35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.001 (2008)

Kinetic H-mode Pedestal Evolution with the Effects of Anomalous Transport

A.Y. Pankin[1], G. Bateman[1], C.S. Chang[2], F. Halpern[1], A.H. Kritz[1],
S. Kruger[3], S. Ku[2], D. McCune[4], G.Y. Park[2], T. Rafiq[1], P. Snyder[5], and S. Vadlamani[3]
[1]*Lehigh University, 16 Memorial Drive East, Bethlehem, PA 18015, USA*
[2]*New York University, NY 10012, USA*
[3]*Tech-X, Boulder, CO 80303, USA*
[4]*Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA*
[5]*General Atomics, San Diego, CA 92121, USA*

Poloidal and toroidal plasma rotation play a critical role in quenching the turbulent transport, in the formation of the edge and internal transport barriers, in the transition to the enhanced confinement mode, and in the dynamics of ELM crashes. It is important to have a self-consistent model that includes neoclassical and anomalous effects in order to describe the physics of intrinsic and imposed plasma rotation in tokamak plasmas. In this report, the current status of a model that includes plasma transport and rotation effects is presented. The application of this model to understanding of the dynamics of H-mode pedestal formation and ELM crashes is discussed.

The neoclassical effects related to the formation of velocity flow shear at the plasma edge have been successfully computed in recent self-consistent simulations with the kinetic XGC0 code [1]. The formation of an H-mode pedestal and the development of strongly sheared radial electric field profiles after the L-H transition have been demonstrated in simulations carried out using the XGC0 code.

Turbulence-driven transport is modeled in XGC0 as a radial random walk diffusion of particle orbits with diffusivity computed using a predictive transport model. The GLF23 gyro-Landau-fluid and the Multi-Mode fluid based drift-wave transport models are being implemented in the XGC0 code using a new generalized interface to the transport modules and libraries. The interface is created as a part of the Framework for Modernization and Componentization of Fusion Modules (FMCFM) project. The interface utilizes the technologies of encapsulation available in Fortran-95 that replace the COMMON BLOCK approach typical for Fortran legacy codes and allows the creation of a generalized interface to the reduced transport modules. The new interface facilitates access of the integrated modeling codes to the transport models and allows inter-language interfaces using a new library of C++/Fortran-95 wrappers. The functionality of the FMCFM interface is demonstrated in Framework Application for Core-Edge Transport

Simulations (FACETS) project. In order to improve the performance of the coupled kinetic-transport simulations, the GLF23 model has been parallelized. The dynamic evolution of the plasma edge region is shown in self-consistent simulations using the XGC0 code. These simulations include the formation of sheared velocity flows, turbulent transport suppression, and formation of the H-mode pedestal. In the H-mode pedestal region, the turbulence is strongly reduced by the strong $\mathbf{E}\times\mathbf{B}$ flow shear.

Recently, the extended MHD code NIMROD [1,2] has been be coupled with the kinetic XGC0 code using the Kepler workflow system (see Fig. 1). The NIMROD code uses a high-order finite element representation that provides the necessary accuracy for MHD instability simulations. This representation also allows for strong transport anisotropy at realistic parameters. The NIMROD code is routinely used for plasmas with Lundquist numbers larger than 10^8 and for plasmas with very anisotropic heat fluxes, as measured by the ratio of transport coefficients $\chi_\parallel/\chi_\perp > 10^9$. A combination of leap-frog advance and semi-implicit methods for MHD terms makes it possible to resolve the multiple time-scale physics from ideal MHD (μs) time scales to transport (ms) time scales.

Numerous verification studies have been carried out in which NIMROD results have been compared with the results of other MHD codes as well as with analytic scalings [3,4]. In order to assure that the growth rates and peeling-ballooning stability thresholds found with the ELITE code qualitatively agree with the stability threshold found with the NIMROD code, results obtained with the two MHD codes have been compared for a sample equilibrium from the CPES kinetic-MHD coupling studies. The equilibrium selected for this comparison is based on DIII-D discharge 113317.

