model does predict the generally observed features of the solar wind interaction with Venus.

This paper presents the results of specific calculations of the above mentioned model of Breus et al. (1987) which uses as input parameters data obtained by the Pioneer Venus Orbiter (PVO) plasma analyzer (Intriligator et al., 1980) and magnetometer (Russell et al., 1980), during orbit 582, and the hot oxygen density values derived from the PVO borne EUV spectrometer (Nagy et al., 1981). .The results of these calculations are compared with actual observations of the shock front positions and parameters inside the ionosheath. It is shown that this model, which takes into account the mass loading of the solar wind, is consistent with the observed parameters, while previous attempts of matching the results of a traditional gas dynamic model with this same data base were less successful in general (Mihalov et al., 1982).

Model Calculations

The gas dynamic model, which includes mass loading of the shocked solar wind (Belotserkovskii et al., 1985; Breus and Krymskii, 1987; Breus et al., 1987) was solved numerically and compared with experimental results obtained during the outbound portion of orbit 582 of the Pioneer Venus Orbiter. The calculations were carried out for an axisymmetric obstacle characterized by $\gamma = 5/3$ and $h_s/R_{in} = 0.03$ where γ is the ratio of specific heats, h_s is the scale height and R_{in} is the ionopause height at the subsolar point measured from the center of the planet. The unperturbed solar wind density and velocity values were taken from the Pioneer Venus data base (cf. Mihalov et al., 1982) and are $N_\infty = 13$ cm^{-3} a $V_\infty = 390$ km/sec respectively. The subsolar ionopause height was assumed to be 300 km. This corresponds to an ionopause height of about 880 km for the outbound pass, which is close to the observed value of 850 km (L.H. Brace, personal communication). Statistical analyses of the shock front position at the terminator (Tátrallyay et al., 1983) and certain jump parameters across the shock (Tátrallyay et al., 1984) have shown that the values predicted by gas dynamic models fit the observed data best if the Mach number used in the model is the fast magnetosonic Mach number, M_f. Therefore, the calculations discussed in this paper used $M_\infty = M_f = 5.7$, where this chosen value is consistent with the data from orbit 582 (cf. Mihalov et al., 1982).

The effect of mass loading the solar wind was taken into consideration by adding a source term to the right hand side of the continuity equation (Belotserkovskii et al., 1985;

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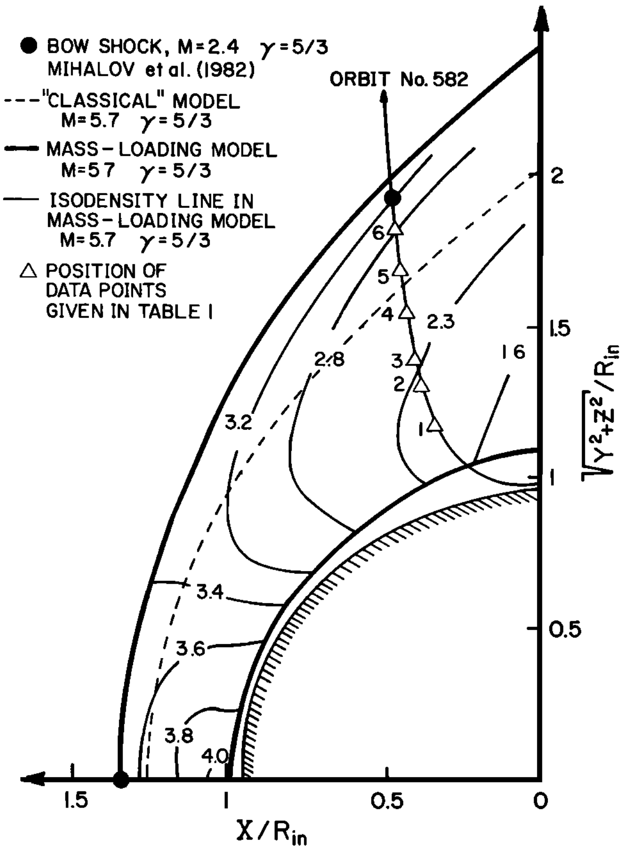

Fig. 1. Calculated isodensity contours obtained by using the model which includes the effects of mass loading. The bow shock location calculated by both the traditional and mass loaded models are also shown.

