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MODELS FOR APPLICATION OF RADIATION BOUNDARY CONDITION FOR MHD WAVES IN COLLAPSE CALCULATIONS

C. T. Vanajakshi
NASA-Ames Research Center, CA 94035

E. H. Scott
Computer Sciences Corporation
NASA-Goddard Space Flight Center, MD 20771

and

David C. Black
NASA Headquarters, Washington, D. C. 20546

The problem of reflection of magnetohydrodynamic (MHD) waves at the boundary of a numerical grid has to be resolved in order to obtain reliable results for the end state of the (isothermal) collapse of a rotating, magnetic protostellar cloud. The only attempt made so far (Dorfi 1982) to resolve the reflection problem made use of an approach similar to the work of Bayliss (1982), where the Navier-Stokes equation for a magnetic, conducting fluid was linearized near the boundary while the density of the external medium was kept constant and the resulting restricted set of equations were solved. While this approach is better than assuming zero magnetic field in the external medium (which causes the energy to flow back similar to a wave along a string tied at the ends) the assumption of small fluctuations, which is necessary to linearize the equations, breaks down when the magnetic braking is efficient and causes large amplitude alfven waves. Since the goal of investigating magnetic braking in collapse simulations is to see if the transport of angular momentum via alfven waves is large enough to solve the 'angular momentum problem' an approximation that artificially suppresses large amplitudes in the MHD waves can be self-defeating.

For this reason, four alternate methods of handling reflected waves where no assumptions are made regarding the amplitudes of the waves have been investigated. In order to study this problem (of reflection) without interference from other effects these methods were tried on two simpler cases:

(1) The analytical case of a perpendicular rotator by Mouschovias and Paleologou (1979) where the magnetic braking of a rigid disk with a radial magnetic field was followed.

(2) A simpler model of this disk in which a 'spike' in the field is generated at a specific time in an otherwise quiescent configuration and the propogation of the wave thus generated and its reflection are followed.

The basic models for the four methods are as follows:

Method 1: The rate of change of $\Delta\mathbf{B}$ (where $\Delta\mathbf{B}$ is the change in magnetic energy) with respect to distance is calculated near the boundary. Using this quantity and the distance between the last two grids $\Delta\mathbf{B}$ in the last grid is computed at each time step. Then this change in magnetic energy is partitioned along the three directions using the ration $(\Delta \mathbf{B})_r : (\Delta \mathbf{B})_\phi : (\Delta \mathbf{B})_z$ in the previous grid. The directions of the components (+) are also echoed from those in the previous grid. This method works for long wavelength alfven waves. When the wavelength is comparable to grid size this approach may become invalid.

Method 2: The fluxes $\frac{\delta B^2}{4\pi}(\bar{v}_a + \bar{v})$ where $\bar{v}_a$ is the alfven velocity and $\bar{v}$ the material velocity are matched between the two grids that border the boundary.

Method 3: This method uses transformations to diagonalize the equations of motion. For the component in the direction of reflection the amplitude of the incoming waves is set to zero. The other components are solved in the normal fashion.

Method 4: This method uses a damping term in the Navier-Stokes equation at the boundary.

$$\rho \frac{d\bar{v}}{dt} = - \nabla p + \rho g - \frac{B}{4\pi} X (\nabla X \ B) + \eta \nabla^2 \bar{v}$$

This damping term can absorb the energy and suppress the reflection.

Results of these studies will be presented.

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