NIMROD Team Meeting Minutes, October 21-22, 2017
Pre-APS-DPP, Milwaukee, Wisconsin

Physical model development and analysis:

Jeong-Young Ji presented new work on closure relations using his general moment formulation of the drift-kinetic equation with collisions. The new aspect is to include geometric effects that modulate the magnitude of magnetic field. He is applying the developments to axisymmetric circular cross-section tori, considering both radial and parallel (azimuthal) drives. Results include plots of convergence on parallel heat flow for poloidal m=0 and m=9 components as the number of moments is increased. Ji has also varied aspect ratio and effective Knudsen number (effective collisional-mfp/qR). He plans to investigate behavior at large Knudsen number, evaluate the collisionless limit, and develop fitted kernel functions, as he has done previously for slab geometry.

Hankyu Lee has worked on incorporating Ji's general moment equations in NIMROD, and he presented his numerical formulation and test results. He starts from the general moment equations and separates them into even and odd moments with respect to velocity. He retains the implicit leapfrog scheme of staggering the even and odd moments by 1/2 time-step. At present, the "momentum-restoring" parts of the collision operator are not included. Lee has tested the heat-flux computation on ion acoustic waves. He compared results with computations using the Braginskii closure and when varying the number of moments used to evaluate the heat-flux.

Joseph Jepson presented the Eulerian form of the drift kinetic equation that he has helped implement in NIMROD. He compared the two versions, delta-*f* and Chapman-Enskog-like, noting the advantages and disadvantages of the two. He has recently tested the delta-*f* implementation on poloidal flow damping in an NSTX equilibrium. A concern is that the closure for electrical potential only works when B^2 is not equal to its flux-surface average. The tests show damping on the expected order of the ion-ion collision time, and the ion distribution evolves from a beam in pitch angle to being essentially isotropic.

Dan Barnes gave an update on the numerical boundary conditions that he has developed for modeling the Tibbar Plasma Technologies system, which has helical electrodes and a resistive wall. The primary new development is that the implementation now allows time-dependent normal-B along the walls. A 2D Poisson equation is solved to find the potential along the wall, given the distribution of normal-J. This solver writes a file for use in NIMROD. The Green's function method is used to solve the external magnetic potential. Barnes' approach handles corners, it leads to a symmetric system, and both the magnetic potential and its derivative converge quadratically. It may serve as a more robust and accurate replacement for the GRIN Green's function implementation.

Kyle Bunkers presented an update on the computation of forcing on walls that results from tokamak vertical displacement with asymmetries. He reviewed the Pustovitov approach (Nuclear Fusion 55, 113032), which uses the fact that the plasma has negligible mass and that the plasma and wall form a closed system with respect to electrical current. The net force can then be computed from the Maxwell stress along the outside of the wall. Bunkers described the implementation of the force computation in NIMPLOT, which is applied to the outer vacuum region. He also presented a verification test of the horizontal forcing computation, where an analytical solution is easily obtained. The NIMPLOT result converges to the analytical value.

Computational topics:

Brian Cornille gave a brief update on the development work that he did on the BLAST code this past summer at LLNL. The code uses vector finite elements that are based on the discrete de

Rham complex. Magnetic evolution is a relatively recent addition, and Cornille added the remap step for the magnetic field, as needed for the code's arbitrary Lagrangian-Eulerian (ALE) method. After describing the ALE formulation, Cornille showed results from a blast-wave test, where magnetic field imposes spatial anisotropy in the propagation of the shock.

Jacob King discussed plans to optimize performance on new computer architectures, include the NERSC Cori Phase II machine, which uses Intel Knights Landing processors. The optimization work is supported by the new SciDAC grant for the Center for Tokamak Transient Simulation (CTTS). The personnel include Xiayoe Li and Scott Williams of LBL and Mark Shephard of RPI to help with the applied math and computer science aspects of the project. King reviewed slides from Li and Williams that were presented to the CTTS team. Of particular interest is Li's development of Strumpack, which is a flexible multi-frontal solver that is expected to be more efficient for preconditioning parallel algebraic systems than SuperLU_DIST. Williams' recommends manual instrumentation for optimization work and using the "roofline" method to identify sections of a code that are theoretically capable of running faster. King also discussed NIMROD's computational infrastructure and suggested that now may be a good time to develop a more abstract version to facilitate optimization and development.

