Some Remarks on the Position and Shape of the Neutral Sheet

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Recent measurements have delineated some of the major features of the structure of the earth's geomagnetic tail [*Ness*, 1965; *Speiser and Ness*, 1967]. The so-called neutral sheet is an important feature of the tail dividing it into two main regions with the largest flux components directed, respectively, parallel and antiparallel to the solar wind. The existing measurements suggest a relatively simple empirical formula for the location of the neutral sheet in the geocentric solar magnetospheric coordinate system, in which many researchers order their data taken in the tail [see for example, *Speiser and Ness*, 1967; *Murayama*, 1966; *Bame et al.*, 1967].

In this coordinate system the X axis points toward the sun; the Z axis, coplanar with the X axis and the earth's magnetic dipole axis, points above the ecliptic plane; and the Y axis, which completes the right-handed Cartesian set, points to the dusk meridian. The X-Y plane rocks with respect to inertial space with a 24-hour period so that the geomagnetic equator always cuts the solar magnetospheric equator along the Y axis. The ordering of data in this coordinate system acknowledges the dual control of the geomagnetic dipole and the solar wind on the direction of the field lines in the tail. Ideally, we would like our X axis to be antiparallel to the solar wind flow vector, corrected for the aberration of the solar wind by the earth's orbital motion. This is not necessarily the solar direction [*Wolfe et al.*, 1966], and the fluctuations in velocity and direction observed will produce a scatter in the measurements of a feature that is well defined and fixed in the ideal coordinate system. Another useful parameter in addition to the spatial coordinates of a feature is the angle between the dipole axis and the Z axis at the time of the measurement. This would be the same as the geomagnetic latitude of the subsolar point if the ideal coordinate system pointed toward the sun. However, again, the nonradial flow of the solar wind introduces a difference between these two angles. Thus we will always have some scatter when we attempt to order the neutral sheet positions in the nonideal coordinate system.

The neutral sheet serves to divide the tail into two regions with substantially equal magnetic fluxes across any Y-Z plane, oppositely directed above and below the neutral sheet. The magnetic equator serves a similar function within the magnetosphere. There is a component of the field toward the dipole axis in the northern hemisphere and away in the southern. Thus a simple rational model of the neutral sheet would place its closest approach to the earth on the geomagnetic equator just outside of the particle trapping region on the night side of the earth. As the neutral sheet extends away from the geomagnetic equator, it may be assumed to quickly take a position so that lines of constant Y coordinate are nearly parallel to the solar wind and perhaps asymptotically approach the X-Y plane at a great distance from the earth.

Assuming that the neutral sheet starts out from the geomagnetic equator and that there is no dependence on the distance behind the earth, it is easy to show that we expect to find the neutral sheet at a distance Z_N above the solar magnetospheric equator where

$$Z_N = F_1(Y_N) \sin \lambda \tag{1}$$

Here Y_N is the Y coordinate at the point of observation, λ is the angle between the dipole axis and Z axis. We define λ as positive when the north magnetic pole is pointed toward the sun and negative when the north magnetic pole is pointed away from the sun.

Such a formula has already been used by *Speiser and Ness* [1967] and by *Murayama* [1966]. *Speiser and Ness* [1967] assumed no Y

dependence and found $F_1(Y_N)$ to be equal to $10\ R_E \pm 3\ R_E$ for $|Y_N| \leq 6\ R_E$. *Murayama* [1966] set $F_1(Y_N) = 8\ R_E$ for $|Y_N| \leq 8\ R_E$ and zero otherwise, in order to estimate the distance from the neutral sheet at the times IMP 1 was within the geomagnetic tail. However we have no a priori reason to exclude either a Y dependence or X dependence.

If we wanted to take account of the tendency for the neutral sheet to approach the magnetospheric equator, we would multiply the right-hand side of equation 1 by a function of the distance of the point of observation behind the earth. Then (1) becomes

$$Z_N = F_1(Y_N)F_2(X_N) \sin \lambda \qquad (2)$$

if the X dependence is independent of Y.

Two sets of data on the positions of the neutral sheet have been reported up to this date. These are the IMP 1 measurements [*Speiser and Ness*, 1967] and the OGO 1 results [*Brody et al.*, 1967]

Table 1 lists the crossings when λ was equal to or greater than 5°. This arbitrary cutoff in λ was chosen since the errors involved are possibly greater than 3° and the plotting of these points in Figures 1 and 2 requires a division by sin λ. In addition several crossings

TABLE 1.

