NIMROD Team Meeting Minutes, April 30, 2017
Annapolis, Maryland

Computational developments:

Carl Sovinec presented work on computation-related topics: avoiding negative densities in VDE computations, converging nonlinear external kink computations, and testing high-order temporal integration. VDE computations that start from a double-null configuration tend to encounter negative density in the private flux region. The situation improves when increasing edge resistivity, but this is numerically costly. Using a moderate level of parallel viscosity helps and does not distort the MHD dynamics. Modeling bubble-swallowing as the highly nonlinear consequence of external kink is demanding with respect to spatial resolution. For the cylindrical problem being considered, results with $0 \le m \le 85$ (Fourier used for azimuthal angle) and quadratic dealiasing are visibly better than lower-resolution results, including $0 \le m \le 64$ with numerical filtering at large-*m* but no dealiasing, otherwise. A comparison of fourth-order, 3-stage diagonally implicit Runge-Kutta methods with Crank-Nicolson on passive advection shows that while DIRK methods can be run accurately at larger time-step values, accuracy per unit of computational work is not obviously better.

Jacob King has invested time in getting NIMROD running on the new KNL Cori Phase II system at NERSC; a similar system is installed at ANL. The computing paradigm is massive concurrency, but the architecture is quite complicated. King used plots from NERSC presentations to describe the architecture, the memory layout, and different options with respect to memory and how data is passed through the 2D mesh interconnect. While examining NIMROD performance on Cori Phase II nodes, he also compared swapping the MKL Pardiso linear algebra library for SuperLU_DIST. The former has Intel-specific optimization, but King found that results are less accurate (at least with standard settings on NIMROD's complex matrices). The number of possible settings (hardware and MPI vs. threading) makes it difficult to test all possibilities. Best performance so far is achieved with SNC/NUMA memory clustering, all MPI, and 64 of the possible 272 CPUs. However, King is going to try compiling with Intel in place of GNU to see if better optimization is available. On a somewhat related topic, he also requested that users submit additional test cases to the regression-test library.

Physical model development:

Eric Held discussed the drift-kinetic equation implementation in NIMROD and focused on subtleties with respect to Hazeltine's form of the DKE. There are terms that are proportional to the temporal derivative of magnetic moment that are often dropped. However, there are some cancellations with contributions from $J_{\|}$, which correct an apparent singularity at 0 pitch-angle. Held finds that this correction improves previously reported computations. He is also investigating what it will take to have implicit coupling between the DKE solution and the flow-velocity advance.

Valerie Izzo is coupling her model of runaway electrons in NIMROD to the AMCC Monte Carlo code from E. Hirvijoki. Conditions in ITER motivate this, since Coulomb collisions will be more important than curvature-drift loss, and secondary (knock-on avalanche) electrons will be very important. The existing RE model is the only one that is coupled to an evolving MHD solution. However, it uses a model that makes assumptions regarding the RE distribution, which may not be valid in ITER. Coupling with AMCC (part of SCREAM project) will allow modeling of large-angle scattering. For computational efficiency, it is presently invoked once per NIMROD time-step, despite large RE displacements. Izzo is presently testing the coupling on relatively simple problems but will rerun some disruption mitigation simulations to investigate the effects of large-angle scattering.

Applications:

Torrin Bechtel reviewed the goals and recent findings from his computational study of beta limits in stellarators. He is focusing on an l=2, n=10 configuration that has enough rotational transform to be representative. He will be benchmarking his results with Suzuki's HINT2 relaxation code. Bechtel's NIMROD computations are showing that when the n=10 symmetry is imposed, for a given level of heating, achievable beta depends on the $\chi_{\|}/\chi_{\perp}$ ratio. When heating is varied at fixed $\chi_{\|}/\chi_{\perp}$, beta increases until the Shafranov shift becomes close to 1/2 of the minor radius, at which point MHD activity causes NIMROD's time-step to drop. In order to compare with HINT2, the toroidal flux function is needed. To determine it as an option in NIMPLOT, Bechtel has installed Josh Sauppe's vector-potential computation into NIMPLOT, and he uses field-line integration to find $\oint \mathbf{A}\cdot d\mathbf{l}_{pol}$. Bechtel also presented work on estimating the effective perpendicular thermal diffusivity.

