Anisotropic Peeling-Ballooning Mode Scans of JET-like Equilibria

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It is well known that neutral beam injection and ion cyclotron resonance heating can induce pressure anisotropy, in which the pressure perpendicular and parallel to the magnetic field lines is different (see for instance the review article and references therein of Hole and Fitzgerald [1]). In JET, ICRH can cause anisotropies of $p_\perp/p_\parallel \sim 2.5$ [2], where $p_\perp$ ($p_\parallel$) refers to the total plasma pressure perpendicular (parallel) to the magnetic field lines. In the UK's Mega Ampere Spherical Tokamak (MAST), parallel NBI heating can lead to anisotropy of up to $p_\parallel/p_\perp \sim 1.7$[3].

Qu *et al* has modified the equilibrium and stability codes to capture the effects of pressure anisotropy. These new codes, HELENA+ATF[4] and MISHKA-AD[5], permit the numerical study of tokamak instabilities in anisotropic conditions. The code combination has been used to analyse impact of anisotropy to ITER pre-fusion power 5 MA, B = 1.8 T ICRH scenarios.[6] These studies involved iteratively re-mapping the toroidal flux function $F(\psi)$ to preserve the q profile (a form of q-solver). The revealed the impact of dominantly core anisotropy with $P_\perp > P_\parallel$ produces an outboard shift of the density 0.16 m off-axis. Analysis using MISHKA-AD showed that the incompressional continuum is largely unchanged in the presence of anisotropy and the mode structure of gap modes is largely unchanged. In contrast, the compressional branch of the continuum is substantively changed, suggesting modification to acoustic-Alfven modes.

In this treatment we utilize the remapping techniques of Hole et al, together with HELENA+ATF and MISHKA-AD to compute the effect of pressure anisotropy on ballooning and peeling-ballooning modes in JET-like equilibria, and compute the marginal stability boundary. The isotropic equilibrium is based on an ELMing time-slice of JET #78672. We have performed a physics scan over moderate pedestal anisotropy in order to study the relationship between anisotropy and ELM stability. A parameterisation of $\Theta(\Psi) = B(1/T_\parallel - 1/T_\perp) \sim \Theta_0 (1+10\,\Psi_n^2)$ is chosen, where Ψ_n is the normalised poloidal flux, and Θ_0 is the on-axis value. This parameterisation increases anisotropy in the pedestal. We have computed results for Θ_0=0, 0.4, -0.4, corresponding to on-axis values of $P_\parallel/P_\perp=1$, $P_\parallel/P_\perp=0.6$ and $P_\parallel/P_\perp=1.4$. Finally, to verify the effect is due to pressure anisotropy we have verified that the surface averaged pressure gradient α and flux averaged toroidal current $\langle j_\phi \rangle$ are not modified by anisotropy.

Figure 1 shows the growth rate versus toroidal mode number for an ELMing time slice with an unstable peeling-ballooning mode in the equilibrium. We see that $P_\parallel > P_\perp$ is destabilising for this equilibrium, while $P_\perp > P_\parallel$ is stabilising. This is opposite to the predictions for pure ballooning theory[7], which predict a destabilising effect when $P_\perp > P_\parallel$.

Figure 2 shows the marginal stability boundary in ($\langle j_\phi \rangle$, α) space. Anisotropy was varied at each point, producing 3 stability grids over ($\langle j_\phi \rangle$, α). The different stability boundaries are overlaid. Changing pressure anisotropy was able to produce a small change in the marginal stability boundary. For large-*n*, we recover the predictions of pure ballooning theory, where $P_\perp > P_\parallel$ is destabilising. For intermediate-n PB modes, we see $P_\parallel > P_\perp$ is instead destabilising.

Figure 3 and 4 show the marginal stability loci for a growth rate of $\gamma^2/\omega_A^2=5\times10^{-3}$ and $\gamma^2/\omega_A^2=10^{-2}$. These demonstrate that pressure anisotropy has a larger effect on the growth-rates of unstable modes, and further validate that $P_\parallel > P_\perp$ is destabilising for intermediate-n modes.

