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An Empirical Model of the Venusian Outer Environment 2. The Shape and Location of the Bow Shock

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Venera 9 and Venera 10 bow shock crossings are analyzed for solar zenith angles in the range from ~25° to ~153°. The best fit to 62 observed crossings gives the location of the subsolar point of the bow shock as ~7600 km from the center of Venus or 1.27 R_v. Comparison of Venera 9 and Venera 10 bow shock crossings with those observed by the Pioneer Venus orbiter indicate that both the secular variation and the latitudinal asymmetry may be responsible for the closer shock crossings of the Venera 9 and Venera 10 spacecraft.

INTRODUCTION

Since the first observations of the Venusian bow shock with the Mariner 5 flyby [*Bridge et al.*, 1967] and the Venera 4 probe [*Dolginov et al.*, 1969], the location of the bow shock has been used to estimate the properties of an obstacle in the solar wind flow [*Spreiter et al.*, 1970; *Gringauz et al.*, 1976; *Vaisberg et al.*, 1976; *Russell et al.*, 1977].

The estimates of the mean subsolar distance of the bow shock vary from 1.23 R_v [*Russell et al.*, 1979] to 1.5 R_v [*Verigin et al.*, 1978]. There are two main reasons for this variation. First, most of the shock crossings were observed at large solar zenith angles (SZA), which makes it difficult to extrapolate meaningfully to the subsolar point. Second, different fit procedures were applied to obtain the mean shock curve from the various observed crossings.

It is important to determine the location of the shock for comparison with models of the interaction and for estimation of the possible absorption of the solar wind by Venus [*Russell*, 1977]. The purpose of this paper is to evaluate the mean location of the Venusian shock for the period of Venera 9 and Venera 10 observations by using the shock crossings at large SZA and to compare this location of the shock with the shock location obtained by using the more recent Pioneer Venus orbiter (PVO) observations.

SHOCK LOCATIONS

Data from the RIEP plasma spectrometer [*Vaisberg et al.*, 1976] and the Venera magnetic field measurements [*Dolginov et al.*, 1978] were used to identify shock crossings. Data were obtained in two measurement modes. In the periapsis mode the counting rate of the RIEP plasma spectrometers and the vector measurements of the magnetic field were recorded every second in the spacecraft core memory. In this mode the accuracy of the shock location can depend on the shock thickness. In the orbital mode the measurements of the RIEP ion distribution function and of the eight vector magnetic measurements were made during a 1-min interval followed by a 9-min interruption of the measurements. Therefore, in this mode the shock location identification has a ±5-min uncertainty.

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The data presented cover the time interval from October 1975 to April 1976. Figure 1 shows all 62 positively identified shock crossings in the Venera 9 and Venera 10 data. Crossings are shown in a cylindrical coordinate system with the X axis along the Venus-sun line and with distance from this line ($\sqrt{Y^2 + Z^2}$) as the second coordinate. The aberration angle of the solar wind was taken into account with the use of corresponding solar wind velocity measurements.

The crossing closest to the subsolar point was at SZA ~25°. Shock crossings were also identified as far as ~93,000 kilometers (~15.3 R_v) downstream.

An approximation of the mean shock was made by employing a second-order curve symmetric relative to the X axis, without employing the often used supposition that the focus of the curve coincides with the center of the planet. Bow shock crossings were modeled by the curve

$$y^2 + Bx^2 + Dx + E = 0$$

The coefficients of the best fit curve were used then to calculate the parameters of the bow shock: the planetocentric subsolar distance R_o, the terminator distance R_T, the focus location on the X axis, the eccentricity ϵ, and the formal Mach number corresponding to the asymptotic angle of the curve.

A least squares best fit program was used to minimize the mean squared distances of individual points from the second-order curve. Figure 1 shows the result of this best fit to all the data points. The best fit curve parameters are shown in Table 1. The subsolar point of this best fit shock is located at 1.295 R_v. The formal Mach number calculated from the asymptotic angle of the shock is ~3.8.

