Overview of the Plasma Science and Innovation Center (PSI – Center)

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The principal goal of the Plasma Science and Innovation Center (PSI-Center) is to achieve significantly improved computational predictive capability for smaller-scale devices. This is being accomplished through the refinement of existing computational tools through adding sufficient physics modeling, boundary conditions, and geometric capabilities while benchmarking results against experimental data. The work emphasizes the modeling needs of emerging concept (EC) experiments, but improved simulation capabilities for all innovative confinement concepts (ICC) are expected. A special emphasis is placed on physics effects that may extend beyond the standard analysis applied to the mainline programs. The PSI-Center is presently concentrating on five focus areas that have been identified as being very important for various EC experiments. The key physics issues are: 1) two fluid / Hall physics, 2) kinetic and FLR effects, 3) reconnection and relaxation physics, 4) transport, atomic physics, neutrals, and radiation, and 5) boundary conditions and geometry. All of these effects are also important in mainline fusion devices, but one or more tend to dominate in particular EC configurations. In some cases, important effects may result from high-frequency electron dynamics or kinetic effects that cannot be calculated from first-principles in a practical manner during global simulations. Here, well benchmarked phenomenological modeling may be the best approach for some applications. There are numerical simulation codes having some subset of these important features, but no existing code covers all of the special needs of innovative/emerging concepts.

We plan to develop the needed features within existing codes to avoid the resource requirements and delays associated with developing completely new models. We have started with two codes: 1) NIMROD[1] which is a 3D code that is periodic in one dimension and employs finite elements in the other two dimensions; and 2) MH4D-like[2] which employs a full 3D unstructured mesh.

The five fundamental issues appear essential in developing predictability for EC experiments and they are the initial focus of the code-improvement activity. Two fluid / Hall physics are very important to many EC experiments. They lead to toroidal field generation when a spheromak is generated in a conical θ-pinch, are responsible for current drive in Rotating Magnetic Field current drive experiments, and affect spheromak relaxation rates. An accurate inclusion of these terms is numerically difficult, and is being developed by the NIMROD team and the CEMM. Kinetic and FLR effects are very important for some EC experiments. FRCs have a high β (low field) interior with only a few ion gyro-radii separating the magnetic null from the separatrix. PIC codes are too time consuming to simulate a full experimental pulse. However, kinetic / FLR effects can be put into MHD models. PIC will be used to represent a minority species in NIMROD and gyroviscous effects will also be added. We also collaborate with Elena Belova to incorporate advances that she has accomplished with the HYM code. Reconnection, relaxation physics are essential for several EC concepts. Relaxation is challenging to model. Since it results from fluctuation correlations, the fluctuation turnover time-scale must be resolved. The NIMROD and MH4D-like codes will be optimized for the computation of relaxation physics problems. Recent theoretical work on two-fluid relaxation in high-β plasmas would benefit from first principle simulations. Transport, atomic physics, neutrals, and radiation can be extremely important in EC experiments, which tend to be relatively small and low temperature, and can be strongly affected by impurity radiation, ionization, charge exchange, neutral dynamics, and collisional transport. We will implement an atomic-physics package into the MHD models, which we hope to take advantage of efforts by the National Transport Code Collaboration (NTCC), and the BALDUR impurity radiation model. Properly treating boundary conditions and geometry is essential for achieving quantitative agreement with experiments. Ideal conducting boundaries are often employed in codes but finite conductivity of metal boundaries needs to be modeled. Insulating boundaries employed by some ECs need to be used in the codes. Work toward including realistic coil geometries and external circuit equations is being started. The effects of a thin layer of cold poorly conducting plasma close to a conducting boundary needs to be included. Some experiments have an insulator between a close fitting metal wall and the plasma. Work is well underway in imposing this boundary condition on a MHD calculation.

PSI-Center accomplishments include making NIMROD and MH4D run on the Center's code-development computer, hiring all personnel, and making progress in modeling eight experiments. The Center has achieved first results with insulating boundary conditions and a strategy is in place to develop a model for neutrals and ionization. The semi-collisionless transport coefficients are under development. We have begun characterizing the nature of linear two fluid FRC tilt to compare to analytic models, and linear n=1 two-fluid calculations have started for the FRC.

While the entire EC community is invited to participate in this Center, nine EC experimental programs [1) Caltech reconnection experiments, 2) FRX-L, 3) HIT-SI, 4) MBX, 5) PHD, 6) SSPX, 7) SSX, 8) TCS, and 9) ZaP] and MST are providing the initial database and test bed for the theoretical and computational efforts of the PSI-Center. This set of experiments has many overlapping areas of physics that complement the PSI-Center's focus. Experimental data will be used to test and calibrate the numerical predictions generated by the computational tools developed by the Center. The Center also works to facilitate information exchange with collaborating partners.

Summary - The PSI-Center is to develop computational predictability for ICC/EC experiments, it will mostly integrate existing and on-going work but some new development is needed. The work is underway to develop codes that will greatly facilitate the exploration of the ICC/EC parameter space and increase the scientific output from experiments.

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