NIMROD Team Meeting Minutes
November 15, 2008
Dallas, Texas

Model Development

Jeong-Young Ji reviewed his general moment formulation of the plasma kinetic equation with collisions. The system of equations includes 'drives' from the relative motions of electrons and ions. Solutions can be obtained for three conditions: 1) uniform plasma, where there are exact solutions, 2) highly collisional plasma, and 3) strongly magnetized plasma with general collisionality and magnetic geometry. Ji reviewed specific results showing how different computations need different numbers of moments to obtain convergence. A significant finding is that ion fluxes differ appreciably from Braginskii results when $T_i > T_e$.

Eric Held presented recent work on using NIMROD to solve the gyro-averaged drift kinetic equation (DKE) as part of a Chapman-Enskog-like (CEL) approach to closures. A new graduate student, Andrew Spencer, will be getting involved in this research. The advantages over using integral closures include modeling of Landau damping, incorporation of time-dependent effects, and the possibility for increased efficiency. The implementation in NIMROD will be related to Held's mixed finite element collisional heat flux, where components of the kinetic distortion are solved simultaneously with temperature. As a test, he has implemented the continuum computation with one velocity-space dimension (a Legendre polynomial expansion in pitch angle) with speed as a parameter. Even this simplified computation reproduces the flattening of temperature across a magnetic island. The next long-term step will be to incorporate a dimension for speed, but Held is also considering other schemes with respect to temporal staggering. A near-term project is to test convergence properties.

Jianhua Cheng from UC-Boulder presented algorithm development for majority ion kinetics in fully electromagnetic computations. The model uses a massless drift-kinetic electron fluid with simulation-particle ions that are subject to the full Lorentz force. Like fluid-only models, quasi-neutrality is assumed, and displacement current is dropped from Ampere's law. The ion weights and electromagnetic fields are solved implicitly—the latter via an implicit Ohm's law—but the ion trajectories are computed explicitly. Tests with spatially uniform background plasma accurately reproduce Alfven waves and ion acoustic waves with Landau damping. The electron-temperature-gradient driven kinetic Alfven instability has also been reproduced. [At the CEMM meeting the following day, there was a question on how the simulation particles maintain quasineutrality.]

Carl Sovinec presented development work by Eric Howell to create a Grad-Shafranov solver from the NIMROD framework. A native solver avoids errors associated with numerical interpolation that affect equilibria read from other codes, and it facilitates scanning equilibrium parameters. The new code, NIMEQ, treats the del-star operator as a total divergence, and the implementation solves for coefficients of an expansion for ψ/R^2. This formulation allows the code to use standard regularity conditions in simply connected domains, and J_ϕ/R can be obtained without extrapolation. The equilibrium magnetic field and current density are obtained after solving the Grad-Shafranov equation with Picard iteration for the rhs. At present, NIMEQ needs to read an existing dump file to obtain the geometry of the domain, meshing, and the normal component of magnetic field along the wall. It produces graphical output and writes a new dump file for NIMROD computations. Tests include transferring the equilibrium solution to the n=0 part of the NIMROD solution expansion and running computations for hundreds to thousands of Alfven times to test the quality of the computed equilibria. The NIMEQ code will soon be made available through the central repository.

Performance Development and Scaling

Sovinec provided an update on nonlinear 3D two-fluid computation. He reviewed the new preconditioner for the two-fluid magnetic-field advance, which uses limited coupling among Fourier components. He also described how data and numerical integration loops have been reordered to reduce latency in the collective communication that is performed before and after each FFT. The new code uses only one call to each integrand routine per grid-block, and loops over numerical quadrature points now occur within integrand routines. Together with the new preconditioning, this improves parallel scaling for the two-fluid algorithm. A weak scaling study shows that the algorithm scales past 1000 processors on the Cray XT-4 at NERSC (Franklin), and starts losing efficiency at the few-thousand processor level. These computations are near the memory limit of the machine, however, and more recent versions of the SuperLU library may solve this problem. Sovinec also presented a physics application of the recent development, the internal kink in a torus. It is a 3D nonlinear computation with a non-reduced two-fluid model. The 'growth-rate' of kinetic energy is observed to increase in the nonlinear phase as the reconnection transitions from a current-sheet geometry to X-point geometry.

