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COMPUTER SIMULATIONS ON THE FAST RECONNECTION MECHANISM

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Abstract

The basic physics of the fast reconnection mechanism is studied by computer simulations. The present paper extends the coplanar spontaneous fast reconnection model to the general sheared field geometry. We find that, even in a sheared field geometry with no magnetic neutral (or null) point, the magnetic field lines of different polarities are cut and connected to one another at the origin through the reconnection process. Once the fast reconnection mechanism builds up, it in fact causes the drastic topological change (or magnetic flux transfer) even in a sheared field. It is also found that the thin (shock) transition layer, associated with the fast reconnection mechanism, is divided into the intermediate wave region and the slow shock region. In the intermediate wave region, a pure finite-amplitude intermediate wave stands almost steadily, where magnetic field simply rotates without changing its magnitude. In the slow shock region, a slow shock is combined with a finite amplitude intermediate wave.

1. Introduction

The fast reconnection mechanism, where standing slow shocks occupy a major part of a system with the diffusion region being localized near an X neutral point, may play a crucial role in solar flares. It has been believed that the fast reconnection mechanism should be driven by external boundary conditions without need of any special form of electrical resistivity (Petschek, 1964; Vasyliunas, 1975; Forbes and Priest, 1987). On the contrary, we have argued the importance of such a (anomalous) resistivity that could be enhanced locally near an X neutral point in accordance with the growth of the global reconnection flow: That is, the fast reconnection mechanism should spontaneously be set up through the self-consistent interaction between such an anomalous resistivity and the reconnection flow (Ugai and Tsuda, 1977; Ugai, 1984). Recent computer simulations systematically examined this problem for different resistivity models and demonstrated that, only when the resistivity enhancement was localized near an X point, the fast reconnection mechanism was fully established (Ugai, 1992).

Although most of the previous studies have been directed to the coplanar field geometry, magnetic field should generally be sheared in actual systems. The following questions should be essential for understanding the basic physics of the fast reconnection mechanism in the sheared field geometry. The first question is how magnetic reconnection proceeds in the absence of any magnetic neutral point? In fact, it is difficult to visualize the field topology in the sheared field geometry. The second question is concerned with the basic structure of the fast reconnection mechanism in the sheared field geometry. The main theme of the present simulations is to clarify these basic questions (for more details see Ugai, 1993 and Ugai and Shimizu, 1994).

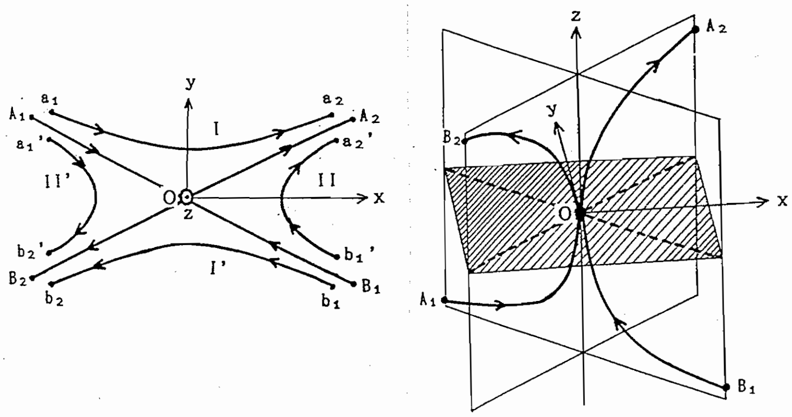

Fig. 1. Schematic drawing of the sheared field lines in an X field configuration.

