Numerical Algorithms for Magnetohydrodynamics of Multifluid Systems

Roman Samulyak
Computational Science Center, Brookhaven National Laboratory

Summary

The purpose of this project is to develop novel mathematical models, numerical algorithms, and computational software optimized for modern supercomputers for the numerical simulation of free surface multiphase magnetohydrodynamic (MHD) flows at low magnetic Reynolds numbers, and to perform simulations in support of magnetically confined fusion and advanced accelerator applications. Our primary goal is to gain through mathematical modeling and numerical simulations a better understanding of physics, and improve the design of experiments and devices critical for the DOE mission. The research is being performed in close collaboration with General Atomics, Neutrino Factory/Muon Collider Collaboration, and the SciDAC Center ITAPS.

Development of Models, Algorithms, and Computational Software

Specialized numerical algorithms, optimized for modern computer architectures such as BlueGene, and new models for complex MHD processes in multiphase systems are necessary in order to advance numerical simulations of nuclear fusion devices such as the International Toroidal Experimental Reactor (ITER) and future accelerators. Mathematical models, algorithms, and software being developed under this project enable the simulation of ITER fueling through the injection of small frozen deuterium-tritium pellets, striation instabilities of the pellet ablation channel, liquid hydrogen or lithium jets proposed for the tokamak plasma disruption mitigation, and the simulation of a mercury jet interacting with intense proton pulses in the target system for the Neutrino Factory/Muon Collider.

FronTier-MHD, a code for 3D compressible free surface MHD flows at low magnetic Reynolds numbers, has been recently developed by our group based on the method of front tracking and adaptive finite volume and finite element techniques for elliptic problems in irregular domains. The explicit tracking of interfaces allows us to apply different mathematical approximations and numerical discretizations in domains occupied by different materials, and thus to resolve material properties and multiple time scales.

In FY07, several new mathematical models and numerical algorithms have been developed for the FronTier-MHD code. Most of them enable qualitatively new capabilities in simulations of the pellet ablation in tokamaks. New developments include the adaptive mesh refinement, a specialized 3D elliptic solver for the potential in the pellet ablation channel, and a conductivity model for weakly ionized plasma with direct impact ionization by energetic particles. Our recent algorithms for the Riemann type problem for tracked phase transition boundaries have also been

Phone: (631) 344 - 3304, E-mail: rosamu@bnl.gov

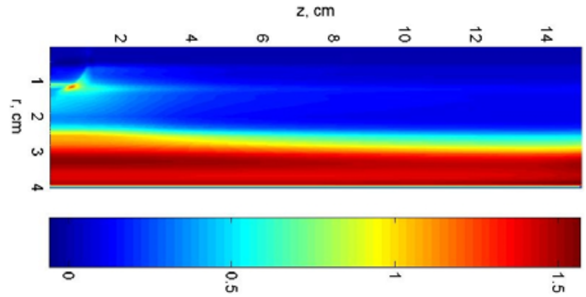
improved. The code has been ported to BlueGene-L.

Future development of numerical algorithms will focus on heterogeneous multiscale methods for the coupling of FronTier-MHD as a subgrid model with a tokamak plasma MHD code in order to achieve advances in the simulation of multiphysics processes in tokamaks such as the pellet fueling and plasma disruption mitigation. We will also work on scalable elliptic solvers in complex domains with interface constraints, adaptive mesh refinement in 3D, and the code optimization for BlueGene-L.

Application Highlights

Fueling Technologies for ITER

Our numerical models and the software enable large scale numerical simulations of complex physics processes associated with the injection of frozen deuterium-tritium fuel pellets in tokamaks. This research, being performed in close collaboration with General Atomics, addresses detailed ablation physics. Therefore it complements global plasma simulations currently being performed at the SciDAC Center for Extended MHD Modeling (CEMM). In our recent work, the pellet ablation rate and lifetime in magnetic fields were systematically studied for the first time and compared with theory and existing experimental databases. Using a novel model for the potential distribution in the ablation channel, we demonstrated the supersonic rotation of the channel, a phenomenon which most likely causes the striation instabilities. The study of striation instabilities will be in focus of our future research. These instabilities, presently not well understood, have a significant impact on the pellet-plasma interaction that will occur in the fueling of burning plasmas in ITER. In the future, we will work with PPPL on heterogeneous multiscale MHD problems and performing simulation on BlueGene.



Rotational Mach number the pellet ablation flow demonstrating supersonic rotation of the channel, the most likely cause of striation instabilities.

Targets for Advanced Accelerators

The design of a liquid mercury jet target able to generate high-flux beams is among the most important problems of the design of Neutrino Factory / Muon Collider and future advanced accelerators and neutron sources. We have performed simulations in support of MERIT, a targetry experiment that is currently (summer of 2007) being performed at CERN. Future work will focus on the validation and benchmarks with experimental measurements, and simulations for future high power neutron sources.

For further information on this subject contact:

Dr. R. Samulyak
Brookhaven National Laboratory
Phone: 631-344-3304
rosamu@bnl.gov

or

Dr. Anil Deane
Applied Mathematics Research Program
Office of Advanced Scientific Computing
Phone: 301-903-1465
deane@ascr.doe.gov