NIMROD Team Meeting Minutes, April 2, 2016
Madison, Wisconsin

<u>Computational development:</u>

Carl Sovinec presented new development for the NIMEQ Grad-Shafranov solver. The changes incorporate an approximate-Newton method to improve convergence during nonlinear iteration. One aspect is using the residual-based formulation as a basis for the iterative solve. Numerical differencing of the FF' and P profiles is applied when solving the Jacobian matrix for Newton's method via matrix-free Krylov iteration. The approach seems effective in both fixed- and free-boundary tests, but more work is needed to achieve second-order convergence when a target-I_p is specified.

Eric Held described some important details of the formulation for drift-kinetic modeling in NIMROD. He has used pitch-angle and a normalized speed parameter as independent coordinates that are more efficient than the conventional energy/magnetic-moment variables for global computations where T varies significantly. Using spectral elements over pitch-angle with non-uniform meshing adjusted for the trapped-passing boundary is efficient, but it implies additional terms in the chain rule for evaluating pitch-angle derivatives. With the appropriate terms now in the code, Held is revisiting the NEO benchmarks to test convergence with flux-surface-adjusted meshing. He is also considering static condensation for the pitch-angle elements.

Jacob King presented neutral-species model development by Univ. of Washington student Sina Taheri. Taheri is working with Uri Shumlak and King to implement a dynamic neutral-fluid model that includes ionization, recombination, and charge-exchange effects. Similar to NIMROD's choices for closures such as the thermal conductivity, there will be options for different levels of modeling with respect to ion-neutral cross-section physics. So far, the neutral continuity equation is implemented, and there is progress on the neutral momentum-density equation. Taheri has laid out a plan for the next steps, including tests for verifying the implementation.

Valerie Izzo gave an update on the installation of NIMROD as a module in the OMFIT workflow manager, which she first presented at the 2015 summer meeting. New functionality includes setting parameters for restarts and for running scans of parameters, including co-dependence of scanned input parameters. There are also new archiving features that are helpful for 3D fields and to create editable plots.

<u>Applications:</u>

Izzo also presented recent work in her extensive study of massive gas injection (MGI) for disruption mitigation. A new avenue is the effect of injection in pre-existing locked modes, which is a realistic scenario. She first summarized the impurity spreading without islands. Initial pressure balance on the plume is altered by radiative cooling, rapid parallel thermal conduction into the plume, and then pressure forcing the impurities along the field-lines. Toroidal effects can make the process asymmetric. With a pre-existing island, the timing and intensity of the radiation flash vary with the relative orientation of the plume and the island. This stems from changes in the spreading process and excitation of higher magnetic harmonics through the evolution. The presence of the harmonic also affects toroidal peaking and the fraction of energy conducted to the wall.

Joshua Sauppe is numerically investigating 3D magnetic reconnection and flux-rope merging in configurations relevant to the LAPD experiment. He is running kinetic simulations with the VPIC code starting with the 2D Fadeev equilibrium. In 2D cases, the kinetic simulations show rapid reconnection with islands apparently passing through each other. In periodic 3D simulations, there is both kink behavior and merging, and Sauppe is investigating what governs one behavior over the other. He is adding sources to compensate for end losses. Sauppe is also starting fluid computations with NIMROD, where realistic plasma parameters are more tractable.

Nick Roberds presented his work on simulating sawtooth oscillations in CTH. He considers four different magnetic configurations with varying levels of vacuum transform (ι_{vac}); all have low shear. He finds that linear growth rates increase with increasing ι_{vac}, and they scale with $S^{-3/5}$ at each level of ι_{vac}. Nonlinearly, the magnetic island driven by the 1/1 is evident, although it is highly shaped in cases with nonzero ι_{vac}. The time between relaxation events tends to shorten with increasing ι_{vac}, which is consistent with results from the experiment. Roberds has studied the convergence properties of computations with and without ι_{vac}. The 3D semi-implicit operator improves temporal convergence, but keeping a small isotropic contribution is important for matrix conditioning. Spatially, cases with ι_{vac} require a large number of Fourier components (~85) to resolve the tearing layer, which is not aligned with the toroidally symmetric mesh.