Charlson Kim gave a presentation on parallel efficiency with respect to the simulation particles. Meshes used for NIMROD fluid computations pose load balancing issues for the particles in that poloidal decomposition is usually done by distributing elements, but this leads to a poor distribution of particles over physical dimensions, particularly near the magnetic axis and the wall. The finite element and PIC computations have conflicting requirements that may need to be addressed by nonuniform particle weights. To complete an action item from the summer meeting, Kim reviewed literature on simulation-particle parallelization. What he found fit into four categories: 1) dynamic load balancing—not so helpful for NIMROD because the number of particles per element does not change significantly, 2) hybrid-ordered particles listed according to physical location—some aspects of this are already in NIMROD, 3) particle vs. domain cloning—some of this can be done with NIMROD, though being implicit, field solves are not as trivial as in other applications, and 4) variable particle numbers. Kim's next steps are to check tuning of options, leverage the existing sorting, further explore cloning, and develop capabilities for variable particle weights.

Applications

Kim also gave a presentation on some of the NIMROD physics applications being conducted by the PSI-Center. He described progress and showed animations on simulating flux injection from a co-planar source. He is specifying azimuthal magnetic field across the injector gap and is using extra resolution at the injector corners to avoid an effective discontinuity. The simulations work pretty well, and using the Hall effect actually helps the injection process avoid poorly resolved boundary layers. A specified inward (pinch) flow will also be tested.

Richard Milroy presented a number of FRC applications that are being conducted by the PSI-Center. [A second NIMROD publication on FRCs is in print—this time by Milroy and Steinhauer.] Most of the simulations have been developed to study issues associated with formation and compression. They use time-dependent boundary conditions for electric and magnetic fields to simulate the staged firing of various coils. Formation simulations with the

Hall effect are new and show qualitatively correct generation of toroidal flows and toroidal magnetic field. The flows are induced on open field and viscously couple to the closed-field region. Configurations that are not symmetric about a midplane, including those with conical coils arrangements, have been simulated; the net toroidal field remains small. Issues that need to be explored include transport, radiation and neutrals, and the behavior of anisotropic transport with a field null. [The demagnetization effect in Braginskii should help.] Simulations of the PHD experiment show significant heating due to adiabatic compression. The group is also simulating FRC-based thrusters, which have relatively high density and low voltage. Giovanni Cone is investigating the stability of oblate FRCs, which can use shells to stabilize tilt but tend to be interchange unstable. Simulations of RMF current drive have progressed through a week-drive phase but need recent preconditioning developments for the Hall term. Future model development for FRC simulations will include particle effects, Chodura resistivity, neutral and radiation modeling, and separate diffusivity shaping for different transport coefficients.

Ryoji Takahashi presented some of the first results from a kinetic-MHD study of tearing modes. The motivation is data from JET, which does not show 2/1 activity predicted by classical delta-prime analysis. This experiment has a significantly larger fraction of hot-particle pressure (>30%) than other large tokamaks. Takahashi and Brennan are using Kim's simulation-particle model with a modification of thes equilibrium flux definition. The linear computations show rotation, but like growth rate, it is much slower than with the internal kink mode. A parameter scan of hot-particle pressure and Lundquist number shows an appreciable effect on the modes even at small (but nonzero) values of hot-particle pressure, particularly for large S.

Tom Jenkins gave an update on modeling the interaction of RF with tearing modes for the SWIM project. He has varied the deposition size and location, keeping net current drive fixed, and finds that effectiveness at reducing islands improves as spot size is reduced. He has obtained a scan of linear growth rate for different deposition profiles by running 2D computations with ad hoc current drive then adding $n>0$ Fourier components with small amplitude. The linear phase of these nonlinear computations provides the linear growth rate results, and their final state provides magnetic energy for each deposition profile. Work on coupling GENRAY to NIMROD was also presented. This part of the effort is now proceeding in a way that will serve the full coupling, where NIMROD computations will use the quasilinear diffusion resulting from the RF rays. The way the ray-tracing information is deposited on NIMROD basis functions is not trivial and is now based on importance sampling to avoid numerical noise.

Scott Kruger described a study of heat conduction across a magnetic island. The motivation is to conduct a numerical assessment of different closure models that have been developed for approximating nonlocal kinetic effects and comparing them with the results from the CEL approach of Held and coworkers. The different models include flux-limited Braginskii, artificial wave propagation (like what's used in M3D), and polytropic models. The study will first focus on single-helicity configurations, and it is using the mixed FE implementation by Held with improved preconditioning.

Jake King presented a numerical study of two-fluid tearing for RFPs. He has compared linear tearing-mode results for paramagnetic pinches in a scan over ρ_s. The two-fluid computations have complex eigenvalues with real frequencies that are comparable to the growth rate. At ρ_s comparable to the minor radius, the growth rate decreases. Nonlinear computations with a single unstable mode saturate at about the same island width, independent of ρ_s, except for the largest-ρ_s case, which may not be fully resolved. At ρ_s=0.1a, the quasilinear Hall dynamo has peak amplitude that is significantly larger than that of the MHD dynamo, but at nonlinear saturation, the two are comparable and offset each other over part of the minor radius. In the large-ρ_s case (0.5a), the Hall dynamo remains dominant at saturation. So far, none of the nonlinear two-fluid cylindrical computations show the fine-scale structure that was observed near the X-point in slab-geometry computations.

