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COMPUTER SIMULATIONS ON DEVELOPMENT OF THE FAST RECONNECTION MECHANISM (EXTENDED ABSTRACT)

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In space plasmas, large dissipative events, such as solar flares and geomagnetic substorms, occur and lead to sudden release of energetic particles. It is recognized that these phenomena result from some large-scale physical mechanism causing drastic release of critically stored magnetic energy. A long-standing task is to clarify what is the basic physical mechanism responsible for such effective magnetic energy conversion. In principle, magnetic energy may be released in a current sheet system by Ohmic heating due to finite electrical resistivity and/or by MHD waves such as switch-off shocks standing in the system. In space plasmas, the magnetic Reynolds number is extremely large, so that switch-off shocks may play a dominant role for the energy conversion. For switch-off shocks to stand steadily in the system, magnetic reconnection should rapidly proceed in the local diffusion region to provide the field component normal to the shock. In this sense, such a reconnection process involving standing switch-off shocks may be called the fast reconnection mechanism. A basic question must be how the fast reconnection mechanism can be set up and maintained in actual systems?

Historically, the magnetic energy conversion mechanism has been analytically studied in a current sheet system with oppositely directed magnetic fields (VASYLIUNAS, 1975). The analytical treatments have considered a two-dimensional region where processes are assumed to proceed steadily ($\partial/\partial t=0$); in the middle of the system, magnetic field diffusion (due to finite resistivity) is dominant and outside the diffusion region magnetic field lines are frozen into the fluid. The possible external flows, outside the shock and diffusion regions, were analytically examined (FORBES and PRIEST, 1987), and it was argued that the fast reconnection mechanism was subjected to boundary conditions. However, there are some basic problems in the analytical treatments. First, the detailed structure of the inner region, involving the diffusion and shock regions, was not determined, and matching between the inner region and the external flow region was not done. Hence, it is not obvious whether or not the steady fast reconnection can be retained in actual systems. Second, the boundaries enclosing the steady region are not physical boundaries and taken merely for analytical purposes. A flare is a strongly time-dependent phenomenon, and the steady region may be considered to be an inner part of the whole system. Hence, it is difficult to provide pertinent boundary conditions consistent with the temporal dynamics in the surrounding region. These problems may be resolved only by examining the temporal dynamics of the system at large.

There has been much debate on the fast reconnection development. As already stated, the analytical studies argued that the fast reconnection mechanism should be externally driven without any special form of electrical resistivity; on the other hand, UGAI has argued the importance of such an (anomalous) resistivity that is locally enhanced near an X point by the fast reconnection process (UGAI and TSUDA, 1977; UGAI, 1984). Also, a simulation model by SATO and HAYASHI (1979) assumed a local plasma injection and argued that the fast reconnection mechanism was controlled by the boundary conditions; on the other hand, BISKAMP (1986) assumed the same boundary conditions and argued that the fast reconnection mechanism could not be sustained. The theme of the present paper is to study the fundamental questions with two-dimensional magnetohydrodynamic (MHD) simulations.

Computer simulations systematically examine in a large-scale current sheet system how magnetic reconnection spontaneously grows from the inner region and proceeds according to different resistivity models; no special boundary condition is assumed. In the present two dimensional situation, all the physical quantities depend on x and y only. Initiated by a small disturbance imposed on the initially one-dimensional current sheet, all the phenomena spontaneously grow from near the origin and propagate outward. Under the same initial-boundary conditions, different resistivity models are assumed, where the resistivity is assumed to be self-consistently determined by macroscopic quantities in the system. We are interested in how the fast reconnection development depends on the resistivity model.

It is found that the reconnection process is strongly controlled by the resistivity model. Only when the resistivity is locally enhanced near an X type neutral point in accordance with the global reconnection flow, the fast reconnection mechanism can rapidly build up and be sustained steadily. In particular, for an anomalous resistivity model, where the resistivity is assumed to increase as the relative electron-ion drift velocity becomes larger when a threshold value is exceeded, the quasi-steady fast reconnection mechanism fully develops from near the origin and extends outward in Alfvén time scales. Figure 1 shows the resulting configurations for such a resistivity model. In Fig. 1b the quasi-steady fast reconnection region, where quantities change little with time, is encircled by dotted lines. The steady fast reconnection mechanism works as an engine that drastically drives the overall system into system catastrophe. Figure 2 shows the resulting configurations for a uniform resistivity model, where the resistivity is assumed to be uniform in space and constant in time. We readily recognize from this figure that the fast reconnection mechanism cannot be established for the uniform resistivity model, so that no drastic plasma acceleration nor magnetic energy conversion can be caused.