King ran through a practice of his Sherwood oral presentation on simulating broadband MHD during QH-mode in DIII-D. This "mode" of operation is of interest for ITER, because it arises with low torque and avoids harmful ELMing behavior. His profiles are taken from fits to a specific discharge, and King compares the nonlinear evolution with and without the experiment's flow profile. Without the flow, high-n activity dominates, and there is no saturation. With flow the simulations reproduce broadband fluctuations with lower-n dominating, and the nonlinear evolution saturates. The resulting particle transport is larger than the heat transport, hence a density pump-out effect. A manuscript on this work has been prepared (and has been accepted for publication in NF since the team meeting).

Kyle Bunkers presented work on applying NIMROD to nonlinear external kink evolution, where the plasma and vacuum regions are distinguished by temperature and Spitzer resistivity. The computations present two primary numerical challenges: tracking the plasma-vacuum interface in the Eulerian representation and resolving the distorted plasma shape with a Fourier expansion for the toroidal angle. Bunkers has investigated expanding the resistivity in Fourier components and dealiasing the resistive electric field term. He also tried using least-squares fitting of coefficients of Fourier components using additional toroidal grid points. Significant improvement in robustness has not resulted from either method. Bunkers is also adding spatially varying resistivity to the limited off-diagonal-in-n preconditioner for the **B**-advance.

Andrea Becerra gave an update on her numerical computations of the RWM. She reviewed the formulation and emphasized the different meshing schemes that are used by NIMROD and the external Green's-function code (GRIN). The first implementation placed GRIN mesh points according to NIMROD's nonuniform node spacing, but this performed poorly. Uniform GRIN meshing with cubic interpolation does converge, albeit slowly. Slow convergence is also observed with analytical (Bessel-function) responses for a periodic cylinder. However, using a meshed external vacuum region shows algebraic convergence that is close to the expected p+1 rate, where p is the degree of the polynomial basis. Becerra is re-checking the formulation and implementation that are used for the Green's-function approach.

Craig Jacobson presented a validation study for modeling macroscopic dynamics in RFPs. He described the selection of validation metrics and the development of a primacy heierarchy. The focus of the current effort is the scaling of magnetic fluctuations with S. The study includes two nonlinear codes, DEBS and NIMROD. Previous DEBS results have been evaluated with respect to MST in terms of the RFP sawtooth period and in terms of a composite metric. New computations are run from the paramagnetic pinch state. For different resonant m=1 tearing fluctuations, NIMROD S-scalings vary from -0.21 to -0.27 over 10,000<=S<=50,000. This low range of S can be matched by MST with its new programmable power supply. S-scalings from the experiment are stronger, but other factors such as pinch parameter, viscosity, and the external circuit for the toroidal field, i.e. control of reversal, may be influencing the comparison. A related study with information from the RELAX experiment (low R/a=2) is also underway.

Zz Riford presented recent work on modeling non-inductive startup in the Pegasus ST. He summarized some of John O'Bryan's results, which are the basis for the present study. While there is substantial agreement with the magnetics measured in experiment and simulation, the simulations produce temperatures that are lower--considerably lower than some experiments, depending on the configuration. Possible factors include viscous heating, the poloidal flux swing (not modeled), and the injector configuration. New computations use the two-fluid, two-temperature model and compare the influence of viscous heating from prescribed viscosity and from the full Braginskii viscosity, implemented by O'Bryan. The initial phase of the evolution shows significantly higher ion temperature with viscous heating, but results may still be well short of the experiment.

Torrin Bechtel gave an update on his study of magnetic-topology evolution and energy transport in toroidal stellarator configurations. He is considering two configurations, one based on CTH without inductive current and an l=2, m=10 torsatron generated with the IFT code. The latter has much more shear than the former. The computations have temperature-dependent resistivity and thermal conductivity and are driven by volumetric sources of heat. Temporal convergence with the CTH-like computations shows puzzling behavior, even when using the 3D semi-implicit operator. Confinement with the torsatron configuration appears more robust, but the additional resolution that is required seems prohibitive.

John O'Bryan reported on his study of spheromak formation and optimization, which is based on the SSPX configuration. He has modified the injector boundary condition to avoid some artifacts of the original prescription, and the computations can model flux compression from an external coil. The simulations are being applied to study what happens as the injector waveform is varied, including multi-pulse operation similar to what was attempted in SSPX. A current-filamenting mode can appear prior to the column mode, and it is undesirable as it increases the required injector voltage. Poloidal flux amplification from the column mode is important, but O'Bryan finds that high amplification is not a sufficient condition for extending lifetime and maintaining confinement. Computations with flux compression are providing data on power-supply requirements for a design study.