Magnetic reconnection has been introduced in order to give an intuitive feeling to changes of magnetic field configurations. In Fig. 1 (left panel), the well-known X-type field configuration, associated with the coplanar reconnection process, is shown. Then let us impose a uniform sheared field component B_z (> 0) on the configuration. For simplicity, we assume the field lines in the region I and I' to intersect the y axis (at $y = y_1$ and $-y_1$) and the field lines in the region II and II' to intersect the x axis (at $x = x_1$ and $-x_1$). When these field lines approach each other and have just met at the origin, they lie in the separatrix surfaces. The three-dimensional display of the field lines in the separatrix surfaces is schematically illustrated in Fig. 1 (right panel). The field lines b_1- b_2 and a_1-a_2 now become B_1-O-B_2 and A_1-O-A_2, respectively. Note that at the origin the component tangential to these field lines is directed to the positive z. After they are reconnected, the field line segments A_1-O and O-B_2 are now connected to become the (reconnected) field line a_1'-b_2' in the region II', and similarly the other half segments become the field line b_1'-a_2' in the region II. We hence recognize that, even in the absence of any magnetic neutral point, magnetic reconnection leads to an effective topological change in the magnetic field and hence to effective flux transfer.

The phenomenon to be studied here is 2.5 dimensional in the sense that variables depend on x and y but not on z, whereas both the flow velocity u and the magnetic field B may have z components. As an initial configuration, a current sheet system with antiparallel field components (B_{x0}) as well as a uniform sheared field component (B_{z0}) is assumed. As an initial disturbance, a small electrical resistivity is imposed in a local region near the origin in the initial time range $0 < t < 4$. Initiated by this disturbance, all the phenomena will develop from near the local region and extend outward on Alfven time scales. The reconnection process is strongly influenced by the resistivity model (Ugai, 1992), so that in the present study, an anomalous resistivity is assumed to increase with the relative electron-ion drift velocity when a threshold value is exceeded. The resistivity model is imposed after the initial disturbance is removed.

2. Results

In the absence of the sheared field component B_{z0}, the (coplanar) fast reconnection mechanism fully develops for the anomalous resistivity model (Ugai, 1992). After the initial disturbance is removed, the current sheet thinning proceeds with zero resistivity, and the threshold value is eventually exceeded so that the anomalous resistivity significantly grows. Note that the plasma inflow toward the inner reconnection region is not externally driven but spontaneously grows. The fast reconnection mechanism is eventually set up almost quasisteadily. Figures 2(a) and (b) show the resulting magnetic field and plasma flow configurations [projected onto the (x, y) plane] for the case of B_{z0}=0.25.

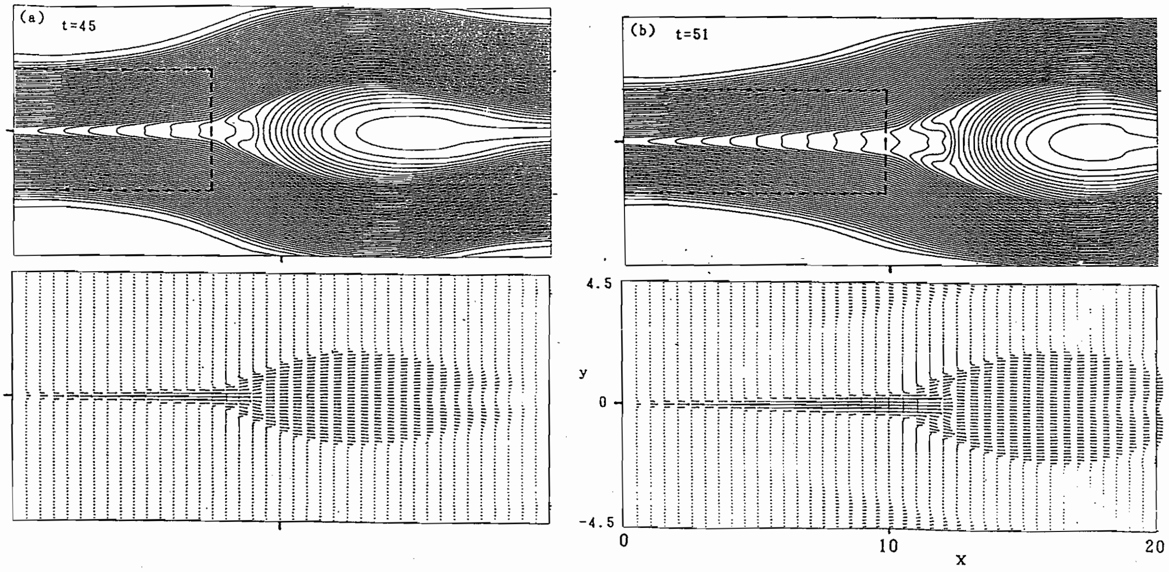

Fig. 2. Magnetic field and plasma flow configuration , projected onto the (x , y) plane.

