NIMROD Team Meeting Minutes, April 21, 2018
Pre-Sherwood, Auburn, Alabama

Computational development:

Jacob King reported on tests of semi-implicit operators for the **B** and *P* equations to help stabilize a fast growing mode observed in linear computations with equilibrium flow for his EHO study. The numerical mode appears near the magnetic separatrix and has wavelengths of order of the element size. Sufficiently small timestep reduces the growth rate of the numerical mode and allows the physical mode to grow faster, but that approach is not practical for these large-scale computations. The numerical mode is resistant to existing tools. King reviewed the numerics of semi-implicit methods for hyperbolic systems, and he showed results from von Neumann analysis with and without new semi-implicit operators in the **B** and *P* equations. King implemented these terms and found that they reduce the numerical mode's growth rate, but that they also impact the physical mode.

King led a discussion on new development to generalize NIMROD's block-based data structures. The primary motivations are to 1) make the continuum kinetic computations more efficient, 2) allow unstructured blocks of elements for geometric flexibility, and 3) allow edge-based elements for better representation of vector fields. The plan is to take advantage of the object-oriented features that were added to Fortran in the 2003 and 2008 standards, where abstraction and polymorphism will allow flexibility without duplicating loops for each block type. The polynomial expansions will also be abstracted to facilitate the new vector-element representations. King started work on this last year, and after discussions at the NIMROD coding camp in January, Eric Howell and Brian Cornille have also worked on the development. Unit testing and documentation have been emphasized.

Dan Barnes presented his work to improve the Green's function approach for resistive wall/external vacuum modeling. For the Tibbar application, he had implemented a Green's function approach that shows second-order convergence for both the field and for its derivative. An improved version should be able to get to high (~6) algebraic convergence. The Green's functions are based on elliptic integrals. High-order quadrature methods, modified to account for the source point/observer point singularity, are from a paper by Young and Martinsson. Barnes has been testing the approach with a stand-alone code and finds lower than expected convergence. [Since the meeting, Barnes has found errors in the integration rules of the Y&M paper and has tried contacting the authors.]

Physical model development:

Hankyu Lee described his implementation of generalized moment equations in NIMROD for use in parallel closure relations. The equations result from gyro-averaging the Fokker-Planck equation and then projecting onto Legendre polynomials. Closures relations are derived from the moment equations, assuming spatially sinusoidal drives of prescribed wavelength. Lee compared closure-relation values resulting from computations using his modified version of NIMROD with results from analytical theory.

Eric Held presented work on two different topics. He first compared three forms of the drift-kinetic equation, and noted that Ramos included terms from the evolution of magnetic moment. For use in NIMROD, this system is transformed to the lab frame, which agrees with Hazeltine's form, with the exception of a drift term from $\partial \mathbf{B}/\partial t$. Held put these terms back into the

NIMROD system and has developed a fully linearized version. His second topic in the presentation is theory for strongly coupled plasma (not related to NIMROD at this point). In strongly coupled conditions, the Landau form of the collision operator applies, but it requires a different (non-monotonic) screening potential, which has been derived by Baalrud. Held discussed details on the scattering cross section calculation and implications for transport.

Joseph Jepson is benchmarking NIMROD's drift kinetics by comparing steady-state results with analytical predictions. He has been working with the computationally simpler delta-*f* form (fixed kinetic background), but a difficulty is that a separate relation is needed for the background potential distribution. Jepson applied flux-surface averaging to the quasi-neutrality relation and combined with toroidal momentum conservation to arrive at a relation for potential. Using this information, he has tested poloidal flow damping and the development of asymptotic poloidal flows due to ion temperature gradients in a circular, large aspect-ratio equilibrium and in NSTX equilibrium.

Andrew Spencer is focusing on the development and testing of the Chapman-Enskog-like (CEL) drift-kinetic implementation, which separates the evolving-Maxwellian fluid moments from the kinetic description. He noted where the fluid variables appear in the kinetic equation and discussed possible temporal discretizations, i.e. whether to stagger the kinetic advance from that for temperature. He is using two anisotropic heat flow cases for testing and finds that the kinetic implementation is of comparable accuracy as anisotropic thermal conduction with T and $q_{\|}$ as separate expanded fields (a mixed method). The nonlinear system will need nonlinear iteration, and Spencer reviewed how Picard or Newton methods could be applied.

