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Boundary conditions and plane magnetic reconnection

Manuel Núñez*

Departamento de Análisis Matemático, Universidad de Valladolid, 47005 Valladolid, Spain

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Abstract

It is well known that several classical models of plane magnetic reconnection turn out to be more or less efficient according to the choosing of the boundary conditions. We prove analytically that one important datum, the variation of the area of the reconnection region, may be found, except by resistive effects, directly in terms of the flux and stream functions at the boundary. If we include the Hall effect in our model, the vertical component of the field at the boundary is also necessary. Since this area is a measure of the capacity of the system to keep the magnetic nozzle open, this provides a rigorous quantitative measure of the essential role of boundary conditions on the efficiency of the process.

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Keywords: Reconnection region; Current sheet; Flux and stream functions

1. Introduction

Magnetic reconnection is one of the most important astrophysical processes because of its relevance in the behavior of the magnetospheres of stars and planets, being e.g. responsible of such spectacular phenomena as solar flares. Its theoretical study began with Sweet (1958) and Parker (1957, 1963), who analyzed the collision of two plasma masses possessing opposite magnetic fields. The resulting

* Tel.: +34 983 423924; fax: +34 983 423013.
E-mail address: mnjmhd@am.uva.es

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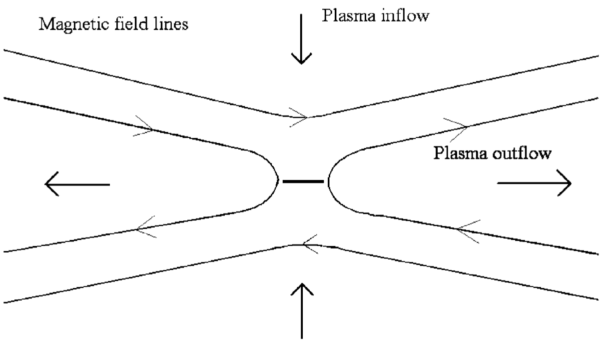

Fig. 1. Reconnection at magnetic neutral lines.

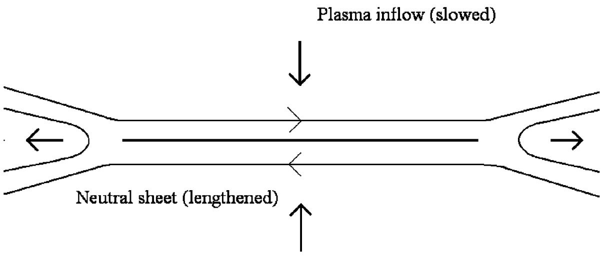

Fig. 2. Throttling of the plasma flow.

configuration is a familiar one (Fig. 1): the plasma approaches the neutral sheet where magnetic field lines reconnect, and escapes laterally.

The occurrence and properties of this type of geometries in a quasi-static two-dimensional situation was studied in depth by Syrovatskii (1971), Imshennik and Syrovatskii (1967), Syrovatskii and Bulanov (1981). The process is physically sound, but it produces a conversion rate from magnetic to kinetic energy far lower than the one actually found in many astrophysical events, actually explosive. Moreover, the tendency of this configuration is to lengthen the magnetic nozzle and therefore to slow the outflow of plasma (Fig. 2), thus diminishing the efficiency of the energy conversion: it is often said that the plasma is throttled. The first attempt to overcome this problem was due to Petschek (1964), who tried to keep the current sheet short by postulating the existence of magnetoacoustic shocks taking the plasma rapidly away from the neutral, or current sheet. Petschek's mechanism was later developed and generalized (Axford, 1967; Sonnerup, 1970; Yeh and Axford, 1970; Vasyliunas, 1975). However, the stability of the Petschek configuration was questioned by numerical experiments who failed to keep the current sheet short (Biskamp, 1986, 1993); it later became clear that an appropriate election of boundary conditions could stabilize it and yield fast reconnection rates (Yan et al., 1992; Priest and Forbes, 1992, 2000). The preferred explanation today argues that ions and electrons decouple near the current sheet: this allows the presence of dispersive waves known as whistlers, which help in taking the plasma away from the sheet and thus avoid the throttling of the process. Hence two-fluid MHD equations are necessary to model the plasma at least in the vicinity of the current sheet, yielding correct results in several instances (Drake et al.,