EVOLUTION OF CORONAL MAGNETIC STRUCTURES

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INTRODUCTION

Several classes or types of coronal transients are believed to originate near the solar surface at the base of pre-existing coronal magnetic loops. These loops often lie beneath an overlying open-field region in a typical coronal- or helmet-streamer configuration. Recent experimental results indicate that these pre-existing magnetic loops may be torn open by the explosive force of the solar phenomena responsible for the transient. Numerical solutions of the time-dependent, two-dimensional, dissipationless, MHD equations of motion (the equations are discussed by Steinolfson et al. (1978)) are used to examine the formation of a coronal streamer magnetic structure and the evolution of the streamer following an explosive solar event in the closed-field region.

CORONAL STREAMER

The coronal-streamer configuration is obtained by starting the calculation with an initial state consisting of a closed dipole magnetic field superimposed on a radial, hydrodynamic solution for the thermodynamic variables and velocity. This initial state, of course, does not represent a steady-state solution to the complete two-dimensional equations, so the time-dependent solution will evolve until it relaxes to or approaches a steady-state solution (the coronal streamer). Coronal-streamer configurations have been obtained previously by Pneumann and Kopp (1971), who used a time-independent analysis, and by Endler (1971) and Weber (1978). In all of these previous studies, the temperature was assumed to be constant; that assumption is not made in the present work. The initial values used in the simulation are as follows: The temperature and density at 1 $R_\odot$ (solar radii) are taken to be 1.8×10^6 K and 2.25×10^8 cm^{-3}, respectively, and the magnetic field is 2.35 G at the solar surface at the equator which yields a value for the plasma beta of 0.5. The polytropic index is 1.05. The initial magnetic field lines are shown in Figure 1(a). The vertical

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axis represents the equator, the horizontal axis is the pole, and the region shown is from the solar surface to 5 $R_{\odot}$. The solution is symmetric about the equator. The dashed curves represent the radii at which the sound speed Mach number (longer dashes) and the Alfvén speed Mach number are equal to one. The initial state relaxes to approximately a steady state after 16 hours and the resulting magnetic field lines are shown in Figure 1(b). The relaxed configuration is that of a coronal streamer with open field lines overlying and adjacent to the closed-field region. The velocity is approximately zero in the closed-field region as shown in Figure 2(a). The velocity at 5 $R_{\odot}$ at the equator is very nearly

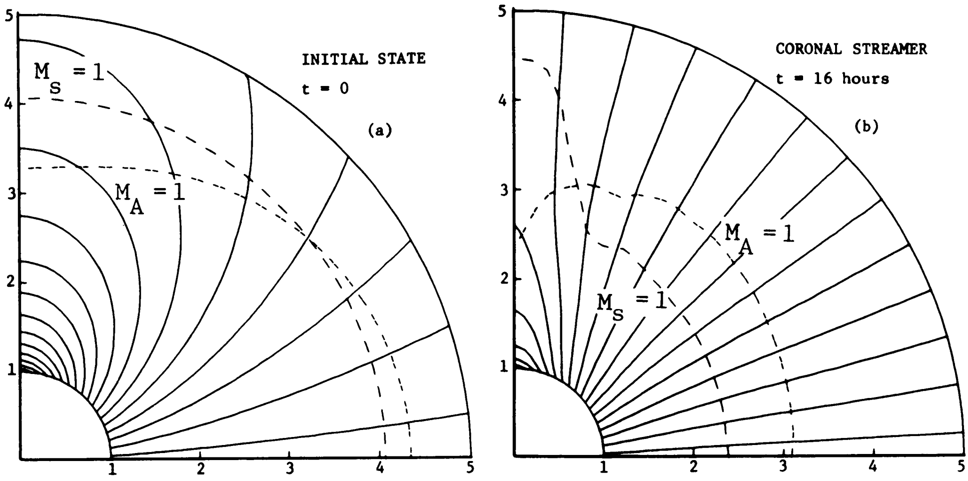

Figure 1. Magnetic field lines (a) initially and (b) after the numerical solution has relaxed to a steady state coronal-streamer configuration.