Breus et al., 1987). In order to be totally rigorous one would also need to add corresponding source terms to the momentum and energy equations. However it was shown by Bierman et al. (1967) that the major effect is that associated with the continuity equation and therefore in these first order calculations the momentum and energy source terms are neglected. It was assumed that the only important source of this mass loading in the ionosheath is the photoionization of the hot oxygen corona, because the hydrogen densities are smaller in this region (Keating et al., 1986) and other possible processes, such as charge exchange and impact ionization, do not qualitatively change the main results (Breus et al., 1987).

The altitude distribution of the hot oxygen was taken, in accordance with the model calculations and observations (Nagy et al.,1981), to be:

$$n_o(h) = 3 \times 10^4 \exp\left\{-\frac{h-400}{400}\right\} \mathrm{cm}^{-3}$$

where h is the distance from the Venus surface in kilometers. The characteristic time for the photoionization of oxygen, τ, was adopted to be 10^6s (Torr and Torr, 1985).

When the bow shock is at a distance of 2000 km at the subsolar point, the mass loading effect near the shock is less than 3% of that near the ionopause; most of the mass-loading takes place on in a region of about 400 km near the ionopause. Therefore it was assumed in the calculations presented here that mass loading takes place only inside the ionosheath and not outside the bow shock. These calculations assumed an axisymmetric geometry and therefore do not address the questions of possible asymmetries in the mass loading process (Cloutier, 1976; Romanov, 1978; and Slavin et al., 1987).

The numerical method may be briefly characterized as a hybrid, finite-difference, marching McCormac-type algorithm, which numerically integrates the nondissipative time-dependent axisymmetrical MHD-equations. The bow shock was fitted by means of the appropriate Rankine-Hugoniot shock jump conditions; any other possible irregularities of the flow were captured by the numerical method. The hybrid nature of the algorithm implies that the order of approximation varies from first to second, depending on the solution's degree of smoothness at every local point. This feature of the algorithm is equivalent to the introduction of some artificial viscosity and it allows the elimination of non-physical high-frequency harmonics from the solution, while maintaining a high degree of accuracy in the regions where the solution is relatively smooth. The computation region, bounded by the axis of symmetry, the bow shock and the obstacle boundary, was mapped into a rectangle consisting of 23x23 cells. The dimensions of these cells are decreasing from the bow shock to the obstacle boundary according to a geometrical progression (Belotserkovskii et al., 1985; Breus et al., 1987).

Results

The bow shock positions, calculated for the conditions corresponding to orbit 582 of Pioneer Venus are plotted in Figure 1. The bow shock was observed at 2.13 R_V during the outbound leg of orbit 582 (L. Brace, private communication). The solid line corresponds to the shock position calculated with mass loading, while the dashed line gives the results for the same general conditions but without