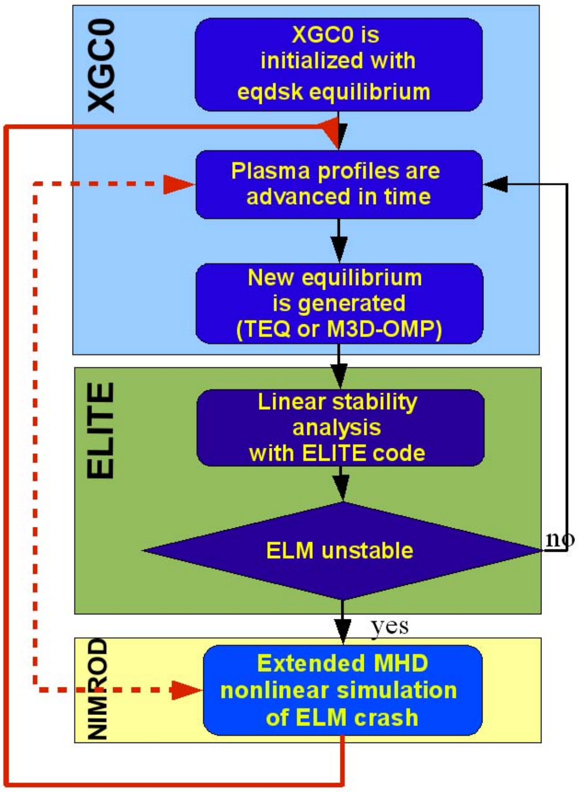

Figure 1: Data flow in the CPES computational framework that is used to follow the ELM dynamics. Red arrows indicate future development in Kepler workflow system to accommodate dynamic coupling between the XGC0 and NIMROD codes.

The growth rates as a function of toroidal mode number computed with the NIMROD and ELITE codes are shown in Fig. 2. The growth rates computed with the NIMROD code are approximately two times the growth rates computed with the ELITE code, and the peeling-ballooning threshold computed with the NIMROD code is lower. The differences in results can be explained by differences in the resistivity profiles in ELITE and NIMROD. The ELITE code is an ideal MHD code with zero resistivity in the plasma core and infinite resistivity in the vacuum region. For linear NIMROD code runs, the resistivity in the "vacuum" region is up to 1×10^6 larger than in the core plasma, approaching the ideal limit. For the free-boundary simulations, the resistivity has the Spitzer temperature dependence $T^{-3/2}$. For the DIII-D simulations shown here, the temperature ratio between the core and edge is approximately 500, which yields a resistivity ratio of approximately 10^5. For the lower resistivities in the plasma region and higher resistivities in the vacuum region, NIMROD yields results that are in better agreement with the ELITE results. Despite the differences in the growth rates, the eigenfunctions computed with NIMROD and ELITE agree reasonably well. This makes it possible to use the NIMROD code for nonlinear evolution studies of ELM crashes and to use the ELITE code, which is better validated against the experimental data, for the linear peeling-ballooning stability analysis of plasma profiles computed with the XGC0 kinetic code.

The dynamics of ELM crashes in several DIII-D discharges have been studied in simulations obtained using the coupled XGC0/NIMROD codes. In these simulations, the linear ideal MHD stability code ELITE is used to determine if the equilibrium is unstable for peeling or ballooning modes that can develop to produce an ELM crash. If the ELITE code finds a mode with a linear

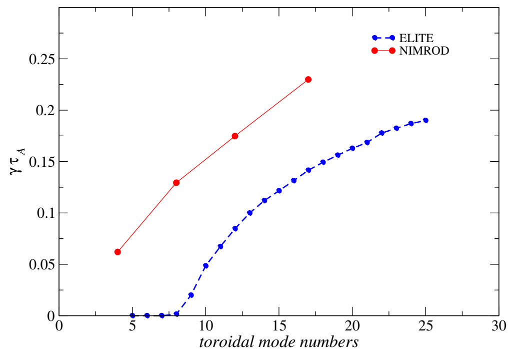

Figure 2: Growth rates as a function of toroidal mode number computed with the NIMROD and ELITE codes for the DIII-D discharge 113317.