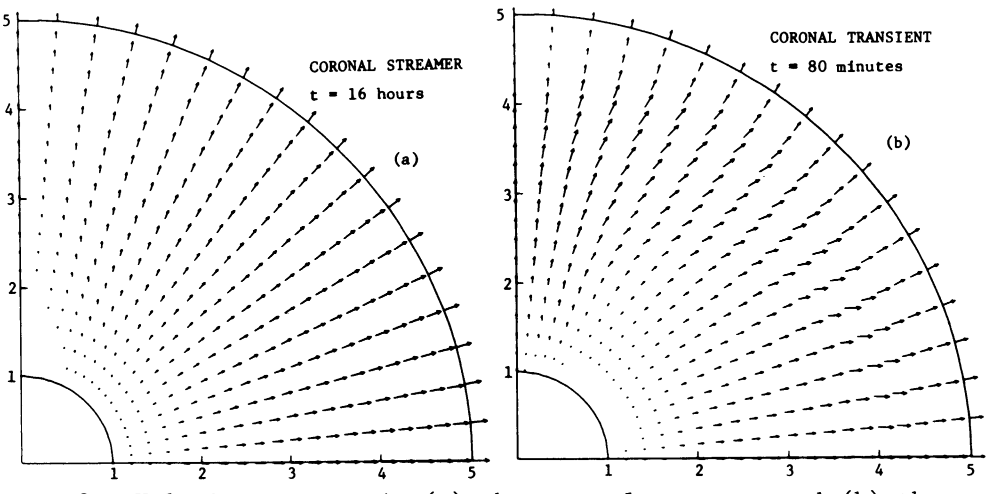

Figure 2. Velocity vectors in (a) the coronal streamer and (b) the coronal transient where the time is now referenced to the introduction of the perturbation which simulates the solar event.

equal to the initial velocity there of 185 km s^{-1} while the velocity at the pole at 5 $R_\odot$ is increased to 417 km s^{-1}. The pressure and density in the closed-field region are increased over their initial values in this region, with the maximum increase at 1 $R_\odot$ being by factors of 4.8 and 4.2, respectively.

CORONAL TRANSIENT

A simulated coronal transient is created by instantaneously increasing the pressure at 1 $R_\odot$ in the closed-field region by a factor of 10 over the initial value. The pressure is maintained at this value for the duration of the calculation. The velocity vectors and magnetic field lines in the resulting transient after 80 minutes are illustrated in Figures 2(b) and 3(a). The initially closed field lines are pushed outward both radially and azimuthally. An MHD shock is formed ahead of the transient at about 4.5 $R_\odot$. At later times the field becomes essentially open inside 5 $R_\odot$ as seen after 180 minutes in Figure 3(b).

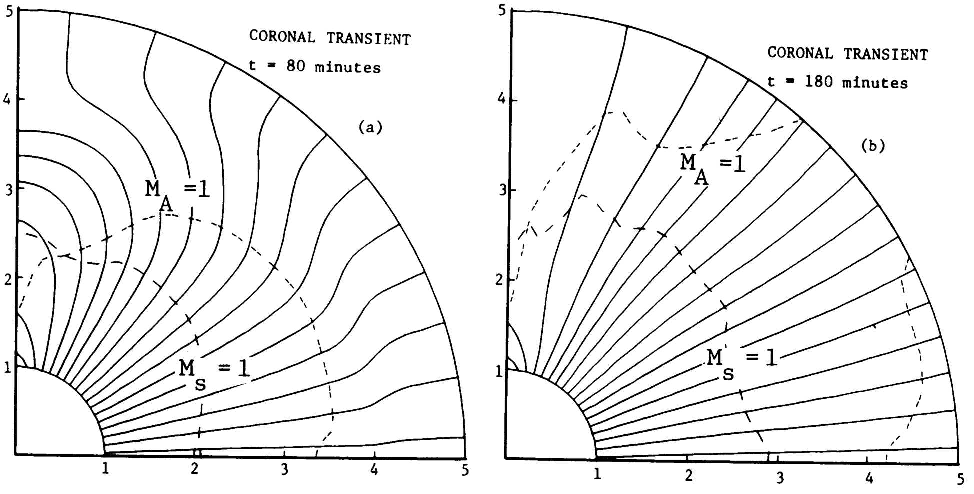

Figure 3. Magnetic field lines in the coronal transient where the time is as for Figure 2(b).

ACKNOWLEDGMENTS

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DISCUSSION

Levine: I am interested in the portion of your model which represents the steady state (i.e., after your model streamer was found):
1. Can you describe the resulting temperature distribution, especially on open vs. closed field lines?
2. Can your numerical technique handle other initial magnetic geometries, as a dipole has the wrong strength distribution at the surface for a realistic solar test case?
3. Would you please describe the energy equation you used in more detail?

Steinolfson: 1. The temperature at the equator decreases in the closed-field region from 1.89×10^6K at 1 $R_\odot$ to 1.8×10^6K at 2.5 $R_\odot$, and in the overlying open-field region further decreases to 1.6×10^6K at 5 $R_\odot$. The temperature at the pole increases from 1.8×10^6K at 1$R_\odot$ to 2.82×10^6K at 5 $R_\odot$.

2. The dipole field was selected since it represents a solution to the equations for the absence of magnetic poles and zero Lorentz force. The numerical technique can handle any reasonable initial magnetic geometries such as a higher multi-pole solution to these equations (e.g., a quadrapole) or an arbitrary configuration - possibly one more closely resembling a streamer than a dipole.

3. The energy equation does not contain any dissipative terms and in its simplest form can be written as

$$\frac{d}{dt}\left(\frac{p}{\rho^\gamma}\right) = 0,$$

where p is the pressure, ρ the density and γ the polytropic index. The derivative is the total or Eulerian derivative, and the equation simply states that the rate of change of the entropy of a fluid particle is zero, or equivalently, that the changes of state of the fluid particle are isentropic.