$2\frac{1}{2}$–D COMPRESSIBLE RECONNECTION MODEL

M. SKENDER
Rudjer Bošković Institute
Zagreb, Bijenička 54, HR-10002, Croatia

B. VRŠNAK
Hvar Observatory
Faculty of Geodesy
Zagreb, Kačićeva 26, HR-10000, Croatia

Abstract. The exact solution of the jump conditions on the RD/SMS discontinuity system in a two–and–half–dimensional ($2\frac{1}{2}$–D) symmetrical reconnection model enables one to analyse the outflowing jet characteristics in dependence on the inflow velocity, and to follow changes in transition to the two–dimensional model. Implications arising from the exact solution and its relevance for solar flares are discussed.

1. Introduction

Magnetic reconnection is considered to play a central role in the rapid conversion of the magnetic energy into plasma energy required for initiating solar flares. Petschek (1964) proposed the so–called fast reconnection mechanism: When two regions of plasma containing oppositely directed magnetic fields are placed in contact, magnetic field lines reconnect in a tiny diffusion region, from which two pairs of standing magnetohydrodynamic waves (SMSs) extend and dissipate the magnetic field energy. Petschek and Thorne (1967) discussed the situation when the merging fields are skewed one to the other, and introduced two pairs of large–amplitude Alfvén waves or rotational discontinuities (RDs) in front of SMSs to satisfy the boundary conditions. A comprehensive treatment of this two–and–half–dimensional ($2\frac{1}{2}$–D) problem has been given by Soward (1982) using the approximation of plasma inflowing slowly and perpendicularly to the symmetry axis of the system. The exact solution of the jump conditions for the RD/SMS discontinuity system in a $2\frac{1}{2}$–D system has recently been obtained by Skender *et al.* (2003). Implications arising from the exact solution are presented in this article.

A. Hanslmeier et al. (eds.), Solar Magnetic Phenomena, 167–170.

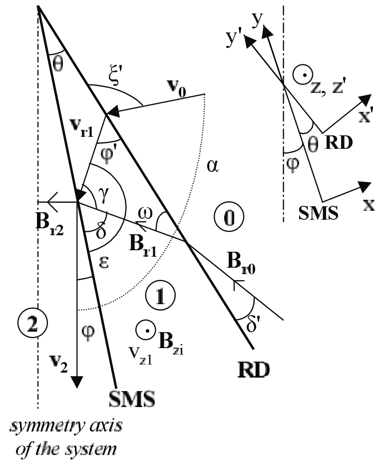

Figure 1. The geometry of the system of discontinuities in the $2\frac{1}{2}$–D symmetrical reconnection problem, depicted in one quadrant. The quantities in the inflow, intermediate, and outflow regions are designated by subscripts "0", "1", and "2", respectively. The xy-plane components of the magnetic field $\vec{B}$ and the flow velocity $\vec{v}$ are denoted by the subscript "r". The direction of the z-component of $\vec{B}$ and $\vec{v}$ is also indicated. The magnetic field generally has x-, y-, and z-components in all three regions, as does the velocity in region 1, while the velocities in regions 0 and 2 have the xy-plane components only. The magnetic field $\vec{B}_2$ is perpendicular to the velocity $\vec{v}_2$. All quantities in a $2\frac{1}{2}$–D model are independent of the z-axis.

2. Background theory

In region 0 (see Fig. 1), plasma of density ρ_0 and pressure p_0 flows into the RD with velocity $\vec{v}_0$, carrying the magnetic field $\vec{B}_0$. Rotated and accelerated plasma proceeds towards the SMS through region 1. At the SMS plasma is heated, compressed, and further deflected and accelerated.

Jump relations for a RD/SMS discontinuity system are derived from the continuity equation, equation of motion under conditions of electrical neutrality and no influence from gravity and viscosity, energy conservation equation for fully ionized H-plasma, which has the ratio of specific heats $\gamma = 5/3$, magnetic divergence relation, and magnetic flux conservation equation. The general forms of these equations are:

$$\frac{\partial \rho}{\partial t} + \rho \vec{\nabla} \cdot \vec{v} = 0\,, \tag{1}$$

$$\rho \frac{D\vec{v}}{Dt} = -\vec{\nabla} p + \vec{j} \times \vec{B}\,, \tag{2}$$

$$\vec{\nabla} \cdot \left[\left(\frac{5}{2} p + \frac{1}{2} \rho v^2 \right) \vec{v} \right] + \left(\vec{v} \times \vec{B} \right) \cdot \vec{j} = 0\,, \tag{3}$$