To decrease the influence of remote flank crossings on the determination of the shape and location of the shock on the dayside, only 48 crossings for the SZA range from ~25° to ~165° were used. These crossings are shown in Figure 2*a* along with two best fit curves. Curve 1 was obtained with the use of all 48 crossings and curve 2 was obtained when the three most remote crossings from the mean curve were omitted. The difference in the parameters associated with these two curves allows one to estimate, as discussed below, the accuracy of the mean curves (see Table 1). Ten runs of the best fit program were made for varying initial conditions and different weightings of the individual shock crossings depending

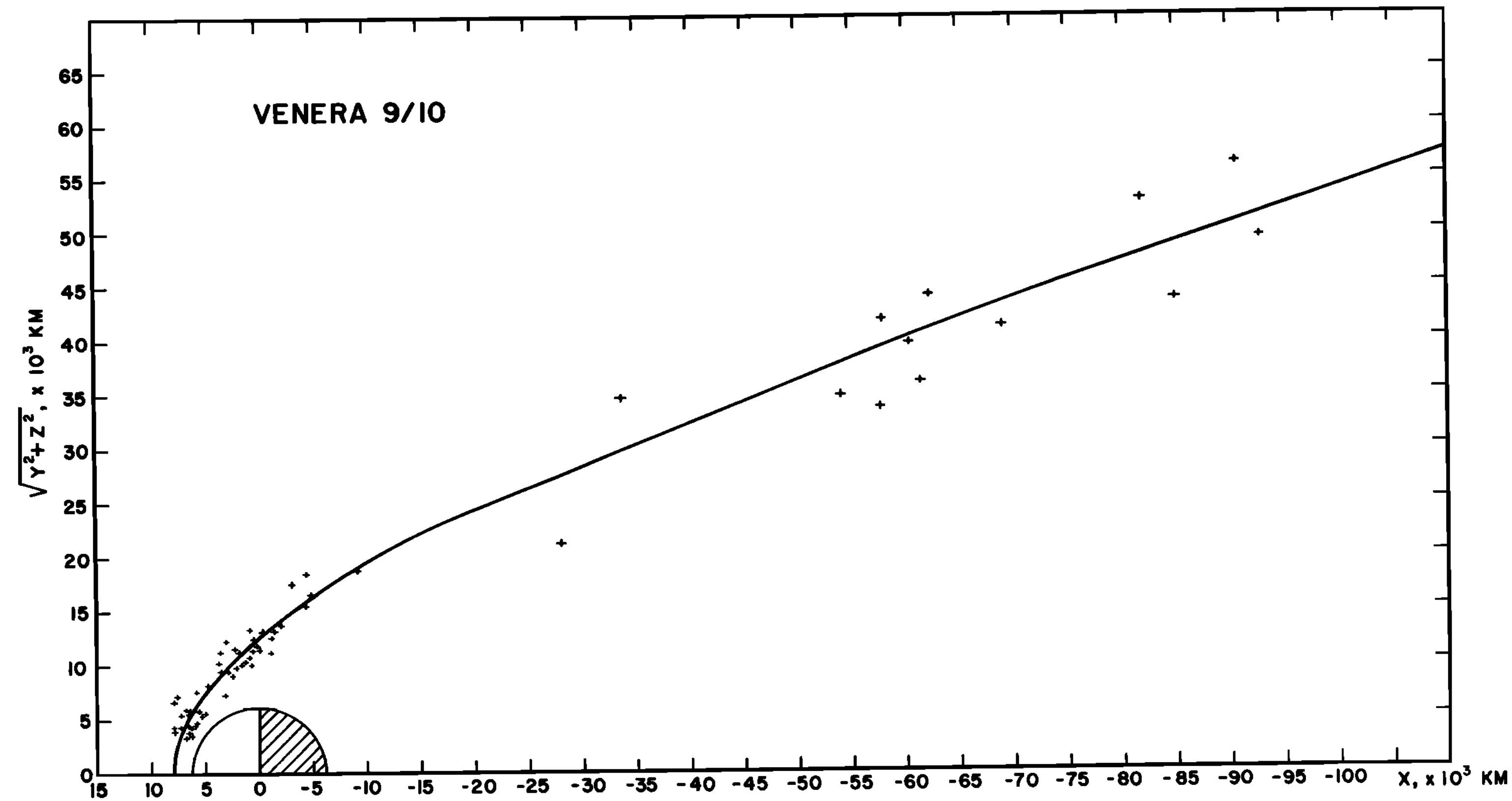

Fig. 1. Venera 9 and Venera 10 bow shock crossings in the cylindrical solar wind aberrated coordinate system. The best fit to all observed crossings is also shown.

