On the Configuration of the Magnetotail Near Midnight
During Quiet and Weakly Disturbed Periods:
State of the Magnetosphere

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Energetic-electron pitch angle data and magnetic field data obtained on inbound passes of Ogo 5 in 1968 near midnight during quiet periods have been studied. From observation of the vector field components along the orbit and knowledge of the satellite position when the pitch angle distributions changed from approximate isotropy (indicating non-guiding center particle motion) to the butterfly distribution (corresponding to adiabatic bounce orbits) the configuration of the near-earth tail field for individual orbits has been inferred. The details of the modeling are presented in a companion paper. We find that quasi-steady field configurations near midnight can occur that are markedly different (ranging from taillike to fairly dipolelike) in different cases, even though the usual magnetic activity indicators ($K_p$, $AE$, auroral zone and mid-latitude magnetograms, and $B_{ZGSM}$ of the interplanetary magnetic field) differ but slightly from one case to another and indicate a quiet magnetosphere. The major differences in the data are that more intense lobe fields occur at the same distance down the tail for the more taillike field configurations ($\sim 30 \gamma$ at $15 R_E$ for taillike configurations and $\sim 15 \gamma$ at $15 R_E$ for more dipolelike configurations). There appears to be evidence that the more taillike configuration is associated with an enhanced dynamic pressure from the solar wind. The data, viewed in the light of previously published data obtained by the present experimenters and others, argue strongly that during quiet times the plasma sheet, in its azimuthal variation, is at its thinnest in the region near midnight. These results affect current ideas of the substorm growth phase and the evolution of energetic-electron pitch angle distributions in the postmidnight magnetosphere.

INTRODUCTION

It has long been recognized that the field configuration in the near-earth regions near midnight plays an important role in magnetospheric dynamics. Normally, during quiet times the closest earthward approach of the cross-tail current system is in the region of the midnight cusp where the field lines first indicate the beginning of a tail geometry [Anderson and Ness, 1966; Fairfield, 1968; Aubry et al., 1972]. The current system changes during magnetic activity, but the changes generally proceed from a starting point near midnight [Akasofu, 1968]. From the extensive studies of the substorm [e.g., McPherron et al., 1973] we have developed a fair idea of the dynamics of the magnetotail, but there is a question concerning the configuration to which the magnetotail relaxes in the absence of such activity. Understanding the quiet-time norm provides insight into the evolution of the substorm and is of particular importance for placing the growth phase [McPherron, 1972; McPherron et al., 1973] in proper perspective.

In addition, understanding the quiet-time field configuration near midnight helps in the understanding of the changes in the pitch angle distributions (PAD’s) of energetic electrons as they drift earthward through the nighttime magnetosphere. Our present understanding of these PAD changes [West et al., 1973a, b; West and Buck, 1974a] is outlined in the section on method of the present paper.

In an attempt to establish the quiet-time magnetic field we have provided case studies of the configuration near midnight at periods remote from intervals of magnetic activity. The data used were acquired on Ogo 5 in 1968 by the Lawrence Livermore Laboratory (LLL) scanning electron spectrometer and the UCLA vector magnetometer experiments (see a preliminary account by West and Buck [1974b]). The electron data serve as tracers of the field configuration and are especially useful at times when they change abruptly from isotropic to butterfly pitch angle distribution and vice versa. (The butterfly PAD is depleted in flux near $90^\circ$ and generally has a loss cone.) We took advantage of quiet times ($K_p = 0^+ \to 1^+$) within 1 or 2 hours of midnight, when Ogo 5 was inbound from the north lobe of the tail.

As a result of our investigation we show that the magnetotail near midnight may exist for hours at a time in widely different quasi-stable configurations which, in their limit, can be characterized as being (1) fairly dipolelike to about $15 R_E$, beyond which the field becomes taillike, and (2) dipolelike to only about $10 R_E$, beyond which the field becomes taillike. These different states not only affect the dynamics of the substorm but also affect the evolution of electron PAD’s in the near-earth plasma sheet past midnight.

In the following sections we first present a discussion of the electron PAD’s in the nighttime magnetosphere to illustrate their use as tracers of the field configuration. Quiet-time data corresponding to both dipolelike and taillike configurations are then presented. To relate these data properly to magnetospheric dynamics, we establish the state of the magnetosphere for each case through the study of auroral zone and mid-latitude magnetograms and the study of the interplanetary magnetic field (IMF). A quantitative measure of the field configurations was obtained through a modeling study of se-
lected data incorporating magnetic field observations and particle trajectory studies. This work is presented in the companion paper [West et al., 1978], herein called paper 2.

