BOUT++ Simulations of Edge Turbulence in Alcator C-Mod’s EDA H-Mode

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Abstract

Energy confinement in tokamaks is believed to be strongly controlled by plasma transport in the edge region just inside the last closed flux surface, and a first principles understanding of these edge processes is an active field of theoretical and experimental research. The Boundary-plasma Turbulence (BOUT++) code is capable of nonlinear fluid boundary analysis in a general geometry. Using experimentally measured profiles as input, BOUT++ calculations show that typical C-Mod EDA H-modes are ideal MHD stable, but become linearly unstable when the pedestal resistivity is included (∇ × B)2 > 10−8Ω−m. The computed resistive ballooning mode growth rate in such slots is shown to scale approximately as n2 and m2, consistent with theory. Inclusion of diamagnetic effects leads to a maximum growth rate at n ~ 25 and mode propagation in the lab frame electron diamagnetism consistent with experimental observations. Nonlinear simulations have reached turbulent steady state, allowing for future comparison with fluctuation diagnostics.

BOUT++ Code

- 3D nonlinear fluid boundary plasma code in a general geometry
- Inertial MHD numerical scheme
- BOUT++ provides an object-oriented framework in C++
- MPI parallelization allows ideal strong parallelism to 50,000 cores
- Multi-developer version control system allows efficient development

Initial Results

- BOUT++ results show significant growth rates for n > 25, with a maximum at n ~ 25
- Experimentally, the QCM typically occupies n=10−25
- High mode numbers (n>30) are damped

Equilibrium Input

- Pedestal separation
- Equilibrium parallel current profile
- Zero current beyond separation
- Equilibrium safety factor profile
- Open field lines

Magnetic Geometry

- Field-aligned coordinates

Growth Rate Calculations

- Non-ideal MHD peeling-balloonning mode theory
- In linear regime, the growth rate scales as n2 and m2
- Growth rates “roll off” as inertial effects begin to limit the plasma response

Conclusion and Future Work

- BOUT++ simulations show that typical C-Mod EDA H-modes are stable to ideal peeling-balloonning mode flux
- BOUT++ results are consistent with resistive ballooning mode theory
- Diamagnetic effects damp high toroidal mode numbers (n>30) and produce mode propagation in the electron diamagnetic direction, in qualitative agreement with experimental observations of the QCM
- Plasma flow will be incorporated into future simulations in order to self-consistently compute the edge radial electric field
- Future gyrofluid modifications to BOUT++ may allow for more accurate simulation of lower collisionality plasmas (e.g. 1-Mode)

Non-Ideal MHD Peeling-Ballooning Mode Equations Solved in BOUT++

- Non-ideal physics
- Include resistive (HRM) resistivity can be represented as non-linear resistivity

In the linear regime, the growth rate scales as n2 and m2

Growth rates “roll off” as inertial effects begin to limit the plasma response

Turbulent steady state has been achieved in nonlinear simulations

8-14 H in C-Mod EDA pedestal, making it relatively resistant compared to ~10−10

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