TABLE 1. Venusian Bow Shock Parameters

Case	Subsolar Distance R_0, km	Distance at Terminator R_T, km	Focus Location X_F, km	Eccentricity, ϵ	Mach Number, M	RMS Deviation Normal to the Curve, km	Number of Crossings Used, N
V9/10 all points (Figure 1)	7,840	12,330	3,220	1.037	3.78	1.82	62
V9/10 (curve 1, Figure 2)	7,670	12,720	2,660	1.040	3.62	0.82	48
V9/10 (curve 2, Figure 2)	7,340	12,940	1,870	1.044	3.49	0.80	45
Mean 10 runs V9/10	7,540 ±245	12,660 ±190	2,500 ±460	1.044 ±0.006	3.52 ±0.20	···	45–62
PVO (curve 3, Figure 2). [*Slavin et al.*, 1979*b*]	8,155	14,770	0	0.80	···	···	86
PVO (curve 5, Figure 2)	8,230	14,820	1,730	1.022	4.82	1.1	86
PVO + V9/10 (curve 4, Figure 2)	7,590	14,760	530	1.015	5.85	1.05	107

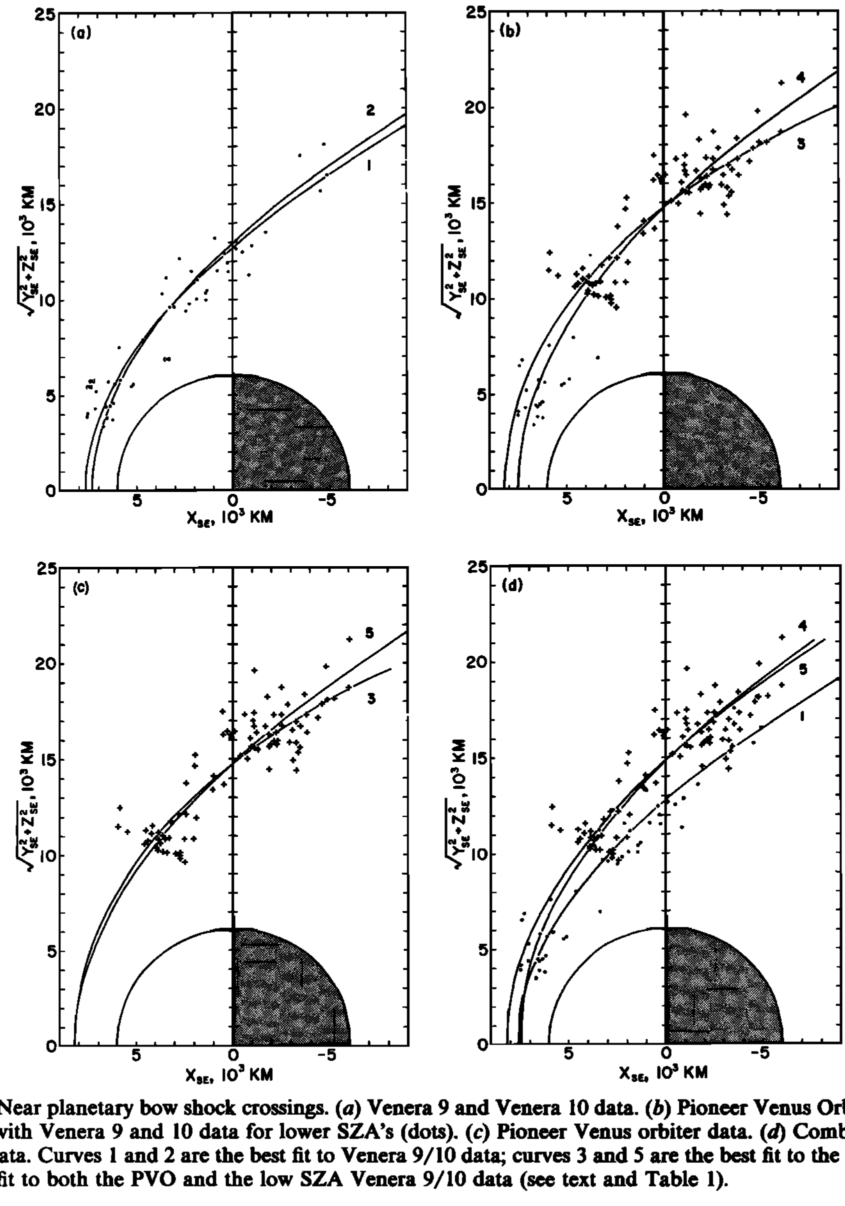

Fig. 2. Near planetary bow shock crossings. (*a*) Venera 9 and Venera 10 data. (*b*) Pioneer Venus Orbiter data (crosses) combined with Venera 9 and 10 data for lower SZA's (dots). (*c*) Pioneer Venus orbiter data. (*d*) Combined Venera 9/10 and PVO data. Curves 1 and 2 are the best fit to Venera 9/10 data; curves 3 and 5 are the best fit to the PVO data; curve 4 is the best fit to both the PVO and the low SZA Venera 9/10 data (see text and Table 1).

on their respective SZA's. The means were calculated from these ten sets of best fit curve parameters. These mean values of the shock parameters are also given in Table 1 and show the accuracy of the approximation.

Recently, the data for 86 Venusian shock crossings by the Pioneer Venus orbiter (PVO) were published [*Slavin et al.*, 1979*b*]. These 86 PVO crossings are shown in Figure 2*b* along with the approximation of the mean shock curve (curve 3) from *Slavin et al.* [1979*b*], which employs a Venus-centered ellipse. The parameters of this ellipse are given in Table 1. *Slavin et al.* [1979*a*] showed that there is a systematic difference between the PVO mean shock location and Venera 9/10 mean shock location.

It should be noted, however, that *Slavin et al.* [1979*a*] compared the PVO shock crossings with Venera 9/10 data taken from *Verigin et al.* [1978]. Verigin et al., however, apparently made no allowance for the solar wind aberration angle. As the Venera 9/10 shock crossings occurred close to the ecliptic plane at the Y_{SE} axis this omission of an aberration term leads to the exaggeration of the difference in the observed bow shock location between PVO and Venera 9/10.