**INSTRUMENTATION**

The details of the spectrometer are presented by West et al. [1969] and in a short discussion by West et al. [1973a]. Briefly, the instrument consisted of a seven-channel magnetic electron spectrometer (~60–3000 keV) mounted on a scannable boom on the earth-sun-oriented Ogo 5 so as to view a direction perpendicular to the earth’s radius vector. The scan rate was 3°/s. The effective energy and respective geometrical factors of the channels providing data for this investigation are as follows: $E_1$, 79 ± 23 keV, 0.180 cm$^2$ keV sr; $E_2$, 158 ± 27, 0.277; $E_3$, 266 ± 36, 0.390; $E_4$, 479 ± 32, 0.605; and $E_5$, 822 ± 185, 4.43. Data were also obtained by an array of proton detectors located in one of the electron spectrometer magnets in line with the entrance aperture. Occasionally, we mention data from the two lowest energy proton channels, $P_0$ and $P_1$, which have energies and geometrical factors as follows: 100–150 keV, 2.06 × 10$^{-3}$ cm$^2$ sr and 230–570, 1.3 × 10$^{-2}$, respectively. ($P_0$ and, to a lesser extent, $P_1$ detected heavier ions producing the same ionization in the particle detectors.) The pitch angles for the particle fluxes were determined by using data from the UCLA triaxial vector magnetometer experiment on Ogo 5. An account of the instrument is given by Aubry et al. [1971]. This magnetometer also supplied the data used to describe the field configuration for each of our case studies.

**METHOD**

Satellite vector magnetometer measurements allow us to infer very little about the field configuration at points remote from the observation point. We have a fair understanding of the field to be encountered earthward of the observation point, but tailward there are large uncertainties as to where, for example, the field lines cross the neutral sheet. In addition to vector magnetic field data, pitch angle and spectral data for energetic particles are usually obtained by satellite investigations, and such particles can be used to probe regions remote from the satellite. For example, electrons travel long distances along the field lines and can serve as probes of the distant field configuration, especially at times when their PAD’s change abruptly; this, of course, assumes that the effects of wave-particle interactions and turbulence are negligible or can be allowed for, which we find is often the case.

We know that the quiet-time PAD’s of electrons drifting azimuthally from dusk into the nighttime magnetosphere beyond 7–9 RE (energy dependent) are depleted in fluxes near 90°, the so-called “butterfly distribution” [West et al., 1973a]. The butterfly distribution has been seen to extend to distances as large as 17 RE in equatorial regions premidnight. To understand readily the formation of this PAD, note that the drift paths of equatorially mirroring electrons in these regions map back along contours of constant B to the afternoon magnetopause, whereas electrons with small equatorial pitch angles follow drift paths which stay inside the magnetosphere in order to satisfy the constraint of constant second invariant. Only those electrons whose drift paths remain earthward of the magnetopause can reach the distant premidnight region from a source on the dayside.

An example of Ogo 5 data acquired near midnight during a very quiet period on August 25, 1968, is shown in the center panel of Figure 1. Here we see the scan-modulated count rate data. The instrument scanned only about 10° between readouts, so that the plotted data points are representative of the counting rates for the total range of pitch angles reached during the scan. The spectrometer scanned so as to view a direction perpendicular to the earth’s radius vector, thus limiting the range of pitch angles from 90° to some minimum angle $\theta_{\text{min}}$ (the pitch angle is given on the figures). The bottom of the envelope of the scan-modulated fluxes in the data of Figure 1 is $j_1$, and the upper envelope, at least until the change to the normal loss cone PAD (perpendicular to the field) at ~1630 UT (8.6 RE), is $j_1$, i.e., 20°–40° pitch angles. Similar data acquired earlier in the evening at $\theta_{\text{min}} = 162°$ (September 17–18) and at $\theta_{\text{min}} = 120°$ (October 21) are reported by West et al. [1973a] and West and Buck [1974a], respectively.

When the eastward drifting electrons encounter a field configuration that is too taillike to maintain adiabatic guiding center motion over their full bounce motion, their anisotropic PAD changes to an approximate isotropic distribution [Speiser, 1965, 1967, 1971; Sonnerup, 1971; Shabansky, 1971; Eastwood, 1972; Pudovkin and Tsyganenko, 1973]. This occurs because, in a taillike field, particles cross the neutral sheet far down the tail where the fields are too weak and the field curvature is too small to maintain adiabatic guiding center motion.

To demonstrate this, we examine the August 2 data of Figure 2. Prior to 0633 UT we note the lack of scan modulation of the data, indicating that the PAD is isotropic (indicative of non-guiding center motion), and after that we find the butterfly PAD (indicative of adiabatic guiding center motion). (Strictly speaking, we should not describe the apparent

![Figure 1](image-url)

Fig. 1. Quiet-time data acquired just before midnight on August 25, 1968. Isotropy was observed briefly at the start of the particle fluxes, followed, after 1118 UT, by the butterfly PAD, as indicated by the scan-modulated particle fluxes. The pitch angles reached during the scan ranged from 90° to $\theta_{\text{min}}$ (also 180°–$\theta_{\text{min}}$). The instantaneous magnetic field direction and relative amplitude are shown by the arrows along the inbound orbit in the bottom panel. The field configuration sketch was inferred from the data in the top two panels.
isotropy which results as nonadiabatic motion, since it has been shown that neutral sheet adiabatic invariants may be applicable [Sonnerup, 1971; Speiser, 1970]; however, when we do so, we mean the breakdown of the first and second adiabatic invariants $\mu$ and $J$. The field configuration for the data of August 2 is modeled in paper 2. We consider electrons injected along the model field lines from a position along the satellite orbit. The result of injection with a $10^7^\circ$ pitch angle at 0610 UT in the orbit is presented in Figure 3, which shows the trajectory of a single electron. (Note that $x$ and $y$ are positive down the tail and toward dawn, respectively.) We show the motion in the vicinity of the plasma sheet. In the $y-z$ plot we note the looping of the neutral sheet, followed by gradient $B$ drifting in the north and south lobes of the plasma sheet, and finally the turning toward the earth and mirroring. The $x-y$ plot shows the motion about the $z$ direction due to the action of $B_z$. As is well known, the $x$-$z$ and $x$-$y$ motions tend to decouple when $B_z$ in the neutral sheet is small enough.

