NIMROD Team Meeting Minutes
April 17, 2010
Seattle, Washington

Model Development

Carl Sovinec started the meeting with a discussion of three topics: time-centered implicit advance, basis functions, and a nonlinear external kink computation. The motivation for considering a time-centered algorithm is to allow a given level of accuracy at larger time-step than NIMROD's implicit leapfrog—at the cost of a more expensive solve per step. The NIMITH code is a time-dependent code for linear computations that uses NIMROD's machinery to provide a theta-centered implicit advance. Initial applications to current-driven tearing show the expected convergence properties of 1% error at $\gamma\Delta t$=0.35 (about 10 larger than the leapfrog for the same accuracy), and a time-step is requires about 2.5 times more CPU time (linear computations). Other computations indicate that the implicit-theta algorithm is less robust, however. The second topic included results from the CYL_SPEC code that has been developed to investigate different spectral and spectral-element basis functions. Possible applications of discontinuous basis functions in NIMROD are being considered. The nonlinear external-kink computation revisits the Rosenbluth, Monticello, Strauss, and White result [PF 19, p. 1987] to test NIMROD, which effectively uses a level-set method and not Lagrangian computation. A special resistivity that varies strongly with density is used. The computation shows the cylindrical column shifting significantly and pushing into the wall.

Scott Kruger presented SBIR work at Tech-X by Ben Jamroz and Travis Austin. They are investigating Newton-Krylov solves (for nonlinear centered advances) using the PETSc solver library. The goal is to accomplish N-K with minimal changes to NIMROD. The coupling to PETSc has been tested with n=0-only computations, first for just the momentum-advection term and then for the full system. NIMROD's semi-implicit operator is already similar to the diagonal part of Chacon's preconditioner, so it is being used as a basis for preconditioning development. The nonlinear solver is functioning at this point, but optimization is needed before meaningful comparisons can be made. Austin is also working on preconditioning for high-order finite elements; direct use of algebraic multigrid with the HYPRE package was not effective. One idea is to use low-order FE discretization to approximate high-order matrices. A second idea uses a least-squares method to approximate the high-order contributions automatically. Tests on the Poisson equation indicate that this second approach will be more effective.

Tom Jenkins gave an update on RF/MHD coupling that is central to the SWIM proto-FSP project. The coupling uses the Integrated Plasma Simulator (IPS) to provide an intermediary between NIMROD and GENRAY. The IPS is essentially a set of scripts that can manage how multiple codes are run and interact. Data is exchanged through the 'plasma state' file. A test of IPS that couples NIMROD and NIMFL has been performed; the data flow is one-way only, but it illustrates load-balancing issues. Initial computations that couple NIMROD and GENRAY have also been performed. Eighty rays are computed with GENRAY and provide very localized deposition. NIMROD correctly reads the netCDF file produced by GENRAY, and the deposition information is assigned to toroidal planes and interpolated using modified Shepard methods. The interface is nearly complete, and fully coupled runs, where NIMROD's evolving profile goes back into GENRAY, should be functioning soon.

Eric Held presented recent benchmarking information on kinetic computations (NIMROD with velocity-space expansions for delta-*F*). The implementation now includes radial derivatives that had been missing, and the formulation is consistent with Ramos' first-order drift-kinetic equation (DKE). The benchmark tests for neoclassical current, and results are compared with those from the NEO code from GA. Resolution for the NIMROD computations includes an 8x8 (Legendre polynomials for pitch-angle / speed grid), and use of the moment method eliminates derivatives with respect to speed. New flux-surface average information is being computed in NIMPLOT for the comparison. The NIMROD results are close to current estimates provided in Jim Callen's report. Held also presented work from two students. Richard Datwyler is creating a two-fluid implementation that includes non-neutral charge effects and solves the full system with the Crank-Nicolson method. It has been tested on light-wave propagation, plasma oscillations, and electron-plasma waves. Andrew Spencer is creating a Focker-Planck code, applying NIMROD's finite elements and Fourier representation to velocity-space dimensions.

