Final Report

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The University of Michigan participated in the joint UCLA/Maryland fusion science center focused on plasma physics problems for which the traditional separation of the dynamics into microscale and macroscale processes breaks down. These processes involve large-scale flows and magnetic fields tightly coupled to the small scale, kinetic dynamics of turbulence, particle acceleration and energy cascade. The interaction between these vastly disparate scales controls the evolution of the system. The enormous range of temporal and spatial scales associated with these problems renders direct simulation intractable even in computations that use the largest existing parallel computers. Our efforts focused on two main problems: the development of Hall MHD solvers on solution adaptive grids and the development of solution adaptive grids using generalized coordinates so that the proper geometry of inertial confinement can be taken into account and efficient refinement strategies can be obtained.

Hall MHD

We have successfully implemented the most important term for the Hall effect into the BATSRUS code. The electric field is modified from the resistive MHD expression $\mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta\, \mathbf{j}$ to the Hall MHD form $\mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta\, \mathbf{j} + \mathbf{j} \times \mathbf{B}/(ne)$, where $\mathbf{u}$, $\mathbf{B}$, and $\mathbf{j}$ are the velocity, magnetic field and current density vectors, respectively, η is the resistivity, n is the number density and e is the electron charge (the magnetic units are chosen such that the magnetic permeability of vacuum is unity). This seemingly small modification drastically changes the character of the MHD equations. In Hall MHD the stable limit for the explicit time step is proportional to the square of the grid resolution. This means that using implicit time stepping is very important. The extra derivative in the induction equation requires higher order approximations at resolution changes. The Hall MHD implementation is fully compatible with the requirements for multiscale fusion codes: non-cartesian block-adaptive grids, implicit time stepping, multispecies plasma etc.

Non-Cartesian Grids

We have implemented generalized curvilinear coordinates into our MHD code. Generalized coordinates provide a smooth mapping from a logically Cartesian grid to an arbitrary curvilinear grid, including spherical, cylindrical and toroidal grids. The generalized grids allow us to match non-planar boundary surfaces more accurately and it also allows the resolution to be concentrated in a continuous manner. Combined with the block-adaptive mesh refinement, the generalized coordinates provide an extremely flexible, efficient and accurate grid structure.

Publications

1. I.V.Sokolov, I.I.Roussev, L.A.Fisk, M.A.Lee, T.I.Gombosi and J.I.Sakai, Diffusive Shock Acceleration Theory Revisited, **Astrophys. J., 642**, L81-L84, 2006.
2. G. Toth, D. L. De Zeeuw, T.I. Gombosi, and K.G. Powell, A parallel explicit/implicit time stepping scheme on block-adaptive grids, **J. Comput. Phys., 217**, 722-758, 2006.
3. I. V. Sokolov, K. G. Powell, T. I. Gombosi, and I. I. Roussev, A TVD Principle and Conservative TVD Schemes for Adaptive Cartesian Grids, **J. Comp. Phys., 220**, 1-5, 2006.
4. Toth, G., Y. Ma, T. I. Gombosi, Hall magnetohydrodynamics on block-adaptive grids, **J. Comp. Phys., 227**, 6967-6984, 2008.

Invited Presentations

1. T.I. Gombosi, D.L. De Zeeuw, I.V. Sokolov, G. Tóth, A.J. Ridley, K.C. Hansen, W.B. Manchester, I.I. Roussev, C.R. Clauer, K.G. Powell, Q.F. Stout, B. van Leer, P.L. Roe, Parallel, Adaptive, Coupled Plasma Simulations, Multiscale Processes in Fusion Plasmas, IPAM UCLA, Los Angeles, CA, January, 2005.

Contributed Talks

1. I.V.Sokolov, I.I.Roussev , T.I.Gomnosi, NUMERICAL SIMULATIONS OF THE MHD PLASMA EQUILIBRIUM USING BLOCK ADAPTIVE GRIDS, Bull.Amer.Phys.Soc., Program of the 47th Annual Meeting of the Division of Plasma Physics, Denver, CO, Oct, 2005.
2. K. Patel, M. M. Kuznetsova, M. Hesse, L. Rastatter, G. Toth, T. Gombosi, Magnetic Reconnection Rate in Collisionless Plasmas, 2005 Fall AGU Meeting, San Francisco, CA, December 5-9, 2005.
3. D.L. DeZeeuw, I.V. Sokolov, T.I. Gombosi, Spetral Index of Particles Accelerated by Shock Waves Depends on the Turbulence Anysotropy, 2006 Spring AGU Meeting, Baltimore, MD, May 23-26, 2006.
4. Toth, G., Ma, Y., Gombosi, T.I., Sokolov, I.V., MHD Simulations on Block Adaptive Grids, 2006 Fall AGU Meeting, San Francisco, CA, December 11-15, 2006.
5. G. Toth, Y. Ma, T.I. Gombosi, M.M. Kuznetsova, Comparison of Hall MHD and the non-gyrotropic resistivity model in the global magnetohydrodynamic code BATSRUS, 2007 Spring AGU Meeting, Acapulco, Mexico, May 21-25, 2007.