When the electrons have turned toward the earth, as is shown in the August 2 example, they will return to guiding center motion. However, relative to the motion prior to the neutral sheet encounter, their pitch angles will have changed, so that an observer nearer the earth will observe an isotropic distribution. Some of the electrons will precipitate, and this precipitation is believed to be an important input to the auroral zone, while others will mirror as they approach the earth and will return to the interaction region in the neutral sheet. Such effects, resulting in isotropic PAD's, can occur during times of dynamic changes such as during substorm growth phases or during quiet times, as described above, as the electrons' azimuthal drift brings them into a region of taillike field. Substorm growth phase effects are reported by West et al. [1973b] and Pytte and West [1978]. In the West et al. [1973b] paper it is shown that no net energy change occurs as a result of randomization. The Pytte and West [1978] paper describes precipitation effects. The present paper describes the processes at quiet times.

The August 2 and 25 data used for the examples highlight the differences that can occur in the field configuration during quiet times. The modeling studies of paper 2 show that the

![Figure 2](image1.png)

**Figure 2.** Quiet-time data acquired just past midnight on August 2, 1968. Note that the low degree of scan modulation in the electron fluxes prior to 06:33 UT indicates that the fluxes have an isotropic PAD. Rather abruptly, at 06:33 UT, scan modulation occurs, indicating the transition to the butterfly PAD.

![Figure 3](image2.png)

**Figure 3.** Trajectory of a 79-keV electron in the model of the August 2 data presented in paper 2. The electron was injected initially (at the point marked with a cross) with a pitch angle of $10^7^\circ$ at $x = x_{GSM} + y_{GSM} = 8.5$ at 1.95 $R_E$ above the neutral sheet. Note that $x$ is positive down the tail and $y$ is positive toward dawn. It will be noted in parts b and c that in the region away from the neutral sheet the drift is toward $-y$ (dusk). This drift results from the increase in $B$ away from the neutral sheet. Complementary data are shown in Figures 5 and 6 of paper 2.
<table>
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<th>Sheet</th>
<th>Isotropic</th>
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<td>weak</td>
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*The $\phi$ and $\theta$ are the solar magnetospheric longitude (or solar azimuth) and elevation, respectively.

$+$Elevation above dipole plane.

$+$Solar magnetospheric coordinates.
Fig. 4. Auroral zone magnetometer data on August 25, 1968, from stations at Leirvogur, Great Whale River, Fort Churchill, Sitka, College, Barrow, Cape Wellen, Cape Chelyuskin, Dixon Island, and Abisko. For the locations of these observatories see the report by the World Data Center A for Solar-Terrestrial Physics [1972]. The pluses denote local midnight at each station. The period of major interest is 1100–1500 UT. The auroral zone was particularly quiet until ~1600 UT.

Fig. 5. Mid-latitude magnetometer data on August 25, 1968, from stations at M'Bour, San Juan, Fredericksburg, Dallas, Boulder, Tucson, Newport, Honolulu, Guam, Kakioka, Gnangara, Yangi-Bazar (Tashkent), and Hermanus [World Data Center A for Solar-Terrestrial Physics, 1972]. The pluses denote local midnight at the station. There is little evidence of activity until ~1900 UT. The data are especially quiet during the hours 1100–1500 UT, the time of major interest in Figure 1. The slow diurnal effects should be ignored.

Data

Despite the fact that the magnetosphere was quiet for all cases in this study, important differences occurred. We present the results for the more dipolelike cases first, starting with August 25. For the more taillike results we begin with the July 20 data, obtained during an especially quiet period, followed by the similar August 2 and 4 data. The July 25 data are presented last as a study of taillike effects during a period of very weak activity. For a ready reference to the observations, see Table 1, which includes the satellite data and the state of the magnetosphere as determined from auroral zone magnetometer stations, mid-latitude magnetometer stations, and AE(11) indices [Allen, 1973], as well as the state of the interplanetary field as determined from Explorer 33, 34, and 35.

Data Showing Dipole Configuration to Large Distances

August 25, 1968. From Figure 1 (center panel) we note that Ogo 5 first encountered energetic particles at 1106 UT (R = 15.0 RE, $\phi_{GSM} = 163^\circ$). The inbound path of Ogo and the estimated field configuration are shown in the bottom panel. The instantaneous neutral sheet position changed markedly on this inbound pass and is shown as a curved line (we used a procedure to determine neutral sheet equivalent, approxi-...
Fig. 7. Particle and field data for July 20, 1968. These data were acquired during an especially quiet period when Ogo 5 was inbound from the north lobe of the tail, about 1 hour past midnight.

Fig. 8. Auroral zone magnetometer data for July 20, 1968. The auroral zone was very quiet, especially for the period of major interest, 0400–0700 UT.

Fig. 9. Mid-latitude magnetometer data for July 20, 1968. A weak current system is evident at 0230 UT. During 0400–0700 UT it was magnetically very quiet.

