NIMROD Team Meeting Minutes, November 14, 2015
Savannah, Georgia

Computational development:

Carl Sovinec presented recent development for the free-boundary capability in NIMEQ. The initial free-boundary implementation updates surface flux values as an outer iteration around the iteration for the nonlinear FF' and P' terms. A new method simultaneously solves coefficients of an expansion of J_ϕ/R and coefficients of $\Lambda = \Psi/R^2$, including surface-Λ values, as part of the inner linear system. This significantly reduces the total number of iterations required to achieve a given relative tolerance, and it permits robust convergence to small tolerance levels that had not been obtainable, previously. The new free-boundary capability is being applied in pre-processing for disruption modeling.

Physical model development:

Jeong-Young Ji presented new work for parallel electron closures that extends his previous results to conditions with effective charge $Z > 1$. This effort is part of his growing collaboration with plasma groups in Korea. The analysis uses Ji's general moment equations to determine closure relations for steady conditions at arbitrary collisionality. The closure relations are integral, and algebraic solutions of the moment equations provide the kernel relations for their integrands. Ji uses a fitting procedure to extend the solutions to the collisionless limit and to provide a relatively simple form for integral computations. A 7-parameter fit is used for arbitrary Z-values, which do not need to be integers.

Applications:

Fatima Ebrahimi described simulation results for the redesigned coaxial helicity injection (CHI) that will be used in NSTX-U. A significant finding is the sensitivity of flux closure to the injector-flux footpoint width. Ebrahimi's simulations of the narrow footpoint configuration show 75% closure with nearly 100% of the plasma current flowing in the closed-flux region after the voltage pulse. Simulations of the wide configuration only show 35% closure. At large S-values, there is a transition to plasmoid instability, where magnetic reconnection may be a combination of spontaneous reconnection from the instability and driven reconnection from evolution due to the transient current drive. Ebrahimi is also investigating macroscopic instability in CMOD equilibria that represent conditions with and without LHCD. Different profiles from experimental reconstruction are found to be stable, unstable to 2/1 or 3/1 tearing, or unstable to a global interchange mode.

Bick Hooper is continuing his study of CHI in NSTX, now focusing on non-axisymmetric evolution. The work is motivated by a discrepancy between axisymmetric simulation results and reported behavior in the experiment. Hooper had previously found instability to an n=1 mode that lies along the expanding current sheet and has high-m. With relatively weak injection, the mode saturates benignly. At strong drive, which leads to larger temperature, he finds that it contributes significantly to magnetic reconnection while broadening the current layer. He has used axisymmetric fields taken from nonlinear simulations to provide equilibria for linear computations. This allows him to assess the influence of different physical effects. The mode is driven by current and is not qualitatively different when changing viscosity, resistivity, and particle diffusivity. For comparison, Hooper has developed an analytical slab model with a current layer. He has found an ideal growing mode, where wavenumber along the sheet appears to be related to the current layer width, consistent with the large-m observed in simulations.

Kyle Bunkers presented recent work on modeling external kink in NIMROD, as needed for simulating 3D evolution that results from or in vertical displacement events. The first configuration is cylindrical with uniform axial current density and large aspect ratio. Bunkers considers three plasma-q values in linear computations and chose a q_{pl}=1.8 equilibrium for a nonlinear convergence study. The computations require 22 Fourier even-m components, $m \le 42$, to distinguish the plasma-vacuum interface late in the nonlinear evolution. A circular cross-section limited equilibrium provides a test of toroidal external kink. Bunkers also checked the double-null diverted equilibrium that has been used for VDE demonstration, but it is linearly unstable for ballooning and is, therefore, not suitable for 3D external kink computation.

Josh Sauppe described two completed linear studies. The first verifies NIMROD on resistive drift waves in slab geometry. Sauppe worked with Vladimir Mirnov on the analytical dispersion relation. They consider the two-fluid model with cold ions and isothermal electrons, which exhibits drift waves but avoids complication from gyroviscosity and magnetization heat flow. The analytics are simplified for large $k_\perp a$ and small $k_\| a \ne 0$. The NIMROD computations and analytics provide results that are quantitatively close, including variation with the wavenumber vector and stabilization due to shear, for sufficiently large electrical conductivity. The second topic is toroidal effects on the linear tearing modes of RFP equilibria. This is important for comparing phase relations of magnetic fluctuations observed along the wall in MST with results from cylindrical computations. Sauppe considered different classes of equilibria for producing core (m=1) and edge (m=0) modes, because the latter are stable with respect to tearing in equilibria that are not specially prepared. Computed phase shifts among fluctuation components for m=1 are consistent with MST measurements. Experimental data for m=0 is not as detailed, but there appears to be greater discrepancy, possibly due to the equilibrium parameters needed to generate linearly unstable m=0.

Tom Jenkins provided an update on giant sawtooth (GS) modeling, including contributions from Eric Held. The large initial distortions found previously with the PIC module have been tracked to the CGL option for the hot-particle pressure. Jenkins switched to using the full-tensor option to make progress while working on the bug. He is also checking normalization factors and is adding commenting to the hot-particle module. He finds that the ability to compare results with Held's continuum closure facilitates the effort, and corrections to the PIC computations have led to better agreement between the two different numerical models. Held has compared two different equilibrium hot-particle distributions for the delta-f computations and finds that the linear computations are not sensitive to the pitch-angle dependence of the equilibria. He has been running GS computations with the RF tail distribution and finds further reduction of sawtooth growth rates due to the tail particles.

