This work was performed under the auspices of the

(1) Abstract

The omnipresence of a macroscopic steady-state edge fluctuation known as the C-Mod’s Enhanced D-Alpha (EDA) H-mode suggests the dangerous mode allowing operation at steady-state Enhanced D-Alpha (EDA) H-mode ((n=15) is the most unstable mode for ELMy operation?)

(2) Motivation

ELMy H-mode operation near the P-B stability boundary - most unstable

(3) Peeling-balloonong (P-B) modes thought to constrain ELMy H-mode pedestals

• Experiments routinely exceed the pedestal current gradient limits set by ideal ballooning theory
• Pedestal current (1) drives low-n peeling modes and (2) reduces magnetic shear, stabilizing high-n ballooning modes
• Peeling and ballooning modes couple to drive the dominant (ELMy) pedestal instability at intermediate 5 ≤ n ≤ 25
• Strong shaping weakens the coupling between peeling and ballooning modes, allowing operation at higher pedestal currents and pressure gradients

(4) Ideal peeling-balloonong modes do not appear to constrain ELMy H-mode pedestals

ELITE2) calculations show: Ideal MHD modes operate near the P-B stability boundary - H-mode operates well inside P-B stability boundary - Nonideal physics excite the QCM, allowing ELMy H-mode operation - Also, prediction of experimental relevant fluctuation levels requires simulation of the nonlinear saturated regime

(5) Nonideal and nonlinear physics can be investigated with the BOUT++ code

• 3D, nonlinear, initial value code for simulating fluid boundary plasma turbulence in a general geometry
• Nonlinear realistic X-point geometry - For consistency with ELITE, simulations conducted within separatrix (vphilower < 0.00999)
• Nonideal affects (resistivity, FLR, etc) can be easily implemented in the BOUT++ code

(6) Previous BOUT++ calculations have shown agreement with resistive-balloonong theory

- In the linear regime resistive-ballooning modes (RBM) growth rates scale as n0 4/3
- Growth rates with smaller inelastic and resistive effects begin to limit the plasma response
- Small discrepancies likely due to the RBM model’s (1) assumption of electrostatic fluctuations and (2) use of a sheared slab geometry

(7) VARY PEDAL altered the pedestal pressure gradient, which was then input into BOUT++

The VARYPED Pressure Profiles

- The VARYPED tool produces a series of ELMs with a variation in pedestal parameters
- Most often, the pressure gradient and current density are varied
- The pressure gradient was varied between 55% and 145% of the experiment value
- The variation is carried out holding plasma shape, total stored energy, and total plasma current constant

(8) Criterion for Ideal MHD Stability

Ideal MHD theory provides the following dispersion relation

\[ \gamma_{\text{ideal}} = -\sqrt{D_{\text{ideal}}} \approx \frac{\omega_{\text{eff}}}{c} \]

where the strong variation of plasma parameters in the pedestal is accounted for with the effective diamagnetic frequency, \( \omega_{\text{eff}} \)

- The stability threshold will be reached when

\[ \gamma_{\text{ideal}} > \Delta \]

• The diamagnetic frequency can be roughly calculated as

\[ \omega_{\text{diam}} \approx \sqrt{2 \frac{\mu_0}{\mu_1} \frac{B_0^2}{r_0^2} \frac{l}{A}} \]

where \( x \) is the plasma’s ellipticity

(9) Resistivity pushes the ELMy H-mode regime beyond the stability threshold set by ideal MHD

- Ideal simulations at the experimental pressure gradient sit well within the stability region
- In qualitative agreement with ELITE
- At moderate pressure gradients, the ideal modes are pushed just beyond the resistive-ballooning stability, with low- \( n \) (n=15) most unstable

(10) Conclusions and Future Work

• BOUT++ simulations were performed to map out the ideal and resistive stability boundaries in pressure gradient space
• Ideal peeling-balloonong modes sit just below the ideal MHD stability boundary, in agreement with ELITE
• Inclusion of pedestal resistivity drives resistive ballooning modes that sit well above the stability threshold set by ideal MHD
• Future work will extend the simulation domain beyond the separatrix and map the stability boundaries in (\( \gamma_{\text{ideal}}, P \)) space
• Future simulations will also seek to predict fluctuations in the nonlinear saturated regime, allowing comparison to and validation with experiment

(11) References


Stable/Unstable

Diamagnetic Drift

\[ \bar{v}_f \approx \frac{\mu_0 B_0^2}{\mu_1 r_0^2} \frac{l}{A} \]