At the time that these data were obtained, $Kp$ was 0+, and $AE(11)$ had been less than 60 $\gamma$ for many hours. Figures 4 and 5 show auroral zone and mid-latitude data, respectively, for this period. Local midnight is indicated by the pluses on the curves. Conditions were especially quiet on this date for the period of interest. These conditions are consistent with the magnetic field conditions in the interplanetary medium as shown by Explorer 33 and 35. In Figure 6 we see that from 0600 to past 1500 UT, $B_{GSM}$ was well northward and quiet. Clearly, August 25 exemplifies all that we expect for a magnetically very quiet day.

September 17–18, 1968. These data, as noted in Table 1, were taken earlier in the evening ($\phi_{GSM} = 162^\circ$). $Kp$ was 0+, and the butterfly PAD was observed inward from 13.9 $R_E$. It is interesting to note that at this time the IMF was near zero. The major feature that characterizes the data of these 2 days and separates them from the next set of data is the low lobe field (~15 $\gamma$) at 15 $R_E$ for August 25 and for September 17–18 (Table 1), as contrasted with lobe fields of ~30 $\gamma$ at 15 $R_E$ for the more taillike data. There is some question as to whether these were true lobe measurements (there may have been some low-energy particles present), but the uncertainties are of no more than a few gammas.

Data Showing Taillike Configuration

July 20, 1968. Magnetically, this was a very quiet day: for the period of interest, $Kp$ was 0+, and $AE(11)$ was less than 62 $\gamma$. Figure 7 shows the magnetic field data in the top panel, the electron data in the middle panel, and a sketch of the inferred
The inferred field configuration was sketched from the field direction determined from the UCLA magnetometer experiment and estimates of the neutral sheet position. The inbound path is annotated with the magnetic field vectors. The neutral sheet position did not change appreciably during our period of interest. The dashed line in the sketch indicates the field line associated with the transition from isotropic to butterfly PAD. The auroral zone and mid-latitude magnetograms (Figures 8 and 9) show a notable lack of activity in the auroral zone during the period of interest, and similarly, there is an absence of correlative effects in the mid-latitude data. Consistent with this, IMF data, as determined from Explorer 33 and 35 and presented in Figure 10, show that the $B_{zim}$ of the IMF was predominantly northward during the interval of interest.

August 2, 1968. For this day, designated a QQ day, $Kp$ was 1, and $AE(11)$ had been less than 100 $\gamma$ since 1900 UT of August 1. Nevertheless, on the basis of some minor activity revealed in the mid-latitude magnetograms and the association with intervals of southward interplanetary fields we regard this as a very weakly disturbed day. Figure 2 shows the magnetic field in the top panel, scan-modulated electron data in the middle panel, and a sketch of the field configuration in the bottom panel. The plasma sheet encounter first occurred at 0330 UT. Possibly, the edge of the sheet moved somewhat southward, away from Ogo, since the electron fluxes dropped after $\sim$0430 UT; at 0520 UT, Ogo moved back into the sheet. The electron fluxes during these periods were essentially isotropic. Our instrument did not look at small pitch angles at this time, but the UCLA scintillation counter spectrometers, looking in six fixed directions, were able to confirm isotropy for the higher counting rate regions after 0600 UT. Energy-dependent transitions to the butterfly distribution occurred as Ogo neared the earth. A detailed examination of the transition from the isotropic fluxes to the scan modulation (indicative of the butterfly PAD) shows that for the 79-keV data the loss of isotropy started at about 0633 UT and that the transition to the butterfly PAD was not complete until about 0636 UT. We use the positions of PAD transition in channels $E_r$ (79 keV) through $E_r$ (822 keV) for the modeling studies in paper 2. Because of their greater rigidity the transitions of higher-energy electrons occurred nearer the earth. The points at which PAD transitions were observed were $R = 8.78$ $Re$ for 79-keV data and $8.43$ $Re$ for 822-keV data, but the actual breakdown in adiabaticity for the particular particle trajectories occurred at the neutral sheet crossings of the respective field lines. Measurements of energetic protons are available for this orbit and show the PAD changes much closer to the earth; transitions were noted at $R = 7.92-6.55$ $Re$ along the orbit for protons of 100–570 keV. The field configuration for this orbit is sketched in the bottom panel of Figure 2. The neutral sheet position remained fairly constant during the period of interest. The dashed curve corresponds approximately to the dividing line between that configuration for which invariant breakdown occurred and that for which guiding center motion prevailed.

The auroral zone magnetometer data for August 2 are shown in Figure 11. Prior to the weak substorm at $\sim$1040 UT, there had been negligible activity. Figure 12 presents the mid-latitude magnetometer data, showing evidence of very weak effects at $\sim$0420 and 0520 UT, somewhat stronger effects at $\sim$0700 UT, and well-developed effects at $\sim$1040 UT. Figure 13 shows the IMF as measured by Explorer 34 and 35. Up to the time of interest ($\sim$0700 UT) the $B_{zim}$ component of the IMF had been alternating north and south by a few gammas. However, only after $\sim$0820 UT did $B_{zim}$ stay appreciably southward, and this was probably the precursor of the substorm at 1040 UT.