Eric Howell is benchmarking two-fluid internal kink dynamics, using the '92 Zakharov and Rogers paper for analytical results, which shows that fluid predictions for $\rho_s > \rho_i$ are very similar to kinetic results. The equilibria (with and without a pressure gradient) are cylindrical and have large magnetic shear to keep the inertial and resistive layers small with respect to the equilibrium scale. He has made progress when using blocks with trigonometric cardinal functions to avoid mesh-scale oscillation that occurs with our standard spectral elements. Howell has verified, quantitatively, the transition from resistive to ideal internal kink with increasing S for MHD. With two-fluid computations and uniform pressure, his computations obtain the transition to collisionless $\rho_s^{2/3} d_i^{1/3}$ scaling at large d_i and the ZR prediction of a flow layer that is larger than the current layer. With the equilibrium pressure gradient, Howell finds that drift effects reduce the growth rate at small d_i, but a second mode appears at large d_i with largely parallel flow inside q=1.

Nick Roberds is studying sawteeth in the Compact Toroidal Hybrid experiment, where the 5-period stellarator coils impose significant asymmetry on the magnetic field, independent of any macroscopic dynamics. He finds that n=1 modes lead to sidebands of the n=5 harmonics. His MHD simulations show complete reconnection, either with or without the stellarator transform. Numerical resolution is challenging. Roberds finds that unphysical stochasticity results if fewer than 86 toroidal Fourier components are used. The standard (2D) semi-implicit operator also requires small Δt to achieve convergence, and matrix conditioning is also a concern. Physics-wise, Roberds finds that increasing the stellarator transform decreases the sawtooth period, as has been observed experimentally. This is attributed to concomitantly smaller minor radius and energy confinement, hence lower temperature and larger resistivity.

Valerie Izzo presented her recent progress on modeling massive gas injection (MGI) for disruption mitigation. She previously showed the importance of including rotation when making comparison between simulation results and experiments that impose n=1 field to control the phase of MHD activity. The previous simulations had large viscosity throughout the outer region. Her recent simulations do not have the large viscosity, but the modeled impurity source presently assumes that the injected velocity matches that of the plasma, so it inadvertently adds significant momentum. Nonetheless, the computations again show a significant drop in core rotation that precedes the impurity penetration. The next step is to add a momentum correction term to avoid the unphysical momentum source.

Torrin Bechtel is studying pressure-driven evolution in toroidal stellarator fields, using the CTH field as a starting point. A significant part of his effort to date has been dealing with numerics. He finds that there can be significant divergence error near the external coils in NIMROD's magnetic field expansion. The error decreases with increasing resolution, but a potentially more efficient initialization may be possible. Many of his computations show a very large interchange mode that leads to negative density. A recent computation using the "fix profile" continuity option and much smaller heating rate, which targets $\beta_{pol} = 1$, is more robust and shows the development of a sequence of magnetic island chains.

Jake King presented work on edge linear modes with the "Meudas" equilibrium and on representing equilibrium scrape-off layer (SOL) current and pressure in our steady-state fields. For Meudas computations, King generally finds good agreement between NIMROD linear MHD results and ELITE. However, the choice of n and T profiles, which are not constrained by force balance at fixed nT, have a large influence on the linear spectrum. Large-n modes are sensitive to resistivity, hence the T profile. Moreover, two-fluid computations are very sensitive to these profiles. King finds that the simple drift ideal ballooning relation over-predicts the drift stabilization that is observed in his computations. He finds that the Hastie, et al., prediction using the local approximation also over-predicts stabilization. Regarding the SOL work, King had previously extended fitted pressure and current profiles across the separatrix to avoid the jumps that are present in EFIT reconstructions. This leads to physically reasonable SOL current and pressure distributions. He is now using the NIMNOSTICS χ^2 computation to compare the quality of resulting equilibria with experimental measurements. The SOL smoothing improves the Thomson T_e match but not the Thomson n_e match. Magnetic coil comparisons are also a little worse, but the offending coils tend to be distant (below the divertor).

King presented Andi Becerra's linear computations for resistive wall mode (RWM) stability in NSTX profiles. The computations build upon the previous cylindrical RWM benchmarking that uses GRIN for the resistive-wall/outer vacuum response. The computations also use the "ideal-like" option for computing the linear modes. The modes are stable with a conducting wall. Computations at different values of β_N use equilibria from different times of the same NSTX discharge. There is a strong dependence on viscosity, but Becerra is able to extrapolate to the marginal stability point at each viscosity value, and the predictions for the marginal β_N-condition are robust. Benchmarking with Steve Sabbagh's DCON results is underway and looks promising.

Kyle Morgan summarized his recent work on simulating HIT-SI and the new 3-injector variant. He finds that the 0-β Hall-MHD computations agree well with HIT-SI results at low frequency, particularly when using specific flux-current phase offsets from the experiment. Agreement of the 0-β modeling is not as good for higher frequency experiments. Simulations at finite-β show the outward magnetic-axis shift that had been missing, although it is again lost with larger parallel thermal conductivity that is thought to be more realistic. The results are sensitive to viscosity and to electron mass, which Morgan has rescaled to avoid artificial effects. The simulated temperature increases with increasing drive frequency, which is consistent with experiment. Simulations of the 3-injector experiment consider the different flux-current phase relations that have been tested experimentally. The simulations show a low-frequency (lower than injector) relaxation oscillation that also is observed in experiment.

Simon Woodruff described 3D simulations of spheromak compression. The design compresses the spheromak in approximately 10 μs to achieve kV-level temperature. Rotation is intended to drive strongly sheared flow that will help stabilize the spheromak during compression. The compression is achieved through time-varying vertical field, which is applied with a segmented electrode arrangement.