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Ballooning Stability of Internal Transport Barriers

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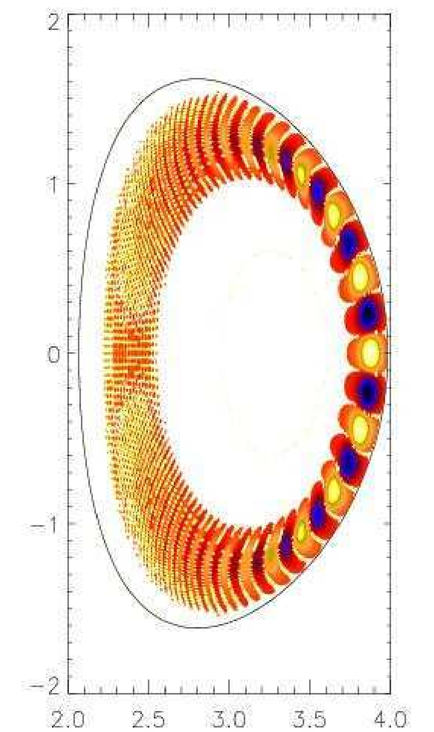

Fig 1. Poloidal cross section of a ballooning mode instability. Areas of intense blue or yellow indicate the largest displacements.

Introduction

It is found experimentally that internal transport barriers (ITBs) generally form in regions of low or even negative shear. The program ELITE[2] was originally written to study edge localised modes (ELMs). However, with increasing interest in ITBs and the related advanced modes of operation, it was decided to modify the code to look at ballooning instabilities centred on ITBs. The new version of the code has been successfully benchmarked against the MISHKA[3] stability code. Fig (1) shows the result from studying an unstable ITB equilibrium in a JET like tokamak. Ballooning theory suggests two important parameters α and shear (*s*) map out three regions. These parameters are defined as: $s = \frac{r}{q}\frac{dq}{dr}, \alpha = -\frac{2\mu_0 R q^2}{B^2}\frac{dp}{dr}$, where r is the minor radius, q is the tokamak "safety factor", B is the magnetic field and p is the plasma pressure. The first stability region is bounded by a line of increasing α and s, where increasing α is destabilising but increasing s is stabilising. This is the normal operating regime for most tokamak equilibria. There is also the possibility for a second stability region of low s and high α. The FAREQ[6] code allows the specification of an analytic q-profile, and was used to generate the initial equilibrium. A number of JET-like tokamak equilibria were generated. α was varied by changing the peak gradient in the pressure profile. In order to maintain constant q-profiles it was not possible to hold β constant. The magnetic shear was varied by

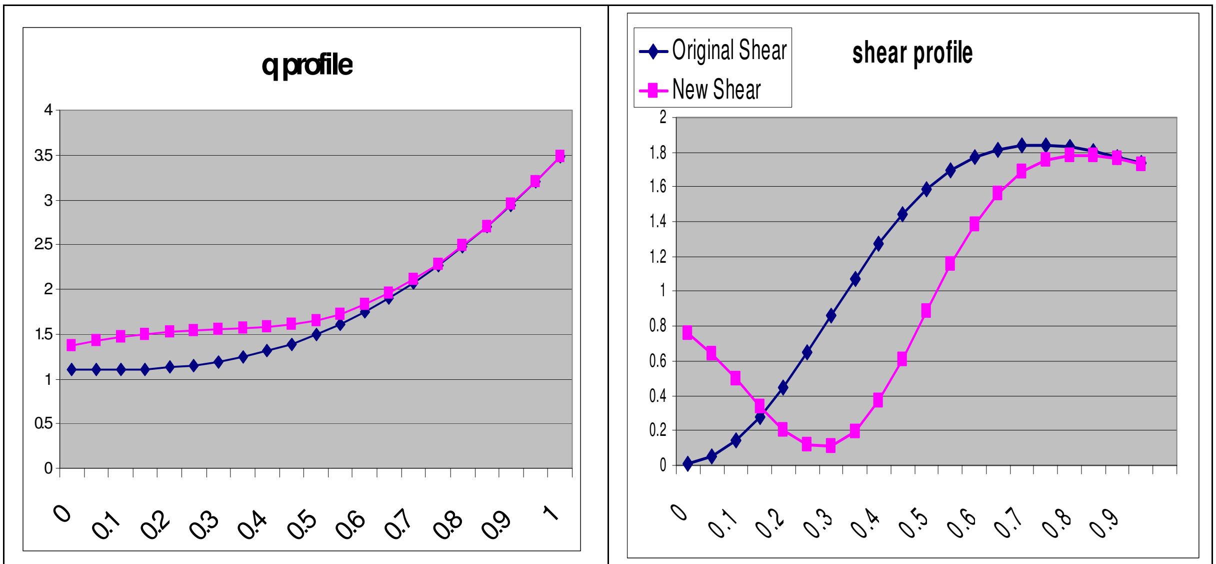

Fig 2. An illustration of how the q-profile was modified in each case. By Adding a guassian to smooth the profile, the shear profile is modified. For a given flux surface the shear can thus be controlled when looking for unstable equilibria.

adding a Gaussian function to the q-profile of varying heights as shown in fig 2. FAREQ output is used as input to the HELENA[5] equilibrium code, which in turn performs an analysis of ballooning stability based on infinite toroidal mode number (n) calculations, with the domain of instability maximised over the radial wave number (θ_0)[7]. From there the ballooning stability for a given n can be calculated in ELITE. Each equilibrium was calculated with varying shear and α at a given flux surface. For simplicity the values of α and s are shown at a fixed flux surface of ψ_n=0.55 in each case which is near the peak α value.