August 4, 1968. On this date, $Kp$ was 0+, and $AE(11)$ had been less than 40 $\gamma$ from 0600 UT to the period of interest at 1700–2100 UT. Figure 14 shows the data from Ogo 5: the top panel shows the magnetic field data, the middle panel shows the scan-modulated 79-keV electron fluxes, and the bottom panel shows a sketch of the field configuration. We note that plasma sheet entry was signaled by both energetic-electron detection and diamagnetic field effects at 1727 UT. The transition from isotropic PAD to butterfly distribution started at $\sim$1832 UT and was not complete until $\sim$1900 UT.

At the time of major interest in these data the magnetosphere was very quiet, as is shown by the auroral zone and mid-latitude magnetograms in Figures 15 and 16. Prior to 0900
Fig. 12. Mid-latitude magnetometer data for August 2, 1968. Obvious effects of current systems show at 0700 and 1100 UT, indicated by the vertical lines. The period of major interest, 0300-0630 UT, was fairly quiet. The data marked by the last four vertical lines, however, do show some weak correlative effects.

UT, there was well-developed activity in both sets of magnetograms, but by the time of interest the magnetosphere was well recovered. Weak activity occurred at ~2100 UT, near the end of the period of interest, and may be of significance.

In Figure 17 we present the IMF for August 4, 1968. For both Explorer 34 and Explorer 35 the IMF was well northward, a condition conducive to a quiet magnetosphere, except for momentary fluctuations from about 0400 to 2000 UT.

July 25, 1968. In the interest of following the systematic changes from a very quiet magnetosphere to a weakly disturbed magnetosphere we present the July 25 data in Figure 10.

18. These data indicate a thin plasma sheet near midnight, ~1.5-$R_E$ half thickness at 10 $R_E$, and are consistent with the results of the other taillike data. On this day, $Kp$ was 1+, and $A(E, 11)$ had been ~100 $\gamma$ for the previous 2 hours. On this pass, isotropic electron PAD's were first encountered at 1010 UT and 10.3 $R_E$, and the transition to butterfly PAD occurred at 1050 UT and 9.4 $R_E$. At 0600-0800 UT, there is evidence of weak substorm activity near midnight in both the auroral zone and the mid-latitude magnetogram, but near the period of interest (1000-1100 UT) the magnetograms show no signs of activity. At Explorer 33, $B_{Z GSM}$ was 2 $\gamma$ southward at 1000 UT and decreased toward zero in the next hour. At Explorer 35, $B_{Z GSM}$ was zero at the start of this period and rose to +2 $\gamma$ by 1100 UT. At both satellites, however, $B_{Z GSM}$ remained mostly southward ~2 $\gamma$ from 0 to 0900 UT.

Polar Cap Magnetograms

At times of extreme quiet we can expect a markedly contracted auroral oval, so that the usual auroral zone magnetograms may miss substorm activity [Akasofu, 1974]. This observation has a definite bearing on our more dipolelike data. The point is still well taken even for the most taillike data, except that the oval was not necessarily as highly contracted. We have examined magnetograms from a variety of polar cap stations (Thule, Alert, Resolute Bay, Godhavn, Mirny, Plateau, and South Pole), and nothing was found to change our assessment of the state of the magnetosphere in each case as previously described.

Akasofu [1974] has shown Defense Meteorological Satellite

Fig. 14. Data for August 4, 1968. (Top) The magnetic field configuration. (Middle) The scan-modulated electron fluxes. (Bottom) Sketch of the field configuration.
Program photographs of a highly contracted oval (Kp = 0) showing weak but discrete auroral forms. Also, weak contracted-oval substorms have been observed after periods of prolonged quiet. For example, Lui et al. [1976] reported a substorm on November 17, 1971, during the last of 4 consecutive quiet days; Kp was 0, and AE ~ 25. No activity was observed in mid-latitude or auroral zone magnetograms. Plasma energization was noted at 11 RE near midnight but not at 6.6 RE. Thus in the light of such observations, one can never rule out minor activity somewhere. Indeed, steady state convection implies reconnection, possibly at some distant point, and this can hardly proceed without the appearance of at least minor activity. In any case, the activity indices do provide a relative means of comparing data and, for this paper, should be viewed in that light.

General Comments on the State of the Magnetosphere

Table 1 summarizes the observations. We have also included Kp and AE(11), which in themselves do a reasonable job of ordering the data in terms of activity. Proceeding from very quiet to weakly disturbed conditions, we have ordered the data as follows: September 17–18 (Kp = 0+, AE < 40 γ); August 25 (0+, <60); July 20 (0+, <62); August 4 (0+, <40); July 12 (1, <55); August 2 (1, <100); and July 25 (1+, <100). In the cases of July 20 and 25, and especially August 4 (mid-latitude), we find evidence of magnetic activity only a few hours earlier than the time of interest. However, for July 25, there was a weakly southward IMF at the time of interest, possibly indicating the flow of magnetic flux into the tail. In none of these cases do we find auroral zone activity. There is, however, weak mid-latitude activity for August 2 and July 25. Thus in terms of the IMF and its contributing influence to magnetic activity the cases should be ordered about as we have indicated. In comparison, on September 17–18, there was hardly any IMF (~1–γ total field), and at the other extreme, on July 25, we found an IMF with a 2–γ southward component.