Fatima Ebrahimi presented results on linear and nonlinear pressure-driven instability in RFPs. The linear part of the study compares MHD and two-fluid modeling with gyroviscosity. The equilibrium current profiles are chosen to be delta-prime stable when there is no pressure gradient. Both m=0 (edge) and m=1 (core) modes are unstable with the pressure gradient. For the m=0 modes, the effect of gyroviscosity is to reduce the growth rate by a factor of two, but there is no stablilization in these cases. For the core modes, the stabilization effect is greater. The nonlinear computations have large pinch parameters for deep reversal. With gyroviscosity, the m=0 modes eventually become dominant. For low-k modes, the effect on the current profile differs from the usual current-driven case; the change in the parallel current can be approximately symmetric about the rational surface. Nonlinear computations with a two-fluid Ohm's law but no gyroviscosity show reduced saturation amplitudes.

Ping Zhu gave an overview of his recent efforts to perform nonlinear ballooning computations with the two-fluid model. This is an important topic, because in H-mode, the equilibrium length scale can approach the ion gyroradius. In addition, two-fluid effects may influence how interchange 'fingers' break off into separate blobs. Zhu uses the ESC code for generating equilibria and the hyper-diffusivity term to prevent noise in the number density distribution. He compared preliminary results obtained with the two-fluid Ohm's law with results obtained with gyroviscosity instead of kinematic viscosity. Asymmetries that are distinct from MHD appear, but the computations need more work to progress through the nonlinear phases.

Bonita Squires presented an update on linear benchmarking of NIMROD with ELITE on peeling/ballooning. She distinguishes a 'halo' region that has high dissipation and low mass density in comparison with the interior. She first scanned Lundquist number in cases without a halo to determine the conditions needed for ideal behavior and found that it occurs for $S \geq 5\times10^7$ (for ballooning in recent equilibria generated by Phil Snyder). She then scanned the location for the transition from interior to halo and found that it needs to be outside the pedestal. After matching growth rates with ELITE at a single n-value (toroidal harmonic), she completed computations over the rest of the spectrum, and there is good quantitative agreement with the ELITE results. A second equilibrium has lower pedestal pressure, and a third equilibrium has a larger kink/peeling drive. NIMROD results for the third case show a bump in growth-rate due to peeling, but results with the density transition are still needed for quantitative comparison. The computed results with the second equilibrium produce odd behavior in the transition to stability. The growth-rate seems to vary as two modes go in and out of phase. Steve Jardin reports similar behavior with the M3D-C1 code in slab-geometry cases.

Chris Carey presented his study of rotational stabilization of jet-like configurations. Nonlinear simulations show stability for current profiles where kink modes are expected without flow, and this motivated a linear study to explain the behavior. Initial value and eigenvalue computations have been performed in periodic pinch configurations with a wall at finite distances from the geometric axis. Rigid rotation reduces growth rates for equilibria that balance the centripetal force with either magnetic forces or pressure gradients. In cases that are still unstable, the resulting modes show a phase shift relative to the no-flow cases. The eigenvalue computations have been performed with a shooting code and are used to 1) verify the NIMROD results, 2) obtain physical insight, and 3) investigate marginal modes that are difficult to obtain with initial-value computations. They have been performed in both Eulerian and Lagrangian reference frames, and there is three-way agreement between the two sets of eigenvalue computations and NIMROD initial-value computations. The stabilizing effect persists as the wall is moved away from the geometric axis, and it is attributed to the Coriolis effect, which distorts radial kink motions into azimuthal motions.

Mark Schlutt described his study of heat transport in stellarators. He is using NIMROD to model straight stellarators with helical magnetic fields imposed at the boundary of the domain. Heating applied near the axis of nonlinear computations produces self-consistent evolution of pressure profiles, magnetic topology, and heat transport. So far, he has used uniform values for parallel and perpendicular thermal diffusivity coefficients. With perturbed initial states, the computations reproduce stable shear Alfven waves. Adding magnetic perturbations at the wall leads to islands that are embedded in the background helical state.

Closing Items

Sovinec noted that there are 36 NIMROD-related presentations at the APS-DPP meeting for this year.

With the next Sherwood meeting being joint with APS-April, the Team discussed having a separate winter/spring meeting. Team members are in favor of this, but specific plans will need to be made.