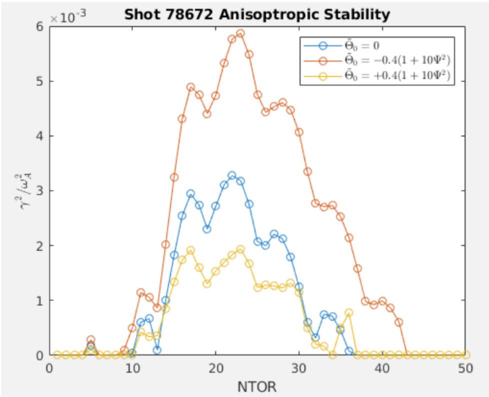

Fig. 1: . Normalised growth rate as a function of n for JET #78672 with illustrative anisotropies: $P_{II}/P_\perp = 1$ (black), $P_{II}/P_\perp > 1$ (red), and $P_{II}/P_\perp < 1$ (yellow).

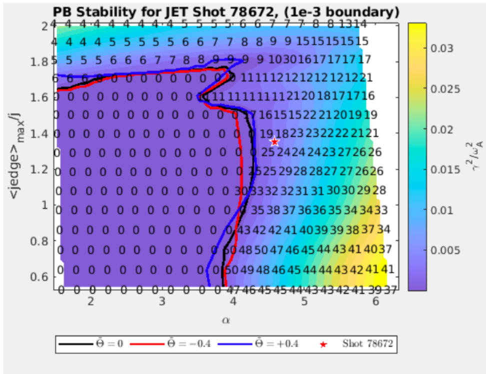

Fig. 2: . Marginal stability boundary in ($<j_\phi>$, α) space for $P_{II}/P_\perp = 1$ (Black), $P_{II}/P_\perp > 1$ (red), and $P_{II}/P_\perp < 1$ (blue). The colorbar represents the growth rate and the number at each point the most unstable mode.

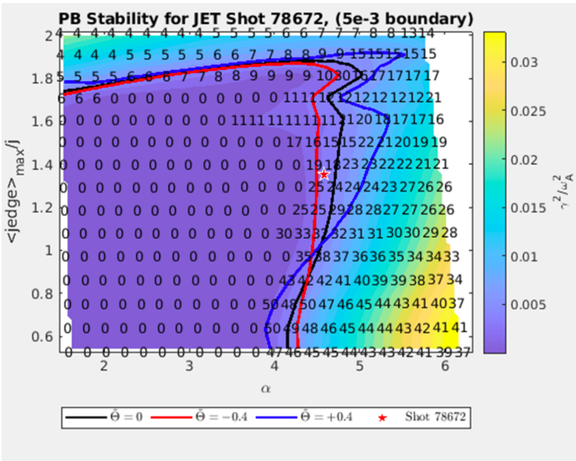

Fig. 3: . Stability boundary for $\gamma^2/\omega_A^2 = 5\times10^{-3}$ in ($<j_\phi>$, α) space for $P_{II}/P_\perp = 1$ (Black), $P_{II}/P_\perp > 1$ (red), and $P_{II}/P_\perp < 1$ (blue).

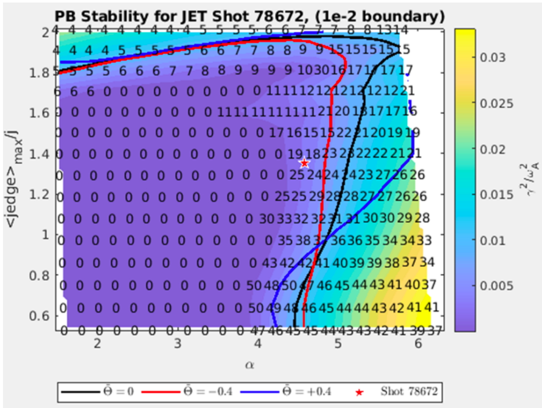

Fig. 4: . Stability boundary for for $\gamma^2/\omega_A^2 = 10^{-2}$ in ($<j_\phi>$, α) space for $P_{II}/P_\perp = 1$ (Black), $P_{II}/P_\perp > 1$ (red), and $P_{II}/P_\perp < 1$ (blue).

In summary we have explored the impact of anisotropy on marginal stability in ($<j_\phi>$, α) space. As shown for high-n ballooning modes, $P_\perp > P_\parallel$ was destabilising, in agreement with ballooning literature. For intermediate-n PB modes, we instead have shown that $P_\parallel > P_\perp$ is destabilising. Future planned research will investigate the sensitivity of the results to changes in the anisotropy profile $\Theta(\Psi)$, as well as highly anisotropic JET cases in which ELMs trigger before the peeling-ballooning boundary. Predicting the impact on ITER scenarios could be important. Computationally, we plan to calculate parallel current in HELENA+ATF in order to clarify the effect of pressure anisotropy on peeling-ballooning stability. Finally, we hope to explore the impact of both and anisotropy and flow on peeling-ballooning modes.

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