MAGNETIC FIELD MODELING

The field configurations presented in Figures 1, 2, 7, and 14 and alluded to in our discussions need to be established more quantitatively, at least in the vicinity of the plasma sheet. A modeling study was conducted, and the details are presented in paper 2. Here we discuss only the most obvious features of that study.

For the modeling studies we concentrated on the data acquired close to midnight to minimize problems associated with coordinate systems. This simplified the modeling of the transition from the hinging region of the near-earth magnetotail to GSM coordinates down the tail. The data acquired on August 2, 4, and 25 fit this requirement and largely exemplify what we were looking for. The August 25 data show a fairly dipolelike configuration to large distances and contain a neutral sheet crossing in an ideal region. These data are also similar to the September 17–18 results. Conversely, the August 4 data show a taillike field. Again there is a neutral sheet crossing at an ideal location. For the August 2 data the neutral sheet crossing is in the hinging region, a circumstance which is not ideal for modeling, but we do have an excellent set of particle pitch angle data. In establishing the field model we took advantage of the changes encountered in the PAD's on the inbound orbit for five electron and two proton energy channels. We followed
the detailed trajectories of the particles from the point of the PAD change along the model field line into the neutral sheet and found that the field parameters established by the magnetic field data properly reproduced the PAD changes. The trajectory analysis was applied also to the August 4 data with good consistency but was not applicable to the August 25 data.

The results of the modeling study are shown in Figure 3 of paper 2; the August 2, 4, and 25 data are shown in the top, middle, and bottom panels, respectively. The results clearly exemplify the extremes that can exist for seemingly very quiet days. It is significant that even for the most dipolelike data the configuration near midnight is more tail-like than that of the Olson-Pfizer model [Olson and Pfizer, 1974], shown by the dotted lines in the bottom panel of Figure 3.

**INTERPRETATION**

Clearly, there are significant differences between the dipole-configured data (August 25 and September 17–18) and the tail-configured data. We believe that the cause is related to the higher lobe field for the latter. The ratios of the respective lobe fields are about 1:2 and are reflected in the higher cross-tail current for the tail-like data. The first question that arises is why there is a higher lobe field. The second question is why such an obviously stressed magnetotail can be relatively stable for what appears to be several hours at a time.

The first question is easier to answer. Since conditions were quiet, we cannot look to a southward IMF for an enhanced lobe field, except possibly for the July 25 data, which we know were for a weakly disturbed period. The solution would appear to lie in an increased dynamic pressure of the solar wind (C. T. Russell, private communication, 1975). In this respect we cite the results of Nishida and Lyon [1972] obtained on Explorer 35 at 60 R. They find a high degree of correlation between the intensities of plasma sheet electron fluxes and solar wind dynamic pressure and also between plasma sheet thermal energy and solar wind velocity. The point, of course, is that the cross-tail current directly reflects the intensity of the magnetic field intensity in the lobes of the magnetotail.

The desired relation seems covered by the Nishida and Lyon [1972] observations, but we felt it instructive to look for a more direct quantitative correlation between the dynamic pressure and lobe magnetic field. Caan et al. [1973] have studied the differences between the measured lobe field energy density and the energy as determined from the Olson-Pfitzer model [Olson and Pfizer, 1974]. At times of a consistently northward IMF they found systematic differences that could be related to the dynamic pressure of the solar wind. Unfortunately, the solar wind data (which need both particle density and velocity) were not complete enough to provide the necessary input for the equation of Caan et al. The Vela group (J. R.

Asbridge, private communication, 1975) attempted to fulfill our needs but had negligible success.

However, there is an indirect approach to the solar wind pressure that can be used. Burton et al. [1975] have studied the effect of the solar wind dynamic pressure on Dst. They show that $Dst = Dst_0 + bP^{1/2} - c$, in which $Dst_0$ is the contribution from the disturbed ring current, $P$ is the solar wind dynamic pressure in electron volts per cubic centimeter, and $b$ and $c$ are empirically derived constants of value 0.2 ± 0.1 and 20, respectively. From this we obtain $P = [(Dst - Dst_0 + c)/b]$. When the effects of the storm-time injection have decayed and $Dst_0$ is zero, we can use this equation to find $P$. (Note that in the evaluation of $Dst$ the ring current contribution $Dst_0$ is negative, and the solar wind dynamic pressure term $bP^{1/2}$ is positive.)

With this equation we have evaluated the apparent dynamic pressure for each day (Figure 19), using $Dst$ as calculated by Sugiura and Poros [1971]. The few cases for which we were able to locate solar wind data are identified as crosses in the figure. Except for the two Vela points on August 24 and 25 the agreement with the $Dst$ results is good. We estimated the tail lobe field from the equation of Caan et al. [1973], which, recast into more convenient units, is $B^2 = B^2_m - 335 \pm 113 + (0.0645 \pm 0.012)P$. Here $B$ is in gammas, and $B_m$ is from the Olson-Pfitzer model [Olson and Pfizer, 1974]; at 15 R we obtain $B^2 = 221 \pm 123 + (0.0645 \pm 0.012)P$. We anticipated that we should use the values of $P$ at the beginning of the period of interest, or possibly earlier, from which we obtained, respectively: July 12, ~21 γ (~28 γ measured, cf. Table 1); July 20, ~28 γ (30 γ); July 25, 40 γ (40 γ); August 2, 30 γ (28 γ); August 4, 33 γ (25 γ); August 25, ~25 γ (15 γ); and September 17, 20 γ (15 γ). Because of inaccuracies in the empirical

![Fig. 17. IMF for August 4, 1968. For our period of interest, 1700-2100 UT, $B_{geom}$ was well northward.](image)

![Fig. 18. Data for July 25, 1968. The magnetosphere was weakly disturbed on this day.](image)
The crosses mark the pressure obtained from available satellite data. The shaded areas are the periods of major interest.

