Towards a Hybrid Multi-fluid/PIC Plasma Capability

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ABSTRACT

Plasma physics systems are often simulated by either a continuum approach (e.g. magnetohydrodynamics or multi-fluid plasma models) or a charged particle description (e.g. Boltzmann equation). Particle-in-cell (PIC) methods are typically applied to solve the Boltzmann equation that is the fundamental equation for the distribution function describing particle motion in the presence of electromagnetic fields. As the plasma density and collisional interaction increases, PIC becomes intractable to simulate directly due to the large number of particles required. In this case, fluid PDE models such as the single fluid magnetohydrodynamics (MHD) and multi-species fluid models are often utilized. In transition regions certain problems may require a hybrid model that combines the fluid and PIC descriptions for tractability.

This presentation describes an initial effort to couple a finite element (FE) multi-species fluid model to a PIC description. The multi-fluid model consists of continuity, momentum and energy equations for each species coupled to Maxwell's equations for the electromagnetic field. The equations are discretized using the continuous Galerkin FE method with a compatible basis to enforce the electric field (edge basis) and magnetic field (face basis) involutions from Maxwell's equations. The resulting set of fluid equations contains a wide range of multiple time and length-scale physical mechanisms, producing a stiff system. To evolve the coupled kinetic-PIC / fluid system for the time scales of interest, we explore the use and development of IMplicit-EXplicit (IMEX) Runge-Kutta time integration methods and pursue initial comparisons with operator split methods. For robustness, efficiency, and scalability the implicit nonlinear fluid physics are solved using a Newton-Krylov method with a GMRES linear solve and an approximate block factorization preconditioner. Algebraic multigrid is applied within the blocks. Code verification problems will be presented to assess accuracy and efficiency of the algorithm.