In the absence of the sheared field component B_z, purely switch-off shocks are set up in the (coplanar) quasisteady fast reconnection region. On the other hand, in the presence of the sheared field, the resulting configurations (Fig. 2) can no longer be coplanar. Figure 3 shows the y-directional changes in quantities, which are measured at x=7.5 across the thin transition layer standing in the quasisteady region [Fig. 2]. In this figure, the transition layer, where quantities distinctly change, is divided into two regions bounded by $y = y_w$, y_s, and y_b, where y_w=0.48, y_s = 0.39, and y_b = 0.21 are taken.

In the wave region $y_s < y < y_w$, the field components B_x and B_z significantly change, whereas the plasma quantities do not change. In this region, only a rotation of magnetic field takes place without changing its magnitude, which can be realized only by an intermediate wave. Hence, this region may be called the intermediate wave region. In the region $y_b < y < y_s$, we readily observe from y_s to y_b that plasma pressure and density distinctly increase in accompany with an increase in the entropy, which are compensated by the drastic decrease in the magnetic energy; in fact, the antiparallel field component B_x is completely switched off. These characteristics can be realized only by a slow shock, so that this region may be called the slow shock region. However, the shock structure is not coplanar, and, coming into the shock region, plasma experiences a large field rotation from 25 at $y = y_s$ to 90 at $y = y_b$. We may hence conclude that a slow shock is coupled to an intermediate wave in the (noncoplanar) slow shock region. This noncoplanar shock structure is recently studied in detail by one-dimensional MHD simulations (Ugai and Shimizu, 1994).

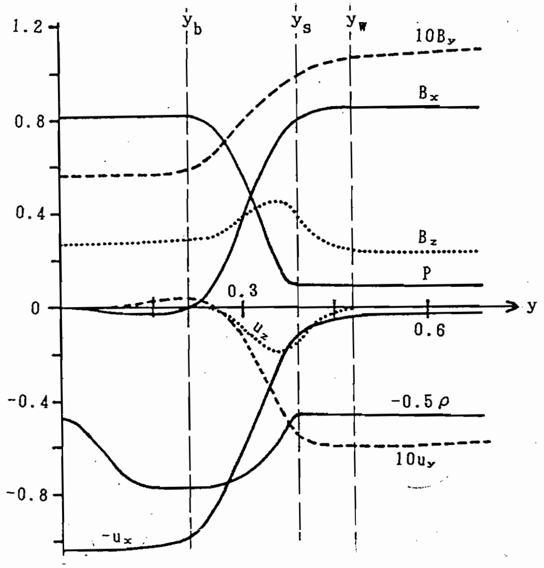

Fig. 3. Three-dimensional display of the reconnected field lines.

3. Summary and Discussion

The present paper extends the coplanar spontaneous fast reconnection model to the general sheared field geometry. The resulting fast reconnection mechanism may be summarized as follows:

(i) Even in the sheared field geometry with no magnetic neutral (or null) point, the magnetic field lines of different polarities are cut and connected to one another at the origin through the reconnection process (Fig. 1). The fast reconnection mechanism is in fact found to cause the drastic topological change (or magnetic flux transfer).

(ii) The thin (shock) transition layer is divided into the intermediate wave region and the slow shock region (Fig. 3). In the intermediate wave region, a pure finite-amplitude intermediate wave stands almost steadily, where magnetic field simply rotates without changing its magnitude. In the slow shock region, a slow shock is combined with a finite amplitude intermediate wave. The antiparallel field component B_x is completely switched off across the transition layer (Fig. 2) as in the coplanar case. This noncoplanar shock structure is recently studied in detail by one-dimensional MHD simulations with much higher numerical resolution (Ugai and Shimizu, 1994).

References

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