Formulae and in $D_{st}$ we can only hope to see the proper trend. Despite this we have found moderate agreement on an absolute basis. The data from July 12 are the major discrepancy. At the beginning of this day, there was a southward IMF and probably injection, since $D_{st}$ dropped to $-34$ gyro. Thus our formula cannot be used without a knowledge of $D_{st}$ at that time.

For the last five cases in Figure 19 there appears to be a clear correlation between predicted pressure and lobe field strength. For July 25, August 2, and August 4, there is a moderately high pressure throughout the day. For August 4 this result is substantiated by Vela data. The low apparent dynamic pressure for August 25 and September 17 fits the picture because these are days showing the dipole configuration. However, the Vela values, taken early in the day on August 25, cast some doubt on these results. Similarly, there is difficulty with the taillike data of July 12 and 20. We feel that although this analysis is not conclusive, these results, combined with the Explorer 35 results of Nishida and Lyon [1972], make a strong case for the role of the solar wind dynamic pressure in determining the quiet-time field configuration.

It seems that the magnetotail near midnight shows a trend toward the two extremes of being either taillike or dipolelike. For the taillike cases the half thickness of the plasma sheet at about $10R_E$ was $1.5-2.5R_E$, whereas for the two dipole cases the half thickness was about $4R_E$. It appears that we have found two stable, or at least quasi-stable, states of the magnetosphere.

For the dipolelike state it seems that the plasma sheet was not well developed inside $14$ or $15R_E$. Certainly, the usual high-density plasma was absent, since there were no obvious diamagnetic effects observed, but there was appreciable cross-tail current present (see paper 2).

For the taillike state it appears that the magnetotail can remain in a stressed condition for hours at a time. It can be argued that the magnetotail shows the stressed conditions for only $1$ or $2$ hours near our particular times, but we do not think that this is the case. Statistical studies indicate that the taillike field near midnight during moderately quiet times may be the norm rather than the exception. Early Vela measurements [Bame et al., 1967; Montgomery, 1968] of plasma energy electrons at about $17R_E$ show a plasma sheet $4-6R_E$ thick near midnight, increasing to about twice that $+3$ hours from midnight. Also, Meng and Mihalov [1972] have analyzed the diamagnetic effects of the plasma sheet at $60R_E$, showing much the same configuration. However, the energetic electron ($>50$ keV) results of Walker and Farley [1972] provide a somewhat different picture. They report Ogo 5 results at $10-24R_E$ that show much less of an azimuthal effect than the other investigators but still indicate some thinning near midnight. The Walker and Farley results used data acquired during active, as well as quiet, periods during 1968 and 1969 at solar maximum, whereas the Vela data were acquired at solar minimum. A substorm expansion and recovery period greatly enhances the observation of appreciable fluxes of energetic electrons some distance above and below the sheet. This is especially true in the region within $+3$ hours of 2300 LT, the region of major expansion effects in the Ogo 5 data, and we expect that this affected the Walker-Farley analysis. The Meng-Mihalov analysis was carried out for different levels of activity. We think it significant that the thinnest plasma sheet noted in their study was for $K_p < 1$. Imp 6 observations of Hones et al. [1976a] at $31R_E$ and $2$ hours before midnight further show that the field can be very taillike during quiet times. The data were acquired on November 3, 1971; $K_p$ was $1-$, and $AE(11)$ was $<100\gamma$, dropping to $36\gamma$ at times. From the cross-tail proton current ($0.65$ MA/R$^2$s) and the lobe fields of 10 $\gamma$ they inferred a plasma sheet thickness of $~0.16R_E$. Neither solar wind data nor $D_{st}$ was available to establish the relation to the solar wind.

Data acquired by Fairfield and Ness [1970] on Imp 4 at $31R_E$ in the tail near midnight provide further insight into the quiet-time field configuration. They find a tendency toward weaker fields during quiet times. For data obtained at all $AE$ they find an average $B$ of $~14\gamma$ and no $B > 36\gamma$. For $AE < 20\gamma$ ($20\gamma$ is about the noise level of the index) they find an average $B$ of $10\gamma$ and no $B > 24\gamma$. It is probably significant that the latter conclusions were based on only $59.4$ hours of data, whereas the former were based on $702.6$ hours of data. Also note that the reported results appear to include both lobe and plasma sheet field values, so that diamagnetic effects are probably present in some of the observations. The authors state that average $B_{ZRM}$ for all conditions is $1.8\gamma$, whereas for quiet times it is $2.8\gamma$; the latter is suggestive of more dipolelike fields. They report an especially quiet period at $0600-2100$ UT on February 14, 1968. When Imp was at $(-31,-12,-4)GSM$, $B_{ZRM}$ varied from $0$ to $+7\gamma$ over periods of $\frac{1}{2}$ hour or so (the natural periods of fluctuation of the magnetotail are of this order). Only at $2100$ UT, at the onset of some weak activity, did they obtain a possible measure of the lobe field; the field of $25\gamma$ is consistent with the predictions of the solar wind dynamic pressure, which was $~2 \times 10^6$ eV/cm$^3$ at that time (Explorer 33 data). The variations in $B_{ZRM}$ might be expected to be associated with the variations in the dynamic pressure of the solar wind, since the pressure varied between $0.7$ and $2.3 \times 10^6$ eV/cm$^3$ on that day, but the correlation is not obvious. However, judging from the pressure values, we might expect the field configuration to lie somewhere between our more dipolelike and our more taillike configurations.

