NIMROD Team Meeting Minutes
October 19, 2019, Fort Lauderdale, Florida

Physical Model Development

Jeong-Young Ji presented his recent work on developing closures for fluid equations. In this case, he is relaxing the usual (Braginskii) approximation that the relative drift speed between electrons and ions is much smaller than the electron thermal speed. This development is motivated by the runaway-electron problem that is associated with tokamak disruption. He uses the mathematical tools of his general moment method, and the derivation does not a priori impose a small mass-ratio approximation. That approximation is used subsequently to simplify evaluations without loss of the large-drift information. Ji shows numerical evaluations of closure coefficients that show sign changes as the normalized drift speed is varied. This behavior is counter-intuitive, and he is checking for possible errors.

Eric Held gave an update on implementing and testing Chapman-Enskog-like (CEL) drift kinetics for evolving fluid moment equations. His presentation considers the low-order (in sound gyro-radius) part of Ramos's derivation for electrons, which is the common part for both species. He noted where terms that are often ignored, such as temporal derivatives of magnetic moment, are retained for long-time evolution. The implicit implementation solves temperature and kinetic moment coefficients simultaneously. Block-based preconditioning works sequentially through different speeds. The group has computed temperature evolution in the presence of a magnetic island as an example computation, and the kinetic response is largest near the island separatrix. A second verification test is unmagnetized ion-acoustic wave damping. Results show accurate damped oscillations, at temperatures that would cause the Braginskii closure to damp perturbations without oscillating.

Computational Development

Andy Spencer presented the work that he and Brett Adair have been doing to compute all parts of the collision operator for CEL drift-kinetic simulations. The general Rosenbluth-potential form is needed for collisions against the perturbed part of the distribution function, and the integrand of the v-space integration includes singularities in pitch angle and in speed. Spencer has adapted a method from astrophysics, where the singular part of the integrand is separated and evaluated with analytical integration. The rest is integrated numerically with orders of magnitude fewer evaluations to achieve the same accuracy as computations with all parts evaluated numerically. The speed representation uses non-classical polynomials for speed coordinates that are normalized by the species thermal speed. Where the singularity occurs depends on whether the collisions are among like or unlike particles. The variable of integration is normalized to the speed of each speed-grid point, and the integral is performed in three numerical pieces: two around the singular point and one for high speeds. Non-classical Gaussian weighting is used, and the method improves accuracy by orders of magnitude.

Trevor Taylor implemented serendipity elements and has tested them in NIMROD's particle tracking. These 2D elements avoid monomial terms that are larger than what is needed for 2D polynomials to be complete to a given degree. He has verified that particle tracking with the new elements matches tracking with NIMROD's standard elements. He is developing machinery to use these elements more widely and will apply them in the particle-deposition aspect of delta-f PIC computations.

Carl Sovinec has investigated explicit hyper-viscosity as a means to damp mesh-scale noise. The explicit aspect avoids expensive 6-vector solves in the velocity advance, but it imposes a stringent constraint on the product of the timestep and the hyper-viscosity coefficient. That constraint can be relaxed by sub-cycling. Sovinec discussed minimal Gauss-Lobatto-Legendre integration as a means to achieve a diagonal mass matrix and showed results from a strongly nonlinear magneto-acoustic wave test. He also showed its application to a sheared-slab plasmoid reconnection computation.

Applications

Jacob King is developing capabilities to accurately model flows in tokamaks, consistent with MHD evolution. This is part of his work on multi-species modeling that is needed to set fitted plasma density, pressure, ion temperature, and electron temperature consistent with experimental measurements and fits. King is working with a between-ELM fit to DIII-D shot 164988, which has beams, but is largely a 2D state without neoclassical toroidal viscosity. He is checking the different possible contributions to net flow, including neoclassical poloidal flow damping and ion-orbit losses near the separatrix. Drift orbit computations show the sensitivity to pitch angle and speed. King has evaluated Shaing's ion-orbit loss formula and neoclassical relations from Callen's 2009 paper. He is also considering possible torque from interactions with neutrals and has applied the recent dynamic neutrals modeling. Torque from neutral beam injection will also be considered.

Eric Howell is using NIMROD to model transport through divertor footpoints in discharges with RMP fields. The perturbations lead to 3D field-line tangles. This has been studied experimentally in DIII-D with n = 3 perturbations in ITER-like discharges that apply an extensive array of diagnostics. Howell is using a kinetic reconstruction of discharge 166439 and has compared vacuum-field and MHD responses. Linearly, the MHD response limits the chaotic field-line behavior to a narrow region near the separatrix. A nonlinear computation shows that the response tends to brake toroidal flow inside the separatrix, and the high-m response is stronger in the nonlinear computation than in the linear result. Nonetheless, the nonlinear computation seems to under-predict the extent of the tangle. It is possible that modeling the wall as a conductor may be limiting the responses, and resistive-wall modeling will be considered.

James Penna presented his computational study of the HIT-III AC-driven spheromak. He described the experiment's configuration and diagnostic array. There is a transition in experimental behavior when the drive frequency is raised above 40 kHz, which is approximately the Alfven frequency for a wave traveling toroidally. In particular, plasma-beta increases with frequency, and the density is about two times larger at 58.5 kHz than it is at 15.6 kHz. Penna has applied both single and two-temperature modeling, and the waveform of the drive is based on the experiment. The simulations converge to the same toroidal current as the experiment, but the magnetic fluctuation level is larger in the simulations. Also, the centroid of the plasma is at larger radius in the experiment than it is in the simulation. A synthetic FIR line-average of density shows a low-frequency (many drive cycles) oscillation that is similar to experiment. Penna showed plots of how the profiles change significantly over the low-frequency oscillation.

Torrin Bechtel has investigated transport in an $l = 2$, $N_p = 10$ stellarator configuration. He reviewed his previous results on loss of flux surfaces and soft beta limits with increasing heating power and Shafranov shift. Parameter scans show that the results are sensitive to parallel and perpendicular thermal conductivity. However, they are much less sensitive to variation in resistivity and viscosity; a factor of 10 change only affects beta by 10%. Bechtel has compared his results with different models of stochastic-field transport. A challenge is estimating the autocorrelation length of the magnetic field lines. In principle, this can be done by field-line integrals, but for much of the domain, Bechtel does not see convergence with respect to integration length. He showed that all field-lines tested exhibit larger radial excursions when they are near the outboard side, regardless of the presence of island structures or a strong Shafranov shift. The central limit theorem cannot be applied trivially, as typically assumed, when computing a magnetic field diffusion coefficient directly from field-line following.

Urvashi Gupta presented her recent work on modeling pressure-gradient effects and thermal energy transport in pinch configurations with magnetic relaxation. She reviewed previous results where thermal effects are important: drift-tearing behavior with two-fluid modeling and helical thermal energy confinement in quasi-single-helicity states. She is now running her NIMROD computations with "stabilized" cylindrical z-pinch fields as the steady-state fields. They are Ohmic equilibria that satisfy steady particle and energy transport relations in the absence of Ohmic heating, which is consistent with NIMROD's time-dependent evolution. Nonlinear computations evolve through a violent interchange-dominated phase, where Gupta uses large magnetic Prandtl number (Pm) to facilitate the computation. Later, the behavior is dominated by longer wavelength tearing, and she is able to reduce Pm. She is applying computational diagnostics to understand fluctuation-induced electromagnetic and thermal energy transport, which flatten the parallel-current and the pressure profiles in the core region.