Modelling plasma edge turbulence with Nektar++

David Moxey (6 month duration)

Collaborators: Prof. Spencer Sherwin, Dr. Peter Vincent (Dept. of Aeronautics)

1 Outline

Nektar++ is a spectral/hp element framework that is designed to simplify the task of applying high-order finite element methods in a variety of application areas. Currently, the framework has solvers for a number of fields including aeronautics, cardiac electrophysiology and oceanographic modeling. The purpose of this project is to leverage the development environment of Nektar++ and the excellent numerical properties of high-order methods to investigate problems in the field of plasma dynamics.

2 Project objectives

The purpose of this project is to support the development of a new solver to model drift-wave turbulence in the edge region of toroidally-confined plasma. Tokomak fusion reactors, in which tritium and deuterium plasmas are magnetically confined and reacted in a torus, are seen as the most promising route to achieve industrial-scale self-sustaining nuclear fusion. However, near the plasma edge, complex magnetohydrodynamical instabilities occur, leading to the development of phenomena such as drift-wave turbulence, allowing plasma to escape confinement. This increases the amount of energy needed to trigger and sustain ignition. Understanding these mechanisms in order to control this phenomenon is therefore important in the context of long-term fusion research.

One of the key challenges for existing physics tools is developing efficient solvers for the elliptic systems arising in these models, particularly when complex cross-sectional topologies are needed to represent the interior of the reactor. Some of the models used to examine this phenomenon, such as the Hasegawa-Wakatani equations, are closely linked to the fluids models which are one of the focal points of Nektar++, in which we have gone some way to solving these numerical challenges. To lay the groundwork for this project, a simple two-dimensional solver has been implemented within Nektar++ to model these equations (fig. 1). The purpose of this project is therefore to extend this toy problem to a toroidal, three dimensional geometry. This will be accomplished through the use of a mixed spectral-element Fourier pseudo-spectral formulation in cylindrical coordinates, which is known to be highly efficient in existing fluids applications.

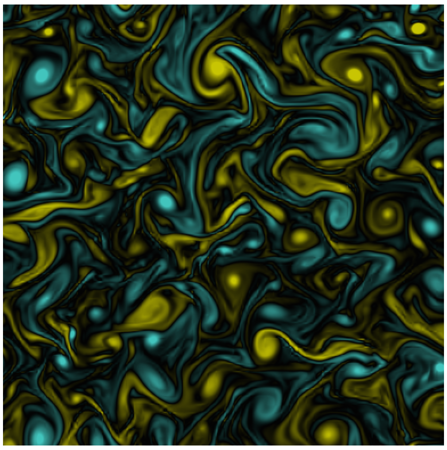

Figure 1: Simulation of drift-wave turbulence in Nektar++ using the Hasegawa-Wakatani equations in two dimensions at at time of $t = 200$. Contours of positive (cyan) and negative (yellow) vorticity are shown.

3 Alignment with PRISM strategy

Retention of key staff: I am one of the principal developers of Nektar++, with a strong background in computational science. I have been and am presently involved in a number of research projects that use Nektar++. One of the purposes of this project is to provide bridge funding between projects. Recently, an EU H2020 project proposed by our group has been accepted that will start towards the end of 2015 and which provides a facility for future funding.

Supporting long-term research: I am actively seeking a permanent academic position, in which Nektar++ will form a key part of my research activities. This will therefore lead to a widespread dissemination of PRISM-funded research to other institutions. This project is also intended to form the basis of an application for an EPSRC Early Career fellowship, in which far more complex models will be considered. However, this project will provide initial evidence as to the viability of these methods in a more complex setting.

Fostering new collaborations: The research is being supported through a new collaboration between ICL, Dr. Benjamin Dudson (York) and Dr. Wayne Arter (Culham Centre for Fusion Energy), who are interested in integrating improved numerical methods into the open-source software BOUT++. This additionally provides another avenue for the dissemination of PRISM research activities.

Collaboration with other PRISM members: Another goal of this project is to investigate the role that accelerator and coprocessor platforms, such as the Intel Xeon Phi, can play in decreasing simulation runtime. To this end, I plan to interact with other members of the PRISM group such as Dr. Peter Vincent and Prof. Paul Kelly, who have extensive experience of these computing environments.

4 Brief workplan

The project will comprise of the following milestones:

- Extension of the Hasagawa-Wakatani solver to a three-dimensional periodic cube.
- Implementation of a Fourier extension to the cylindrical coordinate system in the libraries of Nektar++. This will build upon previous PRISM projects, in which cylindrical coordinates were implemented for the purposes of stability analysis. This will extend the work so that it can be used in a full, three-dimensional solver.
- Testing of the above solver in the context of simple elliptic solutions and the more complex incompressible Navier-Stokes equations.
- Extension of the Hasagawa-Wakatani solver to incorporate the cylindrical Fourier extension.
- Create skeleton code, using Nektar++-generated input data, for use on accelerator platforms in order to investigate their viability in this research.
- Summarise the progress made and future directions in a presentation to the post-doctoral group at the end of the project.