The low frequency of occurrence of data like those obtained...
on August 25 and September 17–18 supports the contention that the more taillike field near midnight is more likely during all periods but those of extreme quiet; we expect that this should affect our interpretation of substorm dynamics and help put the growth phase [McPherron, 1972; McPherron et al., 1973] into proper perspective. In this model, marked thinning of the plasma sheet occurs prior to substorm onset. In the substorm expansion phase the field configuration in the near-earth region near midnight tends toward being dipolar and, under conditions leading to an extremely quiet magnetosphere, may tend to stay that way. (Indeed, this is implied in the statements of most authors in discussing the substorm.) However, in general, it would appear that even though the IMF is probably northward postexpansion, the field becomes more taillike in the late recovery period [Hones et al., 1976b]. The recovery state may depend on how much energy remains in the tail field, and here an enhanced solar wind pressure would be especially important. Finally, convective effects must be considered, if indeed, they are separable from the above. It appears that steady convection can lead to activity, without some of the usual signatures of substorms [Pytte et al., 1978], and convection on a less dynamic scale may contribute to the generation of the observed taillike fields.

The high frequency of occurrence of the necked-down field configuration near midnight provides us with an improved understanding of the azimuthal drift motion of electrons (eastward) and protons (westward) through the nighttime magnetotail. In our earlier presentations of the survey of electron PAD's in the nighttime magnetosphere [West et al., 1973a; West and Buck, 1974a] we indicated a good understanding of the pitch angle effects for the premidnight region but felt we did not understand the effects past midnight too well, because, on the average, the butterfly distribution did not exist beyond midnight to as large radial distances as it did before midnight. As was mentioned in the section on method, we noted the presence of the butterfly PAD, premidnight, to about 17 Rs and indicated that if they are of a dynamic nature, as during substorm growth phases, or are encountered simply as a result of the azimuthal drift into a more taillike, weak-field region, can result in the loss of the butterfly distribution.

The substorm effects on electron PAD's, as presented by West et al. [1973b], seem to be well established. During a substorm growth phase, isotropic fluxes were observed by satellite in the near tail at the same time that Parks [McPherron et al., 1973] observed precipitation on a balloon experiment at Tungsten, Northwest Territories, Canada, 1 or 2 hours earlier in the evening. Also, such preonset precipitation effects have been seen by the Norwegian group [Pytte and Trefjall, 1972] via balloon observations, and satellite-balloon observations of such effects are reported by Pytte and West [1978]. The work of Fritz [1970], using Injun 5 low-altitude data, also supports the contention that the taillike field near midnight is the norm rather than the exception and that the closest earthward approach of the taillike fields is near local midnight. Fritz shows that even during quiet times the pitch angle distribution of >40-keV electrons near midnight, near the latitude of the trapping limit, is isotropic or, at the very least, shows a large relative flux in the loss cone. It is easy to see that the substorm preonset precipitation results from encountering a taillike field configuration near midnight which spreads in azimuth up to substorm onset; however, the results of the present paper (which show a high frequency of occurrence of taillike fields near midnight) provide the argument that enhanced precipitation (in terms of azimuthal effects) should occur near midnight during quiet times as well.

**Summary**

Particle and field data have been analyzed for a number of magnetically quiet days and have shown two qualitatively different states of magnetic field configuration. Two days are interpreted as having a fairly dipolelike field configuration and a weakly developed plasma sheet to almost 15 Rs. In contrast, the other days show a fairly taillike field configuration and a well-developed plasma sheet to about 10 Rs, the dipolelike field lines being present only inside that distance.

The major differences between these extremes are the higher lobe fields for the taillike configuration. Magnetic field modeling and particle trajectory studies (paper 2) show that these differences are consistent with the pitch angle changes observed in the energetic electrons on the inbound orbit. However, it is not at all clear why the lobe field should be high in the one case and not in the other. Except for July 25 and, to a lesser extent, for August 2 the IMF was well northward. We have speculated that different solar wind dynamic pressures are responsible. The solar wind data needed to verify this hypothesis are not available, but we were able to infer the solar wind pressure from equatorial $Dst$ and to find a possible agreement with the hypothesis.

It appears from our study that the plasma sheet field configuration near midnight after long periods of quiet can be very taillike. This conclusion is contrary to the Olson-Pfitzer model [Olson and Pfitzer, 1974]. We have also suggested that the field can be fairly taillike prior to the growth phase of the substorm as the normal process of recovery from a preceding substorm. This is contrary to what is normally anticipated in substorm growth phase models [McPherron, 1972; McPherron et al., 1973], providing a somewhat different perspective from that usually assumed, but is well substantiated by our data.

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