Slavin et al. [1979*a*] suggested that this difference may arise either from solar cycle variations or from differences between the Venera 9/10 orbits and the PVO orbits. That is, for example, owing to the asymmetry of the Venusian bow shock relative to the orientation of the interplanetary magnetic field [*Romanov et al.*, 1978; *Romanov*, 1978], the low latitude Venera 9/10 crossings may have occurred closer to the planet, on the average, than the high latitude PVO crossings.

Assuming that the difference between the PVO shock crossings and the Venera 9/10 shock crossings are mainly connected to the latitudinal asymmetry, we may estimate the mean shape of the high-latitude shock by combining the PVO data with the Venera 9/10 data for lower SZA. The resulting best fit curve (curve 4) is shown in Figure 2*b*, and the corresponding parameters are given in Table 1. While the obtained values do not contradict the degree of shock asymmetry found by *Romanov et al.* [1978] and *Romanov* [1978], the result does not exclude the possibility that the difference between the Venera 9/10 and the PVO shock locations are connected with secular variations.

CONCLUSIONS

The best fits to the Venera 9/10 bow shock crossings appear significantly different from those for the PVO bow shock crossings. Almost all the PVO best-fit parameters are outside the range of uncertainty estimated from the mean of ten runs of Venera 9/10 data. The exception is the subsolar distance, which is difficult to determine accurately from measurements made at large SZA. All the measurements used in this study are made at large or intermediate SZA. The difference between the Venera and the Pioneer data could be due either to a secular change, presumably due to changes in the solar activity cycle, or to a latitudinal asymmetry, due to the interplanetary magnetic field. Evidence for a latitudinal asymmetry has been presented. A solar cycle change is plausible but has not yet been confirmed by other observations.

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