Applications:

Carl Sovinec gave an update on simulating asymmetric vertical displacement events (AVDEs). The presentation had been given at the recent International Tokamak Physics Activity (ITPA) meeting on MHD and energetic particles. A new feature that has been used in computations run since the August team meeting is a hard floor on density and temperature at the 3D node locations. These floors facilitate running nonlinear computations through the thermal quench and into the current quench. Findings include increased growth of edge kink (peeling) modes through contact with the wall, bumps in plasma current during the thermal quench, and net horizontal forcing in computations with asymmetry. There is also evidence of net reversed parallel current density due to kink motions. Whether these reversed currents would last through the current quench remains to be answered.

Bick Hooper presented his most recent study of transient coaxial helicity injection (TCHI) in NSTX. A new aspect is more realistic modeling of density evolution with sourcing through the injector slot. The computations have temperature evolution with Braginskii parallel thermal diffusivity, fixed perpendicular diffusivity, and radiation modeling. The simulations are intentionally driven harder than the experiments had been. Hooper finds that the primary effect of the density evolution is the local change in Ohmic heating density, relative to other terms in the energy density equation. The resulting temperature profile is hollow during injection, due to the Ohmic heating along the current bubble, where density is less than its maximum value (inside the bubble). In 3D computations, the asymmetric instability from the bubble current leads to localized scattering of magnetic-field trajectories. Nonetheless, closed surfaces still form inside the layer of edge scattering.

Fatima Ebrahimi presented her study of edge modes. She noted the frequent occurrence of current sheets in TCHI, VDEs, and H-mode edge profiles, and the plasmoid instability leads to current filaments. She has investigated the process with "force-free" NIMROD computations of TCHI, where density and temperature are not evolved. The current sheet strength (in terms of $J_{\|}/B$) increases with increasing S, and this leads to linear growth rates increasing with S. Nonlinear saturation of the instability includes formation of current filaments that propagate away from the current sheet.

Torrin Bechtel gave an update on his study of beta limits in stellarators. His recent computations have focused on his l=2, m=10 configuration, and he has scanned heating rates and both parallel and perpendicular diffusivity values. In computations with imposed periodicity that matches the *m*=10 fields, increasing heating leads to increasing Shafranov shift until 50% shift is approached. The obtained beta value is sensitive to the diffusivity parameters, so Bechtel is considering more realistic closures, starting with Braginskii. He also summarized efforts to compute the toroidal flux function. The field-line tracing method suggested by Sovinec has an inherent flaw for the stellarator computations. Instead, Bechtel is now making the triangulated surface-integral computation more accurate by using noble irrational field lines to bound triangulated regions. Finally, divergence errors near the boundary may lead to the drift in resulting beta value when continuing reduced periodicity computations with full periodicity. Bechtel is trying to further suppress edge currents to avoid generation of these errors.

Matt Beidler gave a dry-run talk of his presentation for the MHD control workshop. He described simulations that consider the interaction of a tearing mode with a time-dependent magnetic perturbation. A review of the analytics associated with the so-called Taylor problem in a slab shows that the nonlinear state bifurcates and depends critically on the electro-magnetic and viscous force balance. However, these theoretical considerations only address steady-state solutions. Beidler has developed extensions to the theory that consider the time-dynamic evolution and compute final bifurcated state given a time-dependent magnetic perturbation. NIMROD computations compare favorably with these analytics and demonstrate that there is a threshold in the time-dependent perturbation amplitude to move from a screened state to a penetrated state with a transient magnetic perturbation. The dynamics resemble dynamics in the DIII-D tokamak, where an edge-localized mode with an associated large transient magnetic field precedes penetration of a resonant magnetic perturbation. Future work will focus on incorporating more realistic geometric configurations into the analytics and computation that will facilitate experimental comparisons and predictions.

Ping Zhu gave a dry-run talk of his invited talk for the APS-DPP conference. The presentation reports on density and impurity effects on edge localized modes with linear NIMROD computations. With the cbm18 circular-cross section limited equilibrium, it is found that shear-flow is stabilizing to high-*n* modes while destabilizing low-*n* modes. Additionally, the stabilizing influence of the shear flow is stronger at high density and this effect is independent of using single- or two-fluid model equations. In order to understand the relative importance of core versus edge fueling, studies with varied density profiles show that higher edge-density values lead to a larger stabilization relative to increasing the core density. A second part of the talk considers ELM suppression on NSTX through Lithium conditioning. By studying profiles from NSTX experiments with and without Lithium conditioning with linear two-fluid NIMROD computations, Zhu concludes that the low-*n* modes are stabilized by resistivity resulting from an enhancement of the effective average charge number.