THE GRADUATE SCHOOL
of
THE UNIVERSITY OF COLORADO
AT BOULDER

DISSERTATION DEFENSE
of

Christopher A. Leibs

FOR THE DEGREE

DOCTOR OF PHILOSOPHY

Date/Time: Nov. 18, 2014 from 9:30am MST

Bldg./Rm: Grandview Conference Room, 1320 Grandview Ave.

Examining Committee Members:
Tom Manteuffel, Steve McCormick, John Ruge, Hari Rajaram, and Luis Chacón

OUTLINE OF STUDIES

Major Field: Applied Mathematics

BIOGRAPHICAL NOTES

Chris was born and grew up in San Mateo, CA. He obtained his Bachelor of Science in Physics and Mathematics from Rose-Hulman Institute of Technology, Terre Haute, IN. Over the years Chris has collaborated with Los Alamos National Laboratory (LANL), where he originally began doing experimental research in plasma physics diagnostics, specifically Mach-Zender interferometery.

Later, while working towards his Masters degree in Applied Mathematics at the University of Colorado Boulder, he pursued his interest in plasma physics by working closely with the T5 division of LANL. His research involved the GPU acceleration of particle-in-cell methods and fluid based preconditioners.

For the last three years Chris has been a member of the Grandview computational group at the University of Colorado Boulder as a doctoral candidate in Applied Mathematics. His interests include: least-squares finite element methods, adaptive mesh refinement, and multigrid methods.

Chris currently lives in Boulder Colorado and enjoys hiking with his dog, mountain biking, and imbibing a variety of locally crafted beverages. After graduation he plans to continue his research with the Grandview group as a postdoctoral researcher.

THESIS

Complete title of thesis:
First-Order Systems Least-Squares Finite Element Methods and Nested Iteration for Electromagnetic Two-Fluid Kinetic-Based Plasma Models

Faculty Advisor – Dr. Thomas Manteuffel

ABSTRACT

Efforts are currently being directed towards a fully-implicit, electromagnetic, Jacobian-free Newton Krylov kinetic solver, motivating the necessity of developing a suitable fluid-based, electromagnetic, preconditioning strategy. The two-fluid plasma Darwin model is an ideal approximation to the kinetic Jacobian and is the subject of this thesis. The two-fluid plasma (TFP) model couples both an ion fluid and an electron fluid with Maxwell's equations. The ion and electron fluid equations consist of the conservation of momentum and conservation of number density. A Darwin approximation of Maxwell is used to eliminate spurious light waves from the model in order to make coupling to non-relativistic particle models feasible. We analyze the TFP-Darwin system in the context of a stand-alone solver with consideration of preconditioning a kinetic-JFNK approach

The TFP-Darwin system is addressed numerically by use of nested iteration (NI) and a First-Order Systems Least Squares (FOSLS) discretization. An important goal of NI is to produce an approximation that is within the basis of attraction for Newton's method on a relatively coarse mesh, and thus, on all subsequent meshes. After scaling and modification, the TFP-Darwin model yields a nonlinear, first-order system of equations whose Fréchet derivative is shown to be uniformly $\mathcal{H}^1$-elliptic in a neighborhood of the exact solution. $\mathcal{H}^1$ ellipticity yields optimal finite element performance and linear systems amenable to solution with Algebraic Multigrid (AMG). In order to efficiently focus computational resources, an adaptive mesh refinement scheme, based on the accuracy per computational cost, is leveraged. Numerical tests demonstrate the efficacy of the approach, yielding an approximate solution within discretization error in a relatively small number of computational work units.