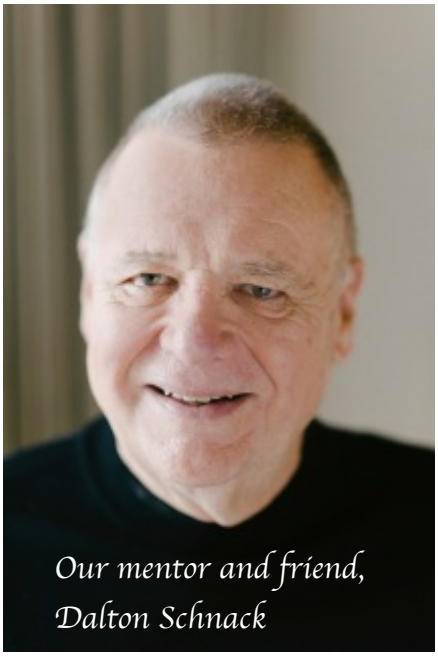
NIMROD Team Meeting Minutes
March 22-23, 2014
San Diego, California

Carl Sovinec opening the meeting with a remembrance of Dalton Schnack, who passed away in December, 2013. Dalton was the founding leader of the NIMROD project and pioneered collaborative plasma code development effort, in addition to 3D MHD computation for MFE and solar physics.


Our mentor and friend, Dalton Schnack

Numerical Methods

Ben Sturdevant presented his work on the sub-cycling and orbit-averaging methods for PIC computations. The work is aimed to run full-orbit computations for long time-scale electromagnetic computations in conditions where the gyrokinetic approximation of $\rho_L / L \leq 1$ is not valid. These methods achieve two ends: 1) they allow the field solves to be done on time steps that are long relative to the particle steps, and 2) they smooth unresolved perpendicular waves. Tests on the ion acoustic wave verify oscillation frequency and damping rates and confirm numerical smoothing for large macro time-steps.

Model and Algorithm Development

Jake King described two computational projects. To facilitate linear computations with an idealized vacuum region surrounding a plasma surface, he developed an option to solve perturbed pressure, flow, and magnetic field, replacing the usually separate density and temperature equations with the pressure equation. The advantage is that equilibrium pressure usually drops more smoothly than density at the edge, so artifacts from nearly discontinuous equilibrium number density are avoided. The option avoids surface-localized noise in EHO computations. He is also investigating the MUMPS solver as an alternative to SuperLU_DIST for the preconditioning step of NIMROD's algebraic solves. The algorithms are not the same, and MUMPS shows much better scaling with respect to memory use. MUMPS also has a hybrid parallelization option.

Andi Becerra presented first results with complete coupling to the GRIN code for representing external vacuum beyond a resistive shell. The vacuum response matrix is computed only once at the start of the computation. First results include large aspect-ratio circular cross-section toroidal versions of the standard cylindrical RWM, and these results are quantitatively close to cylindrical results. She also presented results for NSTX discharge 140110, where the pressure is above the no-wall limit. With a perfectly conducting wall at a location traced from the experiment's copper plates, a growing mode is not observed. With a resistive wall, however, the mode grows at a rate that scales with the wall resistivity, as expected for a RWM.

Carl Sovinec discussed progress on another approach to one or more external regions that are separated by thin resistive shells. They are treated as separate computational regions, and implementation details were described. A basic numerical analysis shows that explicit treatments of the resistive wall have a time-step limitation that scales linearly with mesh spacing

along the wall. This motivated development of an implicit treatment of the resistive wall. Tests of eddy-current diffusion between vacuum regions converge on analytical results and demonstrate numerical stability at time-steps that are above the explicit limit. RWM computations in cylindrical geometry also verify the implementation for linear computations.

Eric Held presented improvements and benchmark computations for his coupled NIMROD/drift-kinetic modeling. The collision operator now directly uses the spectral-element representation for pitch angle. This approach allows more efficient resolution of the trapped-passing boundary. More efficient preconditioning of the coupled DKE distribution function/fluid moment advance has been developed, and steady-state computations are now possible and efficient. Held has completed a benchmarking exercise on neoclassical transport/bootstrap current calculations with the NEO code from GA. One case has reversed shear and high β, and convergence with respect to pitch-angle resolution is non-trivial. Quantitative agreement on profiles and the distribution-function are obtained. Convergence on a non-reversed low aspect ratio case is easier. The NIMROD computations run well in parallel, and large cases with 2D poloidal meshing (unlike most transport codes that solve flux-surface averages only) run in 25 minutes on Edison.

