The influence of the separatrix on external modes.

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Introduction. Ideal MHD stability analysis of tokamaks with a divertor are often based on an equilibrium model which is defined by a flux surface chosen to lie some distance from the seperatrix. A common practice is to select a flux surface which encloses a prescribed fraction, *e.g.* $\psi_{\text{frac}} = 98\%$, of the poloidal flux as the plasma-vacuum interface. This has two consequences, the safety-factor which would approach infinity at the separatrix is limited to a low value, typically $q_{95} \sim 5$. The other effect missing from the fractional flux model is the effect of the changing plasma shape as the separatrix is approached, in particular the local curvature changes rapidly in the vicinity of the X-point and may have additional effects on the stability. This latter point has been studied extensively in the context of high-n ballooning modes, [1], and more recently in the context of medium-n modes [2]. Here n refers to the toroidal mode-number. We now present a study of these issues in the context of the $n = 1$ external kink instability.
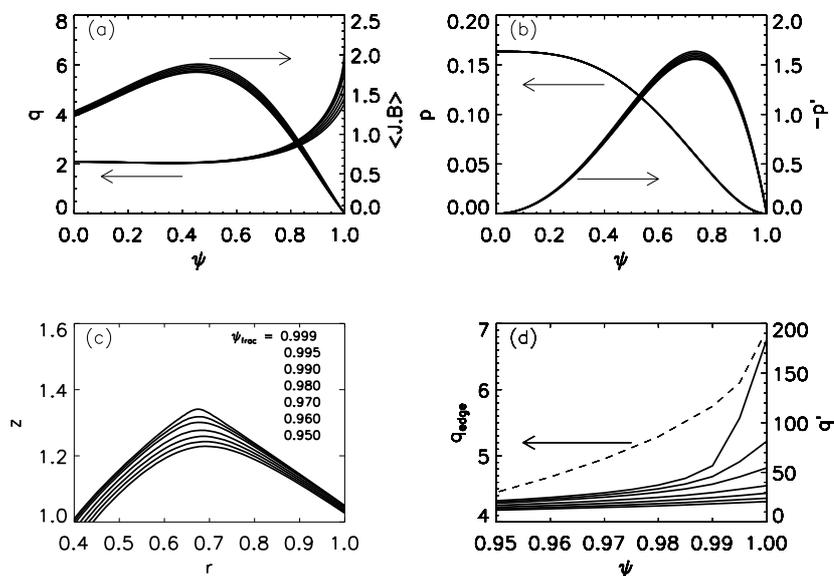

Figure 1: *Plasma profiles and details of the geometry for several choices of ψ_{frac} , the fraction of the flux within the seperatrix that is included in the stability analysis; a) shows the safety-factor q and the surface-average current $< J \cdot B >$, b) shows the pressure and its gradient, $\frac{dp}{d\psi}$, c) shows details of the shape near the seperatrix and d) the variations of q_{edge} and q' near the plasma edge as ψ_{frac} is varied.*

Equilibrium model. The model equilibria used in this study are obtained from

the EFIT code[3]. This code computes a free boundary equilibrium based on external coils and field for selected plasma current and pressure profiles. Here we use the coils and field configuration of the NSTX device. The main geometric parameters are: major-radius, $R = 1.69m$, minor-radius, $a = 0.6m$, and we examine two different shape, a) elongation, $\kappa = 2.0$, and triangularity, $\delta = 0.35$, and b) $\kappa = 1.6$, $\delta = 0.5$. The