Applications:

Torrin Bechtel presented his work on modeling pressure-driven dynamics in toroidal stellarator configurations. His computations use a heat source and anisotropic thermal conduction, and he has mainly focused on an $l = 2$ $m = 10$ configuration. To reduce magnetic divergence errors stemming from field at the boundary, he is now using the OCULUS Biot-Savart solver with high toroidal resolution, followed by spectral filtering. Running NIMROD after this initialization procedure leads to very different evolution of the spectrum of kinetic-energy fluctuations, but there may now be difficulty with achieving convergence of the matrix solves with large parallel conductivity. Nonetheless, a new full-spectrum case with low parallel conductivity may now be showing a physical asymmetric instability.

Shekui Cheng's visa application was not processed quickly enough for him to attend, so Carl Sovinec went through his slides. He is using NIMROD to investigate the effects of plasma flow and edge density on the stability of edge-localized modes (ELMs) and has been making comparisons with measured ELM sizes in EAST. He finds that flow tends to stabilize high-n modes but destabilize low-n modes, and reversed flow has a greater effect than positive flow. In a realistic diverted equilibrium, positive flow increases growth rates for all modes, whereas negative flow reduces it. The trend is consistent with the EAST measurements.

Matt Beidler presented his application of linear NIMROD computations to the problem of resonant magnetic perturbation (RMP) penetration in DIII-D discharges. He is focusing on L-mode discharges, and two similar discharges led to different results with respect to island formation. Beidler uses FGNIMEQ to reconstruct the equilibrium, and he uses the TRIP3D code for the perturbation fields. The initial computations consider the n=1 perturbations from the C-coils, and there is a large m=1 response in the core, where q is slightly above unity. With plasma

flow, the response is a combination of twisting and tearing, and removing the equilibrium flow leads to qualitatively different results.

Cihan Akcay has been working with John Finn and Andrew Cole, investigating locking due to magnetic islands and field errors. As theoretical background, Akcay first reviewed the Glasser effect in the resistive-inertial regime, emphasizing how the backward wave in stable conditions can interact with static field errors. In general, there is generally an offset rotation rate when two-fluid effects are considered. He applies quasilinear theory, balancing electromagnetic and viscous torques, to understand when locking occurs. The group hypothesizes that nonlinearly, the locked island will diminish diamagnetic rotation and, hence, the offset rotation. Akcay is applying NIMROD to cylindrical cases with hollow pressure profiles to reproduce the Glasser effect in a relatively simple configuration. When using the numerical interchange stabilization scheme and using p_computation='at nodes', he is able to reproduce tearing-mode stabilization with increasing plasma-β. Initial nonlinear computations are underway.

Eric Howell is investigating the scaling of tearing-mode torques for disruptions. He would like to develop a tearing-unstable case without a pedestal and is generating model equilibria using DIII-D coil data for this purpose. The study will apply resistive DCON to assess stability quickly, and it will use the heuristic poloidal flow damping. To generate the equilibria, Howell has incorporated the free-boundary solver from nimuw into the FGNIMEQ code. He has incorporated feedback based on a proportional-integral-derivative scheme to maintain vertical centering, relating flux differences to changes in coil currents, as described in Jardin's book. Example results show that this approach is effective in FGNIMEQ.

David Markham is incorporating equilibrium toroidal flow in NIMEQ. This adds two more profiles to the computation, density and toroidal rotation rate as functions of poloidal flux, and the specified pressure function is that before incorporating the effects of flow. Markham has implemented the changes and is comparing his results with those from the FLOW code as a check. Key parameters in the results from NIMEQ and FLOW that he presented differ by less than 1%.

Haolong Li's visa application also was not processed quickly enough for him to attend, and Sovinec went through his slides. He is also implementing toroidal flow in NIMEQ. He is using the Solov'ev equilibrium and one by Maschke and Perrin, which have analytical solutions, for testing. Li achieves both element-size and polynomial-degree convergence for these cases. He is using the implementation to demonstrate effects of flow on equilibrium profiles with a pedestal.