Satellite	Orbit	X	Y	Z	λ
IMP 1	30	− 6.5	−12.7	.1	8
	31	− 6.5	−11.0	−.2	−9
	33	− 5.3	− 8.1	−.2	−5
	34	−18.5	−13.7	−.1	6
	35	−17.5	−11.8	.7	7
	40	−18.2	− 6.2	.5	11
	41	−14.8	− 5.3	1.8	9
	42	−14.0	− 4.5	2.1	16
	43	−27.8	− .1	1.6	10
	43	−25.2	− .4	2.4	9
	44	−27.5	+ 1.3	2.5	16
	44	−19.3	− .3	3.7	25
	45	−16.8	+ .2	4.0	25
	45	−25.4	+ 2.3	3.5	12
	45	−26.5	+ 2.5	3.4	18
	46	−27.5	+ 5.9	2.5	32
	47	−25.0	+ 5.2	4.6	30
	47	−23.8	+ 4.5	4.9	25
OGO −1	142	−14.5	9.5	− .3	− 8
	143	−11.6	6.2	−1.2	−11
	145	−13.3	11.1	−1.3	−11

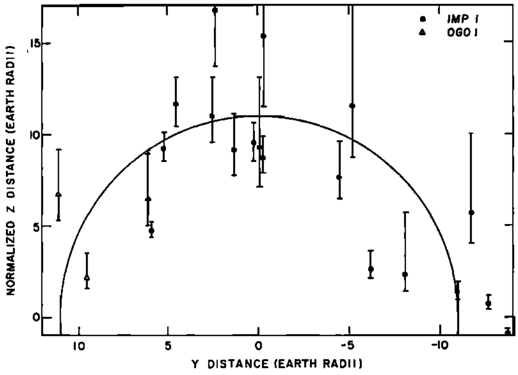

Fig. 1. The distance above the magnetospheric equator normalized by dividing by the sine of the magnetic latitude of the subsolar point plotted versus the magnetospheric Y coordinate for neutral sheet crossings observed by IMP 1 and OGO 1. Distances are in earth radii.

found in the OGO 1 data have been omitted because of insufficient data coverage either before or after the crossing. Figure 1 is a plot of $Z_N/\sin \lambda$ versus Y. The error bars indicate the change that would occur in $Z_N/\sin \lambda$ with a change in λ of ±3°. This plot is equivalent to normalizing the position of the observed crossings to the equivalent position if the dipole axis were aligned with the solar wind. If equation 1 holds, i.e. there is no X dependence, and the neutral sheet starts from a circle in the geomagnetic equator, then within the errors mentioned above we expect the points to fall on a circle. If the neutral sheet started from an ellipse in the geomagnetic equator, the points would fall on an ellipse in this plot. Within the scatter of the data shown here a circle fits just as well as an ellipse. Although a strictly circular shape would not be expected physically, the spread in the data does not justify a more complicated approximation than a circle. If there were a strong dependence of Z_N on X, then the points would fill the circle rather than lie near its edge, provided, of course, there was enough variability of the X coordinates in the sampling. The lack of a strong X dependence suggested by Figure 1 is verified by Figure 2. There those points with Y coordinate between $\pm 1.5\ R_E$ have been plotted versus X. There is no obvious decrease of $Z/\sin \lambda$ with X, but the statistics are poor, and there are no data at geocentric distances greater than 28 R_E.

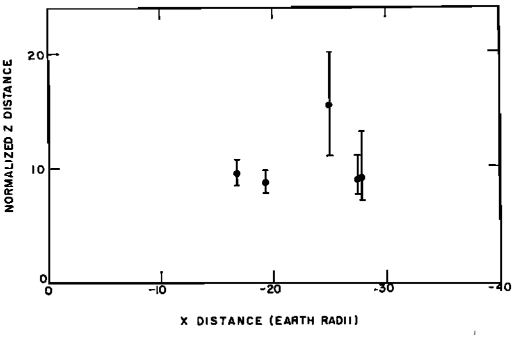

Fig. 2. The distance above the magnetospheric equator normalized as in Figure 1 plotted versus the distance behind the earth for those neutral sheet crossings of Figure 1 with a Y coordinate between $\pm$ 1.5 R_E.

We conclude from the above that in properly ordering data taken in the tail it is necessary to know the direction and velocity of the solar wind outside the tail at the same time as the observations within the tail are being made. This is of course obvious. However, even if the coordinate system used to order the data were rotated with the X axis of the coordinate system pointing in a direction corrected for the nonradial solar wind flow and the associated aberration angle, the neutral sheet does not coincide with the X-Y plane (whenever the dipole is not perpendicular to the solar wind), but rather it is a curved surface touching the X-Y plane at the edges of the tail and furthest from the X-Y plane in the center of the tail. For regions within about 11 R_E on either side of the center of the tail and less than 30 R_E behind the earth, the data presented here suggest that a reasonable empirical fit is given by

$$Z_N = (R_0^2 - Y_N^2)^{1/2} \sin \lambda \qquad (3)$$

with R_0 equal to 11 R_E. Between $Y_N = 11$ and the edge of the tail we expect the neutral sheet to lie close to the magnetospheric equator (the $Z = 0$ plane). Other more reasonable functional forms for $F_1(Y_N)$, giving an asymptotic approach of the neutral sheet to the magnetospheric equator with increasing distance from the center of the tail, would require fitting two arbitrary parameters, e.g., for a Maxwellian. We feel that the above formula should prove useful in studying phenomena in the magnetotail whenever a knowledge of the distance from the neutral sheet is an important parameter.

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