Jianhua Cheng described his work on the Colorado hybrid code GEM that couples fully kinetic ions with fluid or other electron models. The relation for the electric field is derived from the electron momentum equation and Ampere's law. The delta-*f* equation for ions is solved implicitly to avoid time-step restrictions from compressional waves, and the electric field and ion motion are iterated to obtain convergence. Cheng has made the algorithm second-order accurate. The GEM implementation has been tested on several different waves, and numerical damping matches expectations from von Neumann analysis for different values of the implicit-centering parameter. When applied to a Harris-sheet tearing-mode computation, the results at $k_y\rho_i$ differ from the resistive-MHD growth rate, but the scaling with S is similar. Nonlinear computations do not show a Rutherford phase while delta-*f* is still small. New development work includes drift-kinetic and gyro-kinetic electron models.

Charlson Kim covered recent developments for modeling energetic ions and information on the giant-sawtooth application from Dalton Schnack. The delta-*f* advance now uses a separate electric-field expansion, where coefficients are determined by solving a mass matrix. The computations now use the two-fluid Ohm's law when it is specified. The greatest room for performance improvement in the particle algorithm is the iterative search process for particles when using finite-element mappings. Many options are now available: Lorentz motion or drift kinetics, different equilibrium distribution functions, and different spatial profiles. Kim is considering what is needed for application to FRC plasmas, which have very significant kinetic effects. He has examined trajectories of low-, intermediate-, and high-energy particles. Many trajectories are lost, but the confined high-energy orbits encircle most of the plasma, suggesting strong rotation. An electrostatic potential is being added to account for particle loss.

The giant sawtooth application is considering profiles from DIII-D shot 96043, where RF-excited energetic particles lead to a very high-energy tail in the distribution function that lengthens the sawtooth period. The goals of the numerical study include verification and validation of the energetic particle module. The 1700 ms fit is from the point where the energetic-particle effects are expected to be strongest (Choi paper), and Schnack's scans include varying the fraction of hot particles for different maximum particle-energy levels. Kim has also run linear computations without a vacuum region; n=1 stabilization is not obtained for the 1900 ms and 2020 ms fits. There is some evidence of different n=1 modes appearing at different points in the kinetic parameter space.

Andrea Montgomery reported progress on computing resistive wall modes in cylindrical geometry. The equilibrium has essentially uniform current density within the 0-β plasma column. Outside the column, there is large resistivity, and the jump is located at an element border. Results with a perfectly conducting wall and with the rational surface between the column and the wall match analytical results well, verifying the computational set-up. With a resistive wall, E-tangential is computed from the jump in the tangential component of magnetic field across the wall. The computations are presently projecting just the m=+2 or m=-2 component of the magnetic field. The m=-2 results show the expected RWM behavior, including sensitivity to the wall location (to within 6% at this point).

Applications

Ping Zhu described his modifications to NIMFL (field-line tracer) to have it solve the ballooning equation, which is a coupled ODE system for normal and tangential components of displacement. The system simplifies to a single ODE in marginal conditions. This implementation would be able to capture all geometric effects of 2D equilibria with flux-surface shapes determined by NIMEQ. Zhu is presently testing the implementation on circular cross-section tokamak equilibria. The initial condition is located at large poloidal angle, and eigenmodes are solutions that have no derivative when they cross the midplane. It is a form of shooting that is very sensitive to initial conditions. Zhu is considering how to use analytical asymptotic behavior at large poloidal angle to reduce the sensitivity.

Valerie Izzo presented her recent work on runaway-electron confinement during disruption (also as an invited presentation during the Sherwood meeting). Experiments in DIII-D use Argon pellets to induce a disruption that generates a beam of runaway electrons. Late in time, all current is in the runaway beam. Her modeling with NIMROD has passive simulation particles as tracers with a broad distribution of Ar impurity. This focuses on confinement aspects during the early phase. With the Ar distribution, she finds that the electron population rises by a factor of 4, which is similar to the experimental results with pellets. The thermal quench phase occurs faster in the simulation, as there is no delay from pellet ablation. A spike in radiation occurs with the MHD activity, and approximately 3/4 of the electrons are lost (possibly not if the model had magnetic field consistent with runaway electron current). Izzo compares tracer-particle strike points with hard and soft X-ray diagnostics, and there is consistency that the outer divertor is the primary strike point. Examining resonant magnetic perturbation effects, simulations indicate that RMP reduces the loss (improves confinement). Experiments results are mixed, but information on changes in strike-point location is consistent. Future simulations will be improved with a runaway electron generation model and coupling of the runaway current to the magnetic field evolution through a volumetric source.