Contrary to the previous theories, we have argued that local conditions near an X neutral point must be essential for the fast reconnection mechanism to be realized (UGAI, 1992); external boundary conditions may of course influence local conditions and, in this sense, have a secondary (indirect) effect on the fast reconnection development. We have demonstrated that for a suitable anomalous resistivity model the quasi-steady fast reconnection mechanism, involving standing switch-off shocks, can be spontaneously established from the current sheet. It is to be noted that the quasi-steady fast reconnection region (Fig. 1) is an inner part of the overall configuration, outside which the quantities distinctly change with time. Hence, the boundaries enclosing the

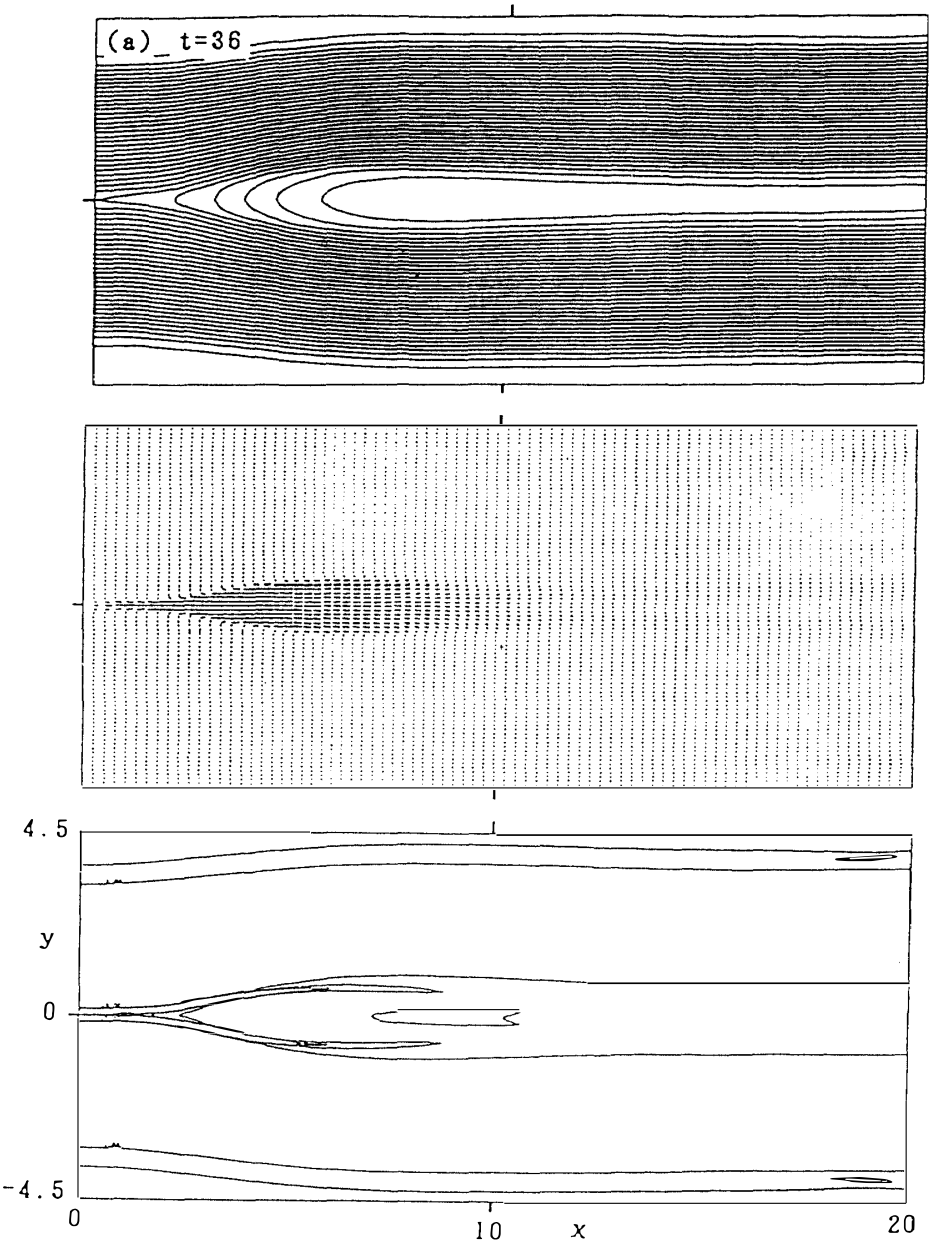

Fig. 1. *Magnetic field (upper), plasma flow (middle), and current density (lower) configurations at (normalized) times (a) $t=36$ and (b) $t=51$ for an anomalous resistivity model where the resistivity increases with the relative electron-ion drift velocity.*