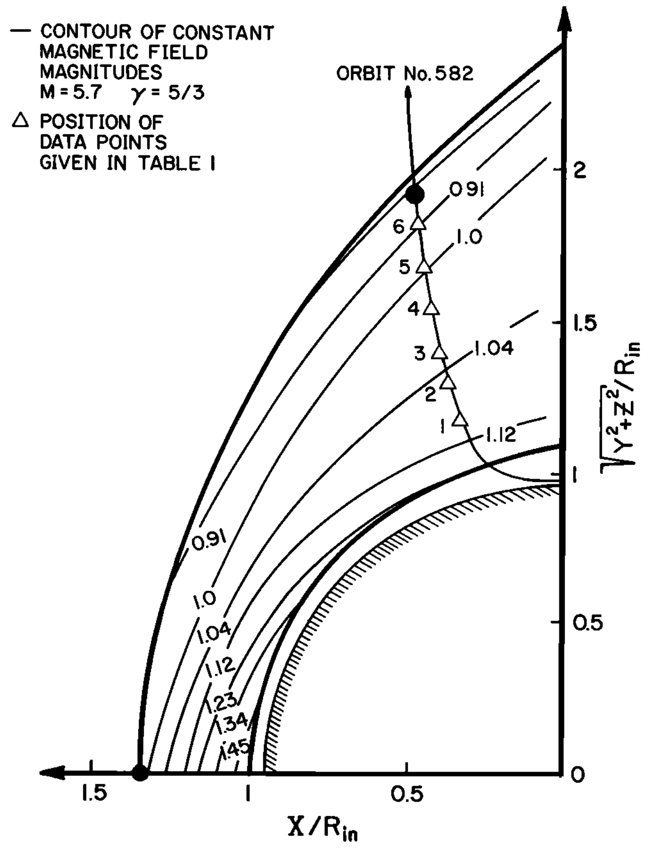

Fig. 2. Calculated lines of constant magnetic field magnitudes obtained by the model which includes the effects of mass loading.

Table 1. Comparison of Measured and Calculated Parameters

			n calculated, (cm^{-3})			B	B calculated, (nT)		
	R_Z/R_S	n measured (cm^{-3})	mass-loaded sw M=5.7	Mihalov et al. (1982)		measured (nT)	mass loaded sw M=5.7	Mihalov et al. (1982)	
				$M_\infty = 2.4$	$M_\infty = 7.6$			$M_\infty=2.4$	$M_\infty=7.6$
1	1.25	12 ± 5	23	19	23	26	22.8	18.9	23.1
2	1.372	13 ± 3	26	21	30	25.5	21.2	16.8	22.3
3	1.493	15 ± 6	29	23	36	25.2-24.2		16.2	23.5
4	1.631	26 ± 7	32	24	46	24.8-14.1		15.9	26.1
5	1.764	40 ± 15	34	25	13	20.4	20.4	15.6	7.4
6	1.908	40 ± 6	37	26	13	17.8-16.4	18.5	15.4	7.4

mass loading. In order to match this observed position with a gas dynamic model, Mihalov et al. (1982) had to artificially reduce the Mach number to 2.4 (the solid circle shows the predicted shock position for that model). The relative density and magnetic field variations in the ionosheath, calculated with the full model, including mass loading effects are shown in Figures 1 and 2 respectively. The trajectory and six measurement locations are indicated in these figures; the measured and calculated density and magnetic field values are given in Table 1. The results of Mihalov et al. (1982) are also given in Table 1 for comparison. It needs to be emphasized that the calculated density values are given in amu rather than number density. Therefore, in a plasma, such as the inosheath, which consists of different ions (e.g. H^+ and O^+) mass density is greater than the number density. As can be seen in Table 1, the calculated density values exceed the measured values at R/R_S less than about 1.6; these differences imply O^+ abundances of only a few percent, which are in reasonable agreement with observations (e.g. Intriligator, 1982; Perez de Tejada, 1982). No O^+ data is available from orbit 582 for specific comparison.

Discussion

The results presented here indicate that gas dynamic model calculations, which take into account mass loading of the shocked solar wind, are reasonably successful in reproducing the observed shock position, density and magnetic field variations inside the ionosheath. The presence of a hot oxygen corona makes this mass loading effect an important one at Venus. The hot oxygen population is predicted to be much less significant at Mars (Russell et al., 1983); therefore the corresponding mass loading should also be less important. On the other hand the very extensive atmospheres around comets imply important effects, as has been indicated by recent measurements near comets Giacobini-Zinner and Halley (Mendis et al., 1986; Gringauz et al., 1986; Somogyi et al., 1986).

Finally it should be noted that the study by Alexander and Russell (1985) has shown that the position of the shock front at the terminator varied during the last solar cycle and is correlated with the 10.7 cm flux. A decreasing solar flux results in decreased O_2^+ densities, which is the source of hot oxygen. Decreased hot oxygen mass loading of the solar wind results in a bow shock position closer to the planetary surface. The predicted terminator shock position is at about 2 R_S, when mass loading is neglected, which is consistent with the solar cycle minimum value obtained by Venus 9 and 10 (Verigin et al., 1978); of course any quantitative comparisons require corresponding and specific solar wind and hot oxygen information.

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