Bonita Burke presented her investigation of peeling instability and how it differs from ballooning. Analytically, she is using the Lagrangian ideal-MHD system with an expansion based on small displacement with respect to the equilibrium scale for radially localized modes. This differs from the $1/n$ expansion that Zhu has used for nonlinear ballooning. Quasi-linear analysis for the peeling shows that k=0, $m\neq 0$ shear flows are generated. Burke is using

NIMROD simulations with three different equilibria that emphasize a range in the balance between peeling and ballooning. There are also separate cases for different initial perturbations (exciting different toroidal components, *n*). The results indicate that the growth of low-*n* modes slows in the intermediate regime, unlike ballooning behavior. The n=6 mode appears to maintain its shape, and n=0 flows grow at twice the linear rate of the n=6. With a ballooning-unstable equilibrium, exciting high-*n* leads to linear growth through the intermediate regime. Exciting low-*n* leads to coupling to high-*n* that grows faster and then dominates the evolution.

Dylan Brennan and Ryoji Takahashi are investigating flow and energetic particle effects in n=1 and n=2 modes for tearing modes that are described in a recent paper by LaHaye. They are using NIMROD to map the stability space using new experimental equilibrium reconstructions. The discharges operate in the hybrid mode with a minimum *q*-value that is slightly above 1 in reconstructions without flow. The equilibria are ideally stable (from DCON and PEST), and the resonant 2/1 mode generates a non-resonant 1/1. Adding energetic particles indicates that the effects of pressure anisotropy are destabilizing for the resonant 2/1, and for a 3/2, as values of minimum-*q* and β_N are scanned. Results with toroidal flow indicate that it is also destabilizing for these modes.

Jacob King gave an update on two-fluid results for pinched *q*-profiles. A new aspect of the single-helicity study is the separation of helical components of vectors along a surface defined by a constant value of *H*, where *H* is found parametrically to have $\mathbf{k}\cdot\nabla H=0$. These plots show the nonlinear ion flows at saturation of the island growth and how they are altered by gyroviscosity. Recent work on multi-helicity two-fluid relaxation includes comparison of Hall and MHD dynamo effects at the start and end of a relaxation event. Both effects are active over broad profiles as the event is beginning, and both become small following the crash. King is also separating the m=0 effects and how different m=1 modes couple.

Eric Howell is investigating linear interchange in profiles for decaying spheromaks. He is focusing on whether two-fluid effects on interchange can explanation the discrepancy in peak temperatures obtained in MHD simulations and the SSPX experiment; the MHD simulations appear to be less robust with respect to resonant perturbations during decay. Computations to compare with results in the DeLucia paper, where the configuration is a simple cylinder with a strongly pinched equilibrium, show initial two-fluid stabilization of a resistive mode. However, the NIMROD results deviate at large Hall parameter, showing a new and possibly numerical mode. Gyroviscosity weakens the stabilization effect in these cases. When the equilibrium is modified to be ideally unstable with respect to the Suydam criterion, both the Hall effect and gyroviscosity are less effective in stabilizing the mode. For realistic toroidal equilibria in a simple can geometry, the Hall term again has a larger stabilization effect for ideally unstable modes, but the Hall parameter has to be very large to see any significant stabilization. Initial work on nonlinear evolution to assess confinement with partial stabilization is underway.

Brian Nelson presented a summary of the PSI-Center's activities. There is a very long list of applications (Caltech, ELF, FRX-L, HIT-II, HIT-SI, LDX, MST, Pegasus, PHD, SSPX, SSX, TCS-U, and ZaP), and NIMROD has been applied to all of them in at least some way. Nelson discussed the addition of neutral-fluid modeling in the SEL code and its application to FRC modeling. He also discussed the VisIT graphics package. The Python utility NimPy converts NIMROD dump files to VTK for VisIT, and this useful script was written by Nelson.

Cihan Ackay gave an update on his mesh-generation software for NIMSET. It is now able to put a layer of small elements near the domain boundary for a resistive layer. He is also able to round the corners of his HIT-SI domain to avoid singular behavior at corners. The algorithm has a hierarchy of objects—segments, sides, and sectors—that are blended with Boolean sum interpolation. Segments include weighting functions to define how meshing is packed along the respective segment. A full mesh is an assembly of sectors. Tests include convergence studies for decaying Taylor-state spheromak profiles and n=1 kink-unstable evolution.