quasi-steady region (Fig. 1) are not physical boundaries, and as have been demonstrated, the boundary values must be determined only by the self-consistent development of the fast reconnection process. It is, therefore, physically questionable that the analytical studies as well as some simulation studies (SATO and HAYASHI, 1979) assume "boundary conditions" without considering the temporal dynamics outside the boundaries. We

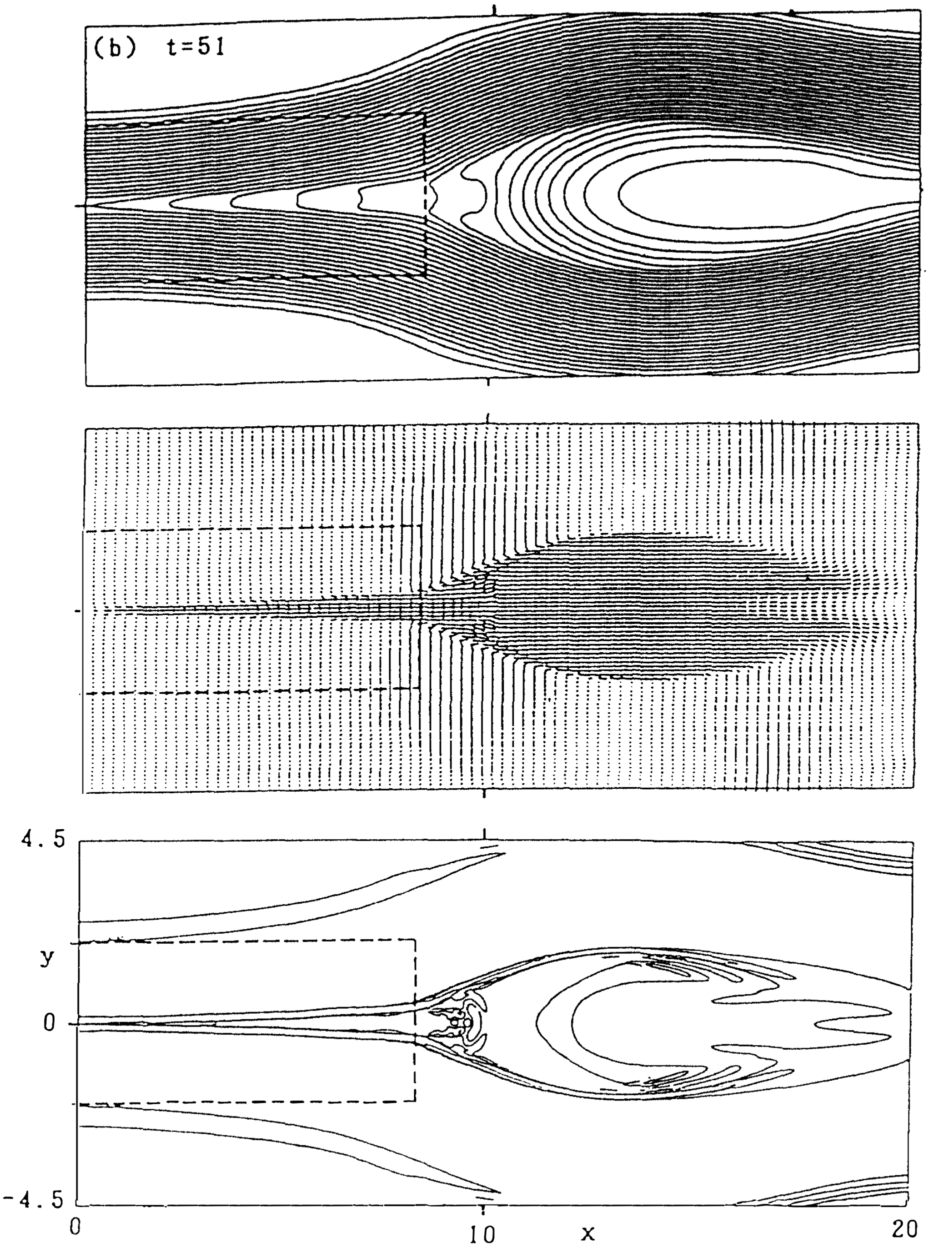

Fig. 1b.

also find that this mechanism depends on the resistivity parameter very slightly. We hence conclude that the fast reconnection mechanism (Fig. 1) may be applicable to large dissipative events in space plasmas, such as solar flares and geomagnetic substorms.