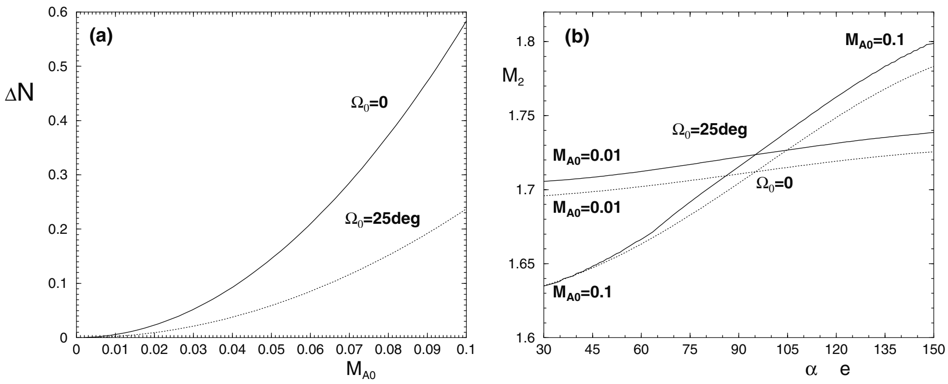

Figure 2. For $\beta_0 = 0.01$, we present the dependence of: (a) the relative difference $\Delta N_{\%}$ of the compression N and the Soward approximation value N_S; (b) the outflow Mach number M_2 on the incidence angle α for the inflow Mach Alfvén numbers $M_{A0} = 0.01$ and 0.1, combined with $\Omega_0 = 25°$ and 0° (2–D case).

$$\vec{\nabla} \cdot \vec{B} = 0\,, \tag{4}$$

$$\vec{\nabla} \times \vec{E} = 0\,. \tag{5}$$

The exact solution of the system is used for analyzing the outflow conditions in dependence of the inflow speed and the inflow incidence angle, at a given shear of the magnetic field and the plasma–to–magnetic pressure ratio β_0.

3. Results and discussion

The exact solution of the jump relations on the RD/SMS system provides the possibility of investigating situations when the inflow is not perpendicular to the outflow, as well as situations of relatively fast inflow, which are often met in the coronal environment. In Fig. 2a the deviation of the compression $N = n_2/n_0$ from the value N_S obtained in Soward's approximation is shown in dependence on the inflow Mach Alfvén number M_{A0}, utilizing $\Delta N_{\%} = 100\,(N - N_S)/N_S$. The values are obtained for $\beta_0 = 0.01$, appropriate for conditions in solar flares. The value of N increases with increasing Mach Alfvén number M_{A0}, which is more pronounced for smaller angles Ω_0 ($\tan\Omega_0 = B_{z0}/B_{r0}$, see Fig. 1). A similarly weak dependence is found for the temperature jump $T = T_2/T_0$, where the value of T decreases with increasing M_{A0}.

Figure 2b shows the dependence of the outflow magnetosonic Mach number M_2 on the incidence angle α (see Fig. 1). We present the results for $M_{A0} = 0.01$ and 0.1, again taking $\beta_0 = 0.01$, at $\Omega_0 = 0°$ and 25°. The graph reveals a considerable change of M_2, but only for a comparatively

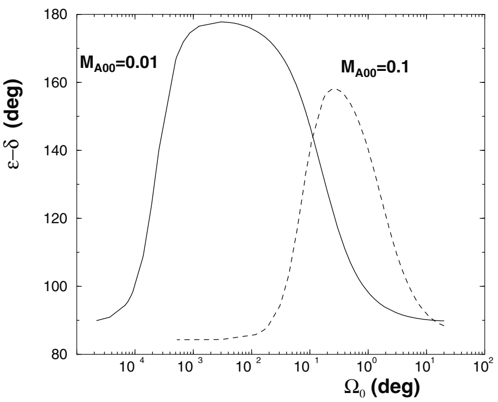

Figure 3. Illustrative results of dramatic changes in transition from $2\frac{1}{2}$–D to 2–D. The difference of the angles $(\epsilon - \delta)$ in region 1 in dependence on Ω_0 is presented for the perpendicular inflow, at two reconnection rates M_{A00} and $\beta_0 = 0.01$.

large inflow Mach Alfvén number (i.e. also for large reconnection rates). The value of M_2 increases when the inflow has a component in the direction of the outflow, while it decreases for the inflow having a component in the direction opposite to the outflow. It determines whether the outflow jet is sub– or super–magnetosonic. In the case of super–magnetosonic outflow, a quasi–perpendicular fast–mode standing shock forms if the jet encounters an obstacle.

The explicit solutions of the full set of jump relations enable us to follow the changes of the geometry of the system in transition from $2\frac{1}{2}$–D to 2–D, which happens, e.g., in two-ribbon flares when the initially sheared arcade of the magnetic field becomes stretched by an eruption. We have presented that the flow/field geometry changes rapidly within $\Omega_0 \lesssim 1°$. Figure 3 shows how the difference between the angles $(\epsilon - \delta)$ in the intermediate region (see Fig. 1) depends on Ω_0. Obviously, at small Ω_0, a perturbation of the transversal magnetic field component in the inflow region might have consequences on the overall stability of the system. Considering the supersonic outflow, this could straightforwardly explain the stochastic and intermittent electron acceleration such as observed in solar flares.

References

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