Implicit-Explicit Time Integration of the Multi-Fluid Plasma Model Using a Continuous Galerkin Spatial Discretization

Sean T. Miller*, Eric C. Cyr†, John N. Shadid††, Sidafa Conde†††, and Edward G. Phillips††††

Computer Science Research Institute (CSRI)
Sandia National Laboratory
Albuquerque, NM, 87123, USA
e-mail: *seamill@sandia.gov, †eccyr@sandia.gov, †††sconde@sandia.gov, ††††egphill@sandia.gov

ABSTRACT

Multi-fluid plasma models describe the evolution of a plasma containing a discrete electron fluid alongside multiple ion and neutral species. These models allow for a more encompassing representation of plasma physics beyond the scope of classic MHD[1]. The addition of electron physics comes at the cost of handling fast time scales associated with the electron plasma frequency. Due to the fast time scales of electron dynamics the full form of Maxwell's equations may be required, which relates to speed of light characteristics.

The electron plasma frequency and speed of light represent stiff dynamics where a stable time step drastically increases the runtime of explicit time integration schemes. Limitations span both small scale plasmas, such as micro-discharge plasmas, where the Courant stability condition associated with the speed of light is limited by grid resolution, to the high energy density plasmas found in Z-pinches and inertial confinement fusion, where the plasma frequency can surpass the speed of light stability limit. These time step issues can be alleviated using implicit time integration schemes which sacrifice accuracy to step over stiff modes. Due to the strong coupling in multi-fluid plasmas, matrices associated with implicit time integration are often poorly-conditions and challenging to solve.

This research studies the advantages of using implicit-explicit (IMEX) time integration schemes to break the multi-fluid plasma model into implicit and explicit portions that represent the fast and slow timescales respectively[2,3]. By representing slower modes, e.g. those associated with ion/neutral speed of sound, explicitly the implicit solution is simplified. Additionally, this reduces total runtime since explicit schemes are generally faster to evaluate. The goal of this research is to develop a scalable approach for controlling the resolution of electromagnetic and electron dynamics based on characteristic time scales. This talk will discuss the advantages and disadvantages of moving between implicit, explicit, and IMEX time integration schemes for multi-fluid plasma models using convergence criteria and comparisons to asymptotic systems such as MHD.

REFERENCES

[1] E. M. Sousa and U. Shumlak. A blended continuous–discontinuous finite element method for solving the multi-fluid plasma model. *Journal of Computational Physics*, *326*, pp.56-75. 2016.

[2] L. Pareschi and G. Russo. Implicit-explicit Runge-Kutta schemes and applications to hyperbolic systems with relaxation. *Journal of Scientific Computing*, 25, pp.129-155. 2005.

[3] W. Hundsdorfer and S. J. Ruuth. IMEX extensions of linear multistep methods with general monotonicity and boundedness properties. *Journal of Computational Physics* 225.2, pp.2016-2042. 2007.