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Project Title: Global Field Aligned Mesh and Gyrokinetic Field Solver in a Tokamak Edge Geometry

Final Technical Report for the Period 1/1/2008 to 12/31/2008

This project was a collaborative research effort between researchers at the California Institute of Technology and the University of California, Irvine. The project was funded by the Department of Energy's Office of Science through its program in theoretical research of magnetic fusion energy science. The key participants in this effort were Dr. Julian C. Cummings at Caltech and Yas Nishimura, who was a postdoctoral research associate at UC Irvine at the time. This report concerns the work performed by Dr. Julian C. Cummings, who was the Principal Investigator for this project.

The overall goal of this project was to investigate the utility of a global field-aligned mesh and a compatible gyrokinetic field solver for simulations of the tokamak plasma edge region. A global field-aligned mesh refers to a simulation grid for the global tokamak geometry in which one coordinate of the grid follows the direction of the equilibrium magnetic field lines. Such a coordinate system may offer advantages for a gyrokinetic particle-in-cell (PIC) simulation because the particle gyrocenters tend to move most quickly along these equilibrium magnetic field lines, with slower drift motions occurring perpendicular to these field lines. Aligning the simulation grid with the magnetic field lines can reduce the frequency with which the gyrocenter motion would cross a simulation cell boundary, thus allowing for a larger time step size with the same level of accuracy in the PIC simulation. Researchers at UC Irvine had already successfully introduced such a global field-aligned mesh into their global gyrokinetic simulation code GTC [Z. Lin *et al.*, Science **281**, 1835 (1998)] for use in the study of core plasma microinstabilities.

At the same time, the Center for Plasma Edge Simulation (CPES) project was underway to develop a new integrated and predictive plasma edge simulation code package that would include a fully kinetic model of neoclassical and turbulent transport in realistic tokamak edge geometry. This model was based upon the X-point included Guiding Center (XGC) code [C.S. Chang, S. Ku and H. Weitzner, Phys. Plasma **11**, 2649 (2004)], which employed a cylindrical (R-Z-ϕ) coordinate system in order to include the region of the magnetic separatrix (*i.e.* the last closed magnetic flux surface) without introducing any singularities near the so-called X-point where open and closed magnetic field lines both pass through. Although this coordinate system was shown to work reasonably well for a fully gyrokinetic edge plasma simulation, it was recognized that a global field-aligned mesh might improve the code performance if problems near the X-point could be overcome.

UC Irvine provided some demonstration codes that could be used to generate a global field-aligned mesh given boundary points describing the equilibrium magnetic field geometry. These mesh generator tools would create a triangle mesh over the poloidal plane, with each mesh point lying on one of a finite set of poloidal magnetic flux surfaces. The global 3d mesh is composed of many such triangular meshes, each one separated from the next by some distance in the toroidal direction. Each mesh point is connected to its toroidal neighbors by following the twist of the equilibrium tokamak magnetic field. Because the open and closed magnetic flux surfaces are separated by the boundary known as the magnetic separatrix, a separate field-aligned mesh must be generated for the region outside the separatrix. Then, a scheme must be developed to integrate the two meshes, so that particle gyrocenters may pass smoothly across the separatrix and even through the X-point region. Furthermore, the gyrokinetic field solver that is used to solve the gyrokinetic Poisson equation must be applied to each of the two separate meshes for the closed and open field line regions. An interpolation and smoothing routine of some sort is needed to ensure that the electrostatic field solution (and its gradient, the electric field) remain consistent across the magnetic separatrix.

The bulk of this one-year exploratory project was spent learning how to use the software provided by UC Irvine and testing it with specific tokamak edge geometry scenarios. We made assessments of the overall quality of the triangular meshes created, in terms of measures such as the variance in triangle area and height/width ratio. We also examined the ability of the associated gyrokinetic solver to produce continuous and smoothly varying electrostatic fields given specific manufactured inputs for the gyrocenter charge density. In this way, we could directly compare the quality of field solver results for the existing cylindrical coordinate system and the global field-aligned mesh. During this brief study, we were unable to develop adequate solutions for the problem of smoothly matching up field solver solutions from the closed and open field line regions. It was our conclusion that the complexities of fully addressing this issue of matching solutions at the separatrix outweighed any potential gains in efficiency from the use of a global field-aligned mesh for tokamak edge particle simulations.