NIMROD Team Meeting Agenda

November 3, 2018 Portland, Oregon

Computational development:

Brian Cornille described his numerical investigation of basis functions for magnetic field in models that have the Hall term. He is using time-dependent electron-MHD as a starting point, because it is the simplest plasma model that has the Hall term. He is using the MFEM library from LLNL to quickly test different expansions and formulations, and so far he has implemented Galerkin formulations with $H(\text{curl})$ and with H^1 elements. The latter formulation has an explicit divergence constraint, but the former does not. Both reproduce linear whistler waves propagating along background field that is aligned with the mesh. He will next investigate cases without mesh alignment and with different formulations for the first-order least-squares method for comparison with the Galerkin formulations.

Physical model development:

Jacob King summarized work on modeling the QH-mode during the broadband-MHD regime in DIII-D discharges. He made minor adjustments to the fitted equilibrium to compensate for the relaxation that is already represented. He stated that using just the **E**x**B** flows assists comparisons with experiment. The new case shows somewhat slower dynamics than the previously studied case. Alexei Pankin is now the lead person on this modeling effort, and plans include two-fluid modeling and comparing real and synthetic beam-emission spectroscopy measurements. King also presented a second topic, addressing the potential pitfalls of having significant implied sources with the force-balance/steady-state fields in NIMROD computations. He is developing more realistic sourcing, including edge neutrals and core neoclassical effects for the axisymmetric fields.

Kyle Bunkers gave an update on his development of boundary conditions that represent magnetized pre-sheath (MPS) conditions. The work is motivated by findings on sensitivity to temperature boundary conditions in computations of axisymmetric VDE. He is adapting the Loizu's model that order terms by the ratio of the sound gyro-radius and the transverse length-scale. Bunkers has incorporated the lowest-order flow and two-temperature conditions and has compared this model with various simplifications of it, including the idealized limiting cases of insulating and Dirichlet cold-wall conditions in single-temperature modeling. Between these two limits of the single-temperature modeling, results with MPS modeling were expected to be closer to the insulating-wall results, but that is not what has been found.

Jeong-Young Ji presented his analytical and computational work on parallel kinetics with developments for closure relations and transport for toroidal plasmas of arbitrary collisionality and aspect ratio. He applies the generalized moment methodology and has extended to the collisionless limit by matching to results that are derived with a simple Krook collision operator. The analytical results with inhomogeneous $|\mathbf{B}|$ are determined with a Fourier expansion in poloidal angle. Ji has checked the convergence of the parallel heat flux and parallel friction, decomposed by different physical drives at varying levels of collisionality, when varying the number of terms in the expansion. His next steps will focus on developing closure relations from his analytical results.

Andrew Spencer has improved the implementation of the Chapman-Enskog-like drift-kinetics, so that the temperature and the perturbation of the distribution function can be advanced in a numerically practical way. He is testing the implementation on heat flow through a magnetic island in slab geometry. The nonlinearity in the DKE is solved implicitly using Newton's method to converge the algebraic system, which reduces the computation time by about 50%. His approach to preconditioning the linear part of the system is to sub-divide it into blocks for T and for each speed value in the expansion of δF. Coupling among different speeds is relatively weak and is not needed in the preconditioning. This work enables stable convergent time-advance of the DKE system at large time-step values.

Eric Howell described the challenges in modeling NTM island evolution and locking that leads to disruption. The range of time-scales is large, and different forms of MHD activity, such as sawteeth and ELMs, may occur during the lifetime of an evolving island. To enable practical modeling, he is resurrecting a heuristic closure and has modified FGNIMEQ. The heuristic closure was derived by Chris Hegna and was implemented during the early days of the NIMROD project by Tom Gianakon. It provides a drag force on poloidal flows and on poloidal current and is capable of reproducing neoclassical tearing and flow damping. The changes to FGNIMEQ allow Howell to alter experimentally fitted equilibrium profiles, while maintaining its shape, in order to avoid sawteeth and, with some help from imposed edge flow, ELMs. The development extends the PD controller in FGNIMEQ to respond to a specified number of shape control points.

Applications:

Eric Emdee is applying NIMROD to examine MHD during lower hybrid current drive (LHCD) in Alcator C-MOD. He showed experimental results from two discharges that are very similar, where one has MHD activity and the other does not. LHCD tends to increase current density in the edge region and reduce it in the core, which can take the 1/1 mode out of resonance. Emdee has analyzed the stability of reconstructed equilibria. The Mercier diagnostic indicates stability to interchange over most of the profile. [Howell commented that the diagnostic needs to be updated, however.] Time-dependent computations have been applied to check for current-driven modes. When considering the parity of computed eigenmodes, the case that crashes experimentally seems to have a tearing mode at the time of the crash. However, the growing mode seems to lose its Lundquist-number dependence over time slices leading up to the crash. Future work includes more direct comparisons between laboratory and synthetic diagnostics.