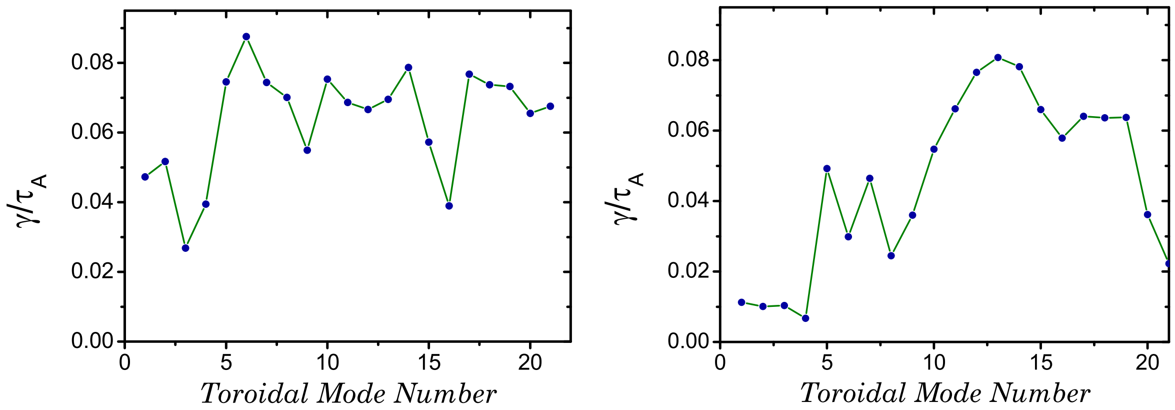

Figure 3: The growth rates as function of toroidal mode numbers computed in the NIMROD simulations of ELM unstable equilibrium for the DIII-D discharge 96333 without two-fluid effects (left panel) and with two-fluid effect (right panel).

growth rate that is above the typical threshold for ELM instability (usually taken to be one half of the ion diamagnetic drift frequency), then the corresponding kinetic equilibrium is transferred to the NIMROD code to perform a simulation of the ELM nonlinear evolution. In these nonlinear NIMROD simulations of DIII-D discharges, it has been shown that the dynamics of the ELM crash is strongly affected by two-fluid effects. These effects are represented by the gyro-viscous and Hall terms that have been recently implemented in the generalized Ohm's law and in momentum equation in the NIMROD code [5-7]. The two-fluid effects tend to stabilize high mode numbers [6]. The stabilization of the high-n modes, which have a relatively fine spatial scale, should make the corresponding nonlinear computation easier. The two-fluid effects on the growth rates are demonstrated in Fig. 3. These effects cause the modes to rotate with a poloidal drift frequency comparable to the diamagnetic frequency, and this rotation makes it more difficult to advance the equations in time. It is shown in Fig. 4 that the ELM filaments are strongly sheared by poloidal rotation in the pedestal and Scrape Off Layer (SOL) regions. Such shearing will influence the heat load associated with ELM crashes and might significantly increase the propagation time of ELMs through the pedestal and SOL region.

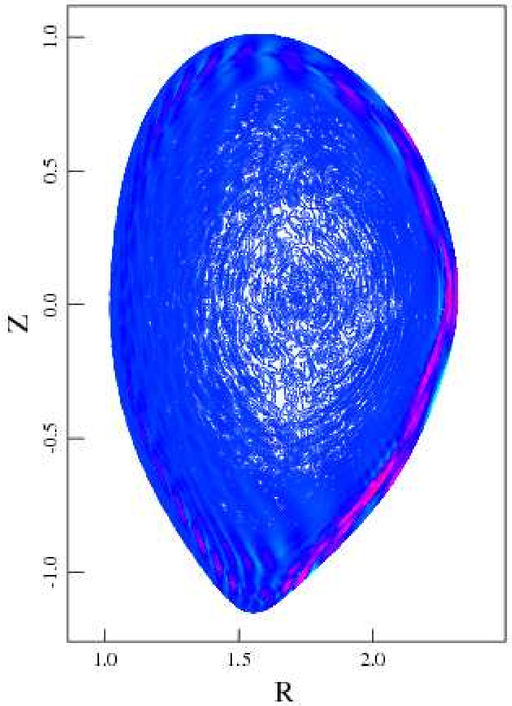

Figure 4: Contour plots of the electron temperature perturbation during nonlinear stage of an ELM crash computed with the NIMROD code for the DIII-D discharge 96333. The code is initialized with ELM unstable equilibrium computed from the plasma profiles that are advanced with the XGC0 code. ELM filaments are sheared by the poloidal rotation.

References

[1] C. Chang and S. Ku, Phys. Plasmas **11**, 5626 (2004).

[2] C. R. Sovinec, A. H. Glasser, T. A. Gianakon *et al*. J. Comput. Phys. **195**, 355 (2004).

[3] C.R. Sovinec, T.A. Gianakon, E.D. Held *et al*. Phys. Plasmas **10**, 1727 (2003).

[4] S.E. Kruger, D.D. Schnack, and C.R. Sovinec. Phys. Plasmas **12**, 056113 (2005).

[5] C. R. Sovinec, D. D. Schnack, A. Y. Pankin *et al*. J. Phys.: Conf. Series **16**, 25 (2005).

[6] D.D. Schnack, D.C. Barnes, D.P. Brennan *et al*. Phys. Plasmas **13**, 058103 (2006).

[7] A.Y. Pankin, G. Bateman, D.P. Brennan *et al*. Phys. Control. Fusion **49**, S63 (2007).