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Implementation of CIP algorithm to magnetohydrodynamic applications

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CIP algorithm [*Yabe et al.*, 2001] has been known to solve the advection equation with few numerical phase errors and have succeeded in solving hydrodynamic problems. Application of the CIP algorithm to magnetohydrodynamic problems is not straightforward because of existence of the transverse mode, Alfven wave. A special treatment of Alfven wave is required to solve MHD equations in addition to the CIP method. *Kudoh et al.* [1998] overcame this difficulty by introducing the MOC-CT method [*Hawley and Stone*, 1995], which follows the characteristic curve of Alfven wave by means of the van Leer's interpolation [*van Leer*, 1977], as a solver of the induction equation. Their approach has succeeded in solving astrophysical phenomena, such as the accretion disk. Meanwhile we adopted the CIP method to solve the advective term also in the induction equation, while the non-advective terms including the magnetic stress terms are solved with the 3rd-order Adams-Moulton method. Although this approach has shown certain results of the three-dimensional nonlinear development of the Kelvin-Helmholtz instability [*Matsumoto and Seki*, 2007], the representation of the transverse mode is not resolved enough to discuss MHD turbulence lead by the 3-D KHI evolution.

To integrate all MHD equations by means of the CIP method, we transformed the original momentum and induction equations to unusual forms by introducing Elsasser variables [*Elsasser*, 1950]. In this formulation, while the compressional terms are remained as non-advective terms, the advective and the magnetic stress terms are expressed in the form of the advection equation, which enable us to benefit from the CIP algorithm. We have tested with the 1-D code based on this formula. The propagation of Alfven wave reveals an exact solution even though it is resolved with a few grids (˜Nyquist wave number). A number of shock tube tests show good agreements with the previous results with less numerical oscillations at the shock front resolved with a few grids. Extension of the 1-D code to 3-D one is straightforward. We have tested a 3-D nonlinear evolution of the KHI by comparing with our previous result. It is found that our new MHD code is capable of following the 3-D turbulence excited by the KHI with less numerical oscillations. Furthermore, inclusion of the hall term in the induction equation is under development to examine its effect on the turbulent evolution. In this presentation we show the governing equations in terms of Elsasser variables and the basic characteristics of our code. We also show the 3-D simulation result of the KHI with/without the hall term in the induction equation as an application to the MHD turbulence problem.