Charlson Kim presented his work on modeling shattered-pellet injection (SPI) for disruption mitigation. He uses a particle-based method to model the kinematics of the ablation cloud, which provides the source location for the injected impurities. Time of flight and the duration of a sequence of cloud sources are key parameters for this aspect of the simulations. Ablation rates are computed from Paul Parks' model, and ionization and radiation are calculated by the KPRAD code. To avoid prohibitive run-times in 3D computations, Kim sets the magnetic Prandtl number to large values and limits the toroidal resolution. Comparing with DIII-D results shows good agreement on thermal quench times and on the fraction of energy radiated for injections of different He - D_2 mixtures. An exception on the agreement is the energy radiated for pure-D_2, where non-injected impurities dominate in the experiment. Radiation in the experiment also tends to be more concentrated temporally. Kim has also started running computations for ITER equilibria.

Debabrata Banerjee is applying NIMROD to model massive gas injection (MGI) using the KPRAD radiation coupling. He simulated a specific discharge (71230) in EAST, which had He gas injection. Relative to the experiment, his simulation had a faster thermal quench (TQ) but a longer current quench (CQ) by about a factor of two, each. There are radiation peaks over time, which is qualitatively similar to the experiment. In the simulation, mode excitation decreases temperature, but that also increases Ohmic heating, and the heating exceeds radiative losses. Banerjee is also running computations for the CFETR design. He has considered two possible equilibrium profiles and finds that the larger equilibrium has a significantly slower CQ. The early reformation of broken flux surface in the advanced CFETR scenario (larger size) probably causes the CQ to be slower.

Ping Zhu presented simulations of asymmetric VDE on behalf of his student, Haolong Li. They modeled EAST discharge 71230, including a resistive wall, and the simulation shows vertical motion with asymmetry that results after the thermal quench is over. A case with a conducting wall also shows vertical motion with asymmetry after the TQ and at the start of the CQ.

Zhu also presented work by his student X.-T. Yan on plasma rotation that results from magnetic perturbation. The underlying physics is neoclassical toroidal viscosity (NTV), and the net rotation is the result of the sum of NTV forces over all species. The group has incorporated the model that was first developed by Shaing and later extended by Sun. Their NIMROD computations start with a circular cross-section toroidal equilibrium that is computed with Zakharov's ESC code, and time-dependent computations include an m=2, n=1 resonant perturbation. They find that electron NTV dominates at low collisionality, and ion NTV dominates at high collisionality. When the perturbation is sufficiently large, the computed rotation saturates at the generalized offset rate.

Torrin Bechtel presented an update on his study of pressure-driven effects in toroidal stellarator configurations. His recent computations have several improvements that avoid errors in the magnetic-field representation. He first showed that increasing beta (via increased heating) leads to increasing Shafranov shift that eventually degrades equilibria computed with limited (stellarator) periodicity. This behavior follows expectations from analytical theory. Bechtel also compared results with varied levels of perpendicular and parallel thermal conduction coefficients and with temperature-dependent Braginskii coefficients. Bechtel has now run computations with full toroidal resolution, which allows instability that breaks the stellarator symmetry. He is finding interchange-like modes, whose growth is sensitive to thermal conduction, but the full-resolution cases are computationally intensive.

Cihan Akcay gave an update on the boundary-integral resistive-wall implementation that he and Dan Barnes are improving. The external vacuum response computation uses a special numerical integration method to handle the source-observer singularity in the matrix integral, while being capable of high-order accuracy. Necessary interpolations are performed on the vacuum side. The implementation for n=0 and n=1 has been tested on randomly located coil fields and on an m=2, n=1 resistive wall mode, and convergence is better than with the GRIN implementation. An analytical verification problem using toroidal ring functions is being developed.

Akcay also presented his study of nonlinear locking to magnetic perturbations in the presence of magnetic resonances and equilibrium flow. The locking is predicted to be at nonzero velocity when there are diamagnetic drifts or with the Glasser pressure-related effect that yields complex eigenvalues for tearing. Akcay reviewed the steady condition, where viscous and electromagnetic forces balance. He emphasized that having complex eigenmodes implies that locking occurs at nonzero frequency. He is running NIMROD computations for cylindrical equilibria with hollow pressure profiles in order to see pressure-stabilization in that geometry.

Linear computations show the transition from pure growth to stabilized rotation with increasing pressure. Nonlinear computations show locking, so far without rotation, which might be an result of the pressure flattening due to parallel conduction along the island, and the Scott effect occurring through MHD physics without diamagnetic rotation.

Ge Wang presented an update on his computations of resistive wall modes (RWMs) in circular cross-section toroidal equilibria. He first reviewed the theory of RWMs and described a Garafalo, *et al.* publication on the RWM causing a disruption in DIII-D. He also described the model, boundary conditions, and the resistive-wall implementation that uses meshed external-vacuum representations. Wang reviewed results for a cylindrical benchmark and then presented a new equilibrium for toroidal computations. The fastest-growing mode in the toroidal case is a (2,1), and its growth rate is sensitive to wall resistivity. However, shorter wavelength edge modes are also linearly unstable, and they may be an impediment to running nonlinear RWM computation with this equilibrium.