THE ERUPTION OF A PROMINENCE AND CORONAL MASS EJECTION WHICH DRIVE RECONNECTION

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Abstract. Two possible limiting scenarios are proposed for the production of a coronal mass ejection. In the first the magnetic field around a prominence evolves until it loses equilibrium and erupts, which drives reconnection below the prominence and an eruption of the overlying magnetic arcade. In the second a large-scale magnetic arcade evolves until it loses equilibrium and erupts, thereby causing a prominence to erupt. In general it is likely to be the non-equilibrium of the coupled system which creates the eruption. Furthermore, large quiescent prominences are expected to be centred within the magnetic bubble of a coronal mass ejection whereas when active-region prominences erupt they are likely to be located initially to one side of the bubble.

A model is set up for the eruption of a magnetically coupled prominence and coronal mass ejection. This represents a development of the Anzer and Pneuman (1982) model by overcoming two limitations of it, namely that: it is not globally stable initially and so one wonders how it can be set up in a stable way before the eruption; it has reconnection driving the CME whereas recent observations suggest that the reverse may be happening. In our model we assume that magnetic reconnection below the prominence is driven by the eruption and the driver is magnetic non-equilibrium in the coupled prominence-mass ejection system. The prominence is modelled as a twisted flux tube and the mass ejection as an overlying void and magnetic bubble. Two different models of the prominence are considered. In one a globally stable equilibrium becomes unstable when a threshold magnetic flux below the prominence is exceeded and, in the other, equilibrium ceases to exist. In both cases, the prominence and mass-ejection accelerate upwards before reaching constant velocities in a manner that is consistent with observations. It is found that the greater the reconnection that is driven by the eruption, the higher is the final speed.

1. Introduction

Coronal transients or mass ejections occur when large amounts of plasma are ejected from the Sun at velocities ranging from 100 km s\(^{-1}\) to more than 1000 km s\(^{-1}\) (MacQueen, 1980). They are in more than 70% of cases associated with prominences (Pneuman, 1980) and sometimes also with solar flares. Their appearance is generally loop-like but Solar Maximum Mission and P-78 coronagraphs suggest the loop is merely a section across a three-dimensional bubble (Hundhausen et al., 1984; Fisher, 1984; Wagner, 1984; Hildner et al., 1986; Low, 1986). This represents magnetic flux and plasma ahead of a cavity which is thought to contain a stronger magnetic field and moves ahead of an erupting prominence (Hundhausen, MacQueen, and Sime, 1984). This three-fold picture of bubble, cavity, and prominence is quite different from the earlier ideas and models which were stimulated by Skylab observations.

Pneuman (1980) modelled a coronal mass ejection as a simple, curved flux tube. This is subject to the forces caused by both a longitudinal and an azimuthal field within the flux tube, a field beneath the flux tube supporting it and gravity. The flux tube is
originally in neutrally stable equilibrium but, when the underlying field is increased, the resulting upward force causes the flux tube to rise like a coronal mass ejection. Pneuman's model does not, however, include a prominence underneath and, since the equilibrium is neutrally stable, the model does not explain how the corona remains unstable before the eruption since any small perturbation would set the flux loop in motion.

Anzer and Pneuman (1982) considered a magnetically coupled coronal mass ejection and prominence. The coronal mass ejection takes the form of either an arcade or a loop in their model. There is a longitudinal field in the prominence and a field along the loop (or arcade). Reconnection takes place under the prominence and this helps to drive the system upwards. The system starts from equilibrium but not a stable equilibrium so that any small perturbation sets the system in motion.

Mouschovias and Poland (1978) modelled the coronal mass ejection as a loop with a longitudinal magnetic field and an azimuthal magnetic field. However, it is assumed that this twisted loop rises at a constant velocity so that it is always in equilibrium.

Yeh and Dryer (1981), in a very interesting paper, showed that forces other than a self-induced magnetic force (such as pressure gradients or the magnetic buoyancy force included here) are necessary to propel a loop outwards.

The above authors have modelled a coronal mass ejection as a loop or an arcade, but observational evidence now indicates that the proper form is a bubble. Since the cross-section through a bubble is the same as the lateral cross-section through an arcade, similar equations hold.

The object of the present paper is to produce a qualitative model for a coronal mass ejection which quantifies the current understanding of bubble, cavity, and prominence. It combines some of the properties of each of the models due to Pneuman, Anzer and Pneuman, and Mouschovias and Poland in a more realistic manner. The loop transient is modelled here as a bubble. The prominence underneath is modelled as a twisted flux tube with both longitudinal and azimuthal field components. The field in the 'loop' of the coronal mass ejection is assumed to be in the same direction as the azimuthal field. In the cavity between the prominence and transient the magnetic field is orientated in the same direction. Finally the field in the region beneath the prominence is allowed to reconnect as the prominence rises.

Reconnection in our model is driven by the rising prominence rather than being itself the driver. Clearly our qualitative model complements fully numerical solutions of the MHD equations which have their own limitations too.

2. The Role of Magnetic Reconnection

Anzer and Pneuman (1982) suggested that reconnection could drive a coronal mass ejection (CME) but this is unlikely because in flare associated CMEs the flare follows the CME by an average 17 min (Harrison, 1986) and there is evidence for reconnection only in a few cases (Illing and Hundhasen, 1983). We would like to suggest, therefore, that instead the reconnection is driven by the CME as the magnetic field lines become stretched out.