Applications

John O'Bryan gave a dry run of his oral Sherwood presentation on modeling localized current injection in the Pegasus ST. He overviewed the stages of tokamak formation from the weakly driven helical current filaments to excitation of merging/flux-rope ring formation to development of a poloidal flux null from the accumulation of rings to a relaxed hollow-current tokamak after injection ceases. He considered the application of squashing-degree computations to the field lines during a ring formation event. A quasi-separatrix layer is identified, and while some of the trajectories go through the reconnection site, others go through a bifurcation point that is analogous to X-points between non-reconnecting magnetic islands in periodic systems.

Valerie Izzo presented results on her simulations of massive gas injection and comparison with laboratory results from DIII-D. Her previous simulation results find that toroidal peaking of radiation is governed by the excited MHD mode, independent of localization of the source of gas. However, a localized source sets the phase. Results from DIII-D show that peaking starts 180 degrees away from the sources, regardless of imposed asymmetries from coil fields, which is consistent with the simulation predictions. However, the phase of the peaking tends to drift. Izzo is now performing more realistic computations with more localized injection. The recent results show more realistic levels of peaking (1.2-1.3), and the penetration of the impurities now follows a helical path, which alters the phase of the peaking over time.

Tom Jenkins discussed the giant sawtooth project that he has recently joined. He noted that Dalton Schnack left a document of comprehensive notes on relevant papers and findings. The energetic particles can be addressed with either of two approaches in NIMROD, the PIC-based capability and the continuum DKE modeling. The CEMM work statement on the project includes development, in addition to the physics application. The development work is improved parallel computing for the PIC computation. Jenkins will use the more efficient continuum approach in the application while working on the improvements for the particle-based approach.

Ping Zhu reviewed his computations on the response to resonant magnetic perturbation for the DIII-D equilibria that are being used for comparing different codes/computational approaches. Zhu has applied MHD and 2-fluid models and emphasizes that both equilibria are linearly

unstable to toroidal harmonics n>5; the perturbation is applied at n=3. The perturbed kinetic energy and magnetic energy in the 2-fluid result is smaller than with MHD, possibly indicating better screening.

Jonathan Hebert gave an update on modeling Ohmic current drive in the Compact Toroidal Hybrid experiment at Auburn. Hebert has been able to control noise in number density by using particle hyper-diffusivity, but the modeling results still miss the hesitations in the toroidal current ramp that occur in the experiment as low-order rational surfaces enter the plasma. He has tested different possible causes for the discrepancy, including field errors and lower initial temperature. He is also considering other discharges where the applied stellarator transform creates doublet flux-surface shapes. The doublet transitions to a conventional equilibrium as plasma current increases. Possibilities for island divertors are being explored with imposed vacuum islands. A new rotational-transform diagnostic for 3D fields identifies O-points and then applies a Fourier transform to determine the transform.

Eric Howell gave an update on his study of interchange in spheromaks. For purposes of comparison with theory by Stringer, he has considered a cylindrical profile where safety factor decreases in radius but does not go to zero at the edge, as appropriate for flux-core spheromaks. However, profiles do not have uniform parallel current density, so the computed results may include current-driven effects in addition to interchange. Equilibria that are representative of decaying flux-core spheromaks have linear instabilities at multiple rational surfaces. Gyroviscosity tends to reduce growth rates, but including the two-fluid Ohm's law leads to growth rates that are larger than MHD. Nonlinear computations show interchange dynamics that have a large impact on profiles when starting at high temperature, but the dynamics have only a relatively small effect when starting from slightly lower temperature.

Josh Sauppe presented two-fluid computations of relaxation in the RFP. He compared different orientations of the equilibrium current and resulting change in parallel flow during a relaxation event and noted the discrepancy between simulation results and results from the Madison Symmetric Torus. Unlike the experiment, the initial two-fluid relaxation event in simulations can actually steepen flow in the core. He has checked free- vs. no-slip boundary conditions, parallel viscosity, magnetic Prandtl number, and cold vs. warm ions. Cold-ion cases show greater cancellation between fluctuation-induced Lorentz and Reynolds forcing. Also, relaxation events after the first event can show different behavior with respect to MHD vs. Hall dynamo, hence Lorentz forcing. Sauppe also finds that equilibrium profiles evolve faster than the resistive time-scale, which does not fit the conditions assumed in two-fluid relaxation theory by Hegna.

Fatima Ebrahimi presented MHD computations of magnetic reconnection in transient coaxial helicity injection (TCHI) in NSTX. The drop in injector voltage creates forces that initiate reconnection. The reconnection layer width scales like the square root of resistivity, consistent with Sweet-Parker reconnection. The resulting fraction of closed-flux current is a little more than 10%. Ohmic heating from the reconnection is observed in the closed-flux region. The next step is to investigate two-fluid effects on the reconnection and flux closure. Ebrahimi also discussed simulations of the plasma Couette-flow experiment (PCX). When starting from purely toroidal field, nonlinear MRI activity starts along the inner radius and propagates outward. The fluctuation spectrum with the Hall effect is narrower than with MHD modeling.