Matt Beidler presented his study of forced magnetic reconnection and the mode-locking bifurcation. He first reviewed previously presented results for linear computations and analysis in slab geometry, which is now published in Physics of Plasmas. He noted the hysteresis effect that is apparent when gradually increasing and then decreasing a magnetic perturbation on a flowing MHD-stable configuration. The difference between linear and nonlinear predictions increases with increasing perturbation amplitude. Beidler also described the cylindrical benchmark comparison that is being pursued with both NIMROD and M3D-C1. Linear flow screening computed by the two codes is very similar, including the variation of **B**-perturbation and phase shift as flow rate is varied. Beidler has also revised the Fitzpatrick cylindrical flow-response analysis to remove the ad hoc poloidal-flow damping, which is not in our cylindrical computations. His nonlinear cylindrical results are consistent with the analytics. New work includes setting-up a toroidal profile that is suitable for benchmarking.

Eric Howell is conducting a study of disruptivity in Auburn's Compact Toroidal Hybrid as a function of the fraction (f) of rotational transform from external helical coils. CTH experiments show that a modest level of external transform allows stable operation with $q(a)<2$, which is not possible in conventional tokamaks. MHD activity does arise; 3/2 modes are common, but disruption only results when the 4/3 mode appears. Howell is using experimental reconstructions from V3FIT. Low-f cases are easier to resolve and are more interesting with respect to disruption. Howell has adapted a 3D current source to maintain the profile more reliably than applying a loop voltage. Howell's simulations show n=2 and n=3 modes that seem consistent with experimental observations. The destruction of symmetry-preserving (n=5 for CTH) islands by the n=2 and n=3 modes leads to an MHD event. Howell also mentioned work by T. Markham and L. Guazzotto to add flow profiles to NIMEQ.

Omar Lopez Ortiz presented his analytical work on high-beta equilibria with flows. The model is by Hameiri and combines the Grad-Shafranov and Bernoulli equations, such that there are now five specified functions replacing GS's two. Lopez is applying a large aspect-ratio expansion to find analytical solutions. He is applying the ordering directly to the variational principle to retain all terms at a given order. The system of interest requires solving through second order. Lopez uses polynomial expansions for the five specified functions, and he has worked-out solutions for cases with circular, elliptical, and D-shaped cross sections. Comparison with results from Guazzotto's FLOW code, where the equations are solved without approximation, confirms the analytics and shows where the approximations are valid.

John O'Bryan reviewed his numerical optimization study of coaxial helicity injection spheromaks for neutron source development, which has been supported by the DARPA program. He focused on two topics: multi-pulse refluxing and compression after formation. O'Bryan chose to model SSPX discharge 19719 as a good example of high-performance (T_e~500 eV) multi-pulsing. He uses his full Braginskii model in NIMROD with a nonlinear boundary condition on density at the throat of the gun to allow mass to push out of this region without going negative. His simulations show that individual pulses in the sequence do not always excite the column mode that leads to flux conversion. After a given pulse, the discharge recedes back toward the gun, and the column mode does not get excited until the third pulse. The computations reproduce the voltage trace and magnetic signals measured in the experiment, despite not modeling the sheath voltage. To optimize performance, O'Bryan has run simulations that scan the injector-current ramp rate, the level of injected current (for a given amount of flux), the amount of flux keeping $(J_{\|}/B)_{inj}$ fixed, and the rate of injector-current decay. A notable finding is that energy efficiency increases with increasing bias flux at fixed $(J_{\|}/B)_{inj}$. The flux-compression computations use a set of discrete external poloidal-field coils with currents ramped in time. They are used when modeling a bowtie flux conserver and the SSPX-shaped chamber. Results are encouraging in that compression helps stabilize kink, and temperatures in excess of 1 keV have been predicted.

Carl Sovinec described new modeling activities for experiments in the Madison Plasma Dynamo eXperiment chamber. The spherical geometry is meshed by assembling new generalized quadrilateral regions using the Stitch code. Limitations with respect to element quality and seaming were noted. Computations for magneto-rotational instability experiments use a weak bias field that is directed from one pole to the other, and electrodes induce a quadrupolar current-density configuration. With increasing injected current, MHD computations push poloidal flux toward the equator. Two-fluid results are sensitive to injector polarity, and the correct polarity pinches poloidal flux toward the axis. Computed toroidal flow profiles largely show rigid rotation, but flows measured in experiment decrease toward the equator, at least in the outer part of the plasma. Collisions with neutral are thought to be important, and a drag term will be added to the modeling. Computations for Parker-spiral experiments have a central core that houses a small dipole coil near the center of the sphere. Current is drawn directly to cathodes on the central rod from anodes at the equator. The resulting flow stretches the dipole field, creating the characteristic spiral fields outside the Alfvén surface, where flows transition to super-Alfvénic. These simulation studies are being pursued by MPDX graduate students Ken Flanagan and Ethan Peterson.