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This is a final report for Dr. Eric Held's Junior Faculty in Plasmas Physics grant entitled, "Derivation and Implementation of Hybrid Fluid/Kinetic Model for Fusion Plasmas". Progress over the three years and six months of this project included work on analytical and numerical fronts.

With regard to analytical progress on deriving hybrid fluid/kinetic models, I completed a derivation of the electron heat flow response along an inhomogeneous magnetic field. This work was carried out in collaboration with Drs. Jim Callen and Chris Hegna at the University of Wisconsin and resulted in the following publication:

"Conductive Electron Heat Flow along an Inhomogeneous Magnetic Field," E. D. Held, J. D. Callen, and C.C. Hegna, *Physics of Plasmas*, **10** (3933) October 2003.

In addition, I successfully derived an integral form for the parallel component of the parallel ion stress tensor in slab geometry. This derivation included allowing for arbitrary collisionality as well as a nonlocal momentum restoring term. This work unified previous collisional and collisionless results in a single integral expression which was discussed in the following publication:

"Unified Form for Parallel Ion Viscous Stress in Magnetized Plasmas," E. D. Held, *Physics of Plasmas*, **10** (4708) December 2003.

Progress has also been made on the numerical implementation of the hybrid fluid/kinetic model in the plasma fluid code NIMROD. These developments were highlighted in an invited talk that I gave at the 2003 APS-DPP meeting in Albuquerque. This talk discussed the massively parallel numerical implementation of integral closures in NIMROD as well as a semi-implicit time-stepping scheme for stabilizing the advance of the fluid equations. In terms of tokamak physics, it was shown that the integral closure robustly flattens temperature across magnetic islands and hence may provide the correct perturbed bootstrap current drive of neoclassical tearing modes. Furthermore, preliminary simulations of wall heat loads for a disrupting DIII-D-like plasma showed qualitative agreement with experimentally observed localized heat loads, striation in the poloidal direction along the wall and a smooth distribution toroidally. The contents of this invited talk as well as the implementation of the nonlocal closures in NIMROD were summarized in the following publications:

“Nonlocal Closures for Plasma Fluid Simulations,” E. D. Held, J. D. Callen, C. C. Hegna, C. R. Sovinec, T. A. Gianakon, and S. E. Kruger, *to appear in Physics of Plasmas*, May 2004.

“NIMROD: A Computational Laboratory for Studying Nonlinear Magnetohydrodynamics,” C. R. Sovinec, T. A. Gianakon, E. D. Held, S. E. Kruger, and D. D. Schnack, *Physics of Plasmas*, **10** (1727) May 2003.

Finally, a numerical implementation of the parallel ion stress was worked on prior to the February end date of this project. This included a more efficient calculation of the heat flow and stress closures. We now use a spectral method to identify dominant parallel wave numbers in the thermodynamics drives and follow this up with a linear fit to those drives as an expansion in sin and cos functions. Using this approach the closures may be calculated 100 to 1000 times faster than our previous method. This improvement will permit numerical simulations of long time scale plasma phenomena which incorporate the hybrid fluid/kinetic model developed in this project.

With regards to the educational benefits of the project, my two graduate students, John James and Michael Addae-Kagyah, who were supported by my Junior Faculty Award, have also made progress. Both John and Michael have accompanied me to several Sherwood Fusion Theory and APS-DPP meetings and reported their research in posters. John has worked on applying the integral heat flow closure in NIMROD to the problem of electron heat confinement in reversed field pinches. Michael is assisting me with the application of the integral parallel stress closure in NIMROD. In short, both are progressing steadily toward their PhDs while contributing to theoretical/computational efforts in magnetic fusion.

In summary, we have made substantial progress toward deriving and implementing an improved hybrid fluid/kinetic model in NIMROD. The financial support of the Junior Faculty program was instrumental in this progress.

Thanks.

Sincerely,
Dr. Eric D. Held