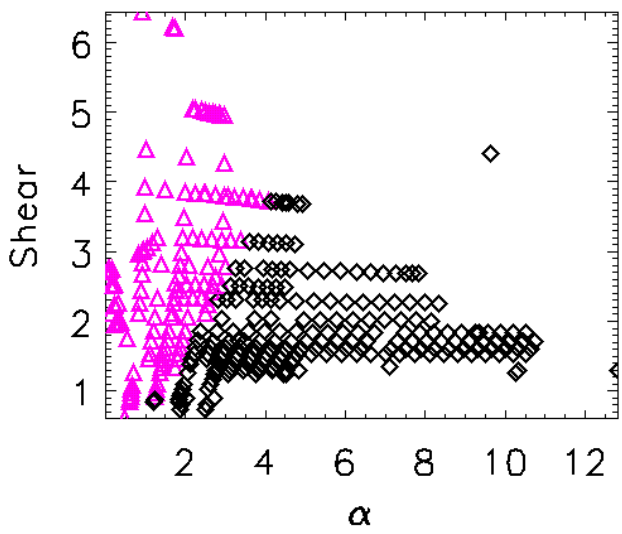

Fig 3. Infinite n stability for a range of equilibria with different values for s and α. purple is stable; black is unstable at ψ_n=0.55

Results

As can be seen in fig 3, the infinite-n ballooning calculations show a clear boundary between the first stability region and the unstable region, in line with analytic theory. However, there is little evidence of a second stability region at the lowest s attainable with the particular class of equilibria used. After these equilibria had been generated, the stability of some of them was computed with the ELITE code, for n of 20, 15 and 25, shown in figs 4, 5 and 6 respectively; the results are given as a contour plot showing the growth rates for different values of s and α. The strong yellow colours indicate large growth rates. As expected, for any given value of s and α the growth rate is higher for higher n values. As the value of n tends towards infinity it would be expected to recover the infinite-n limit shown in Fig 3. Fig 4 shows the most extensive study; at low α a first stability boundary seems evident (the n=20 domain of instability is all within the inifinite-n unstable domain). There is no clear second stability behaviour (growth rate decreases as α increases) but at low s very high α values are stable). Comparing Figs 4 and 5 between the values of n=15 and n=25 it can be seen that the region of instability is enlarged, and the boundary is shifted down. Only the change between yellow and blue should be used to interpret the position of the stability boundary as black areas lack data points.

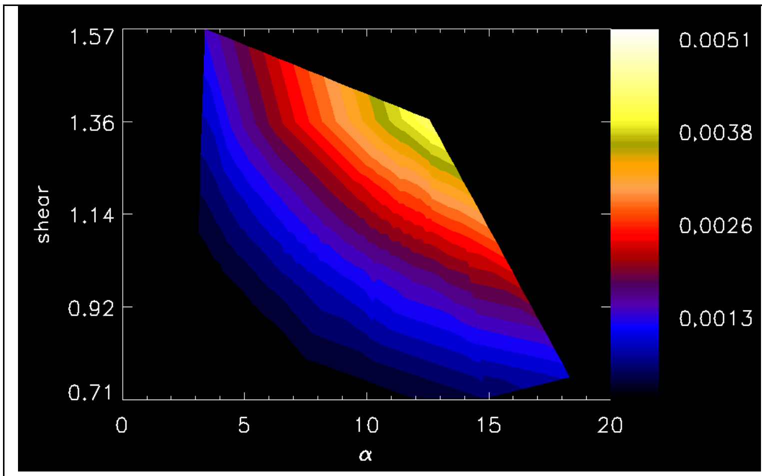

Fig 4. Contour plot showing ELITE growth rates at n=20. The colour bar indicates the initial growth normalised to the Alfvén time.

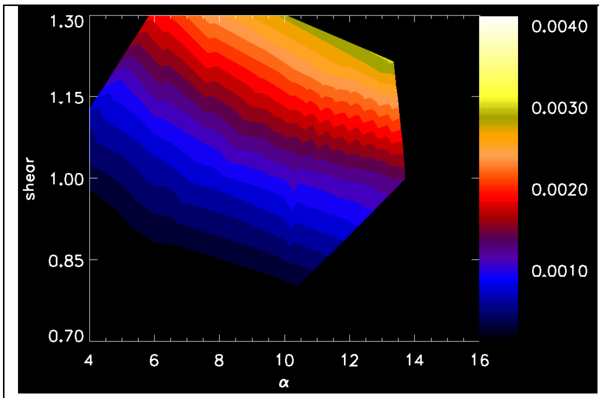

Fig 5. Contour plot for n=15

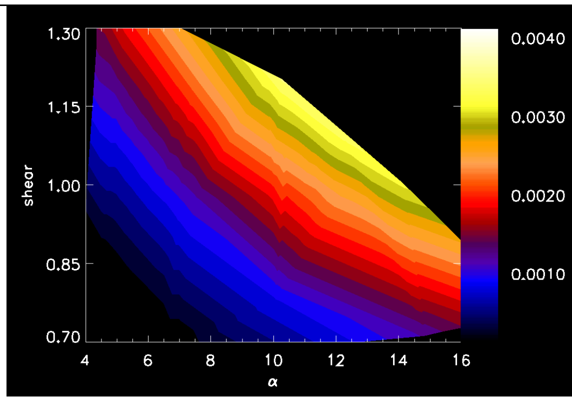

Fig 6. Contour plot for n=25

Conclusions

The results suggest that the ITB equilibria are entering the second stability region, where the combination of high α and low s are stable to moderate n modes. The existence of ITBs is consistent with the fact that they are not unstable to low to mid-n ballooning modes – the most destructive modes. In practice very high-n ballooning modes are likely to be stabilised by kinetic effects. It is not possible to form an ITB in a high s region because it would be ballooning unstable to low to moderate-n modes and would quickly disappear.

Acknowledgements:

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