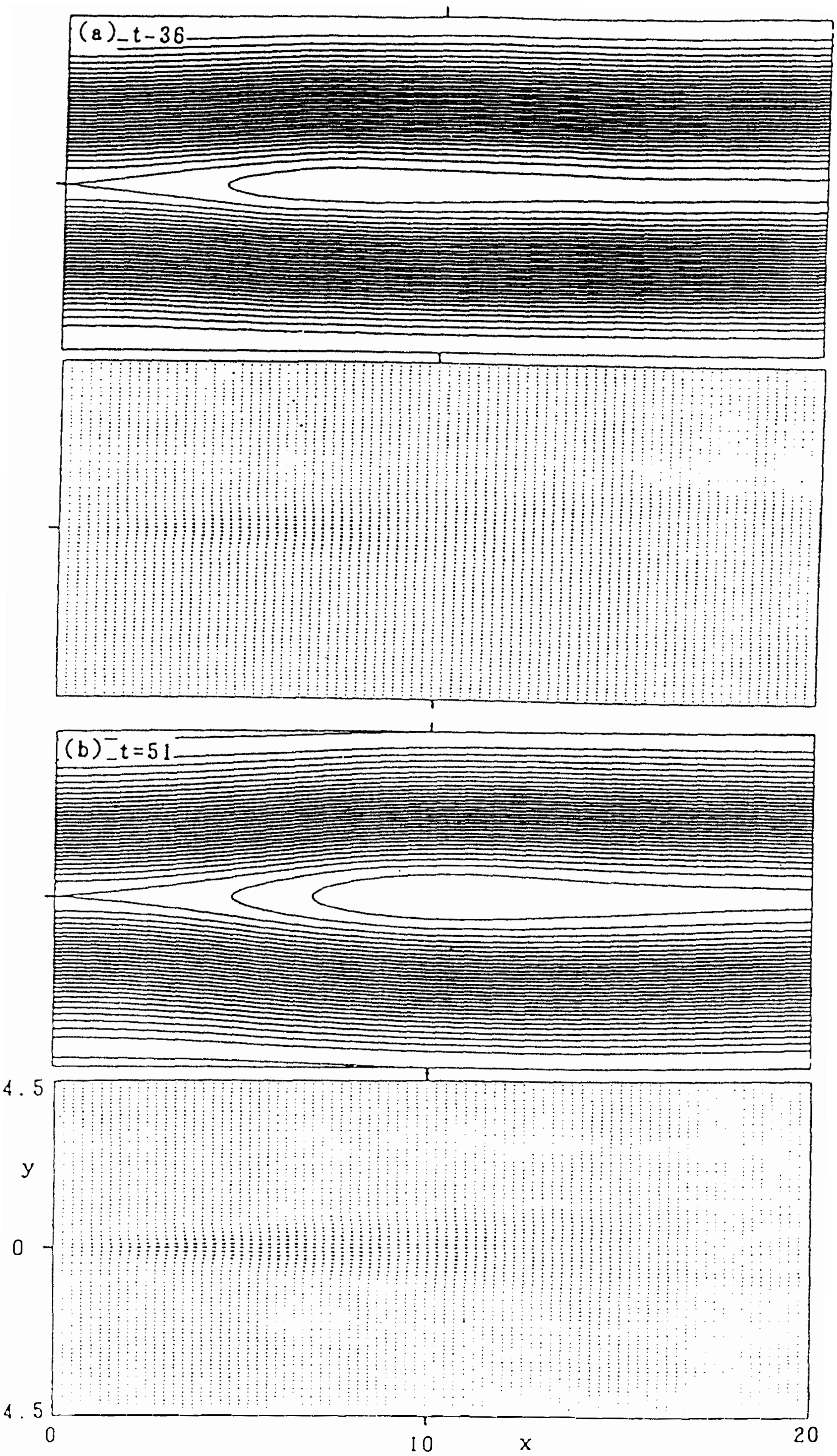

Fig. 2. Magnetic field and plasma flow configurations for a uniform resistivity model at times (a) $t=36$ and (b) $t=51$. All the conditions, other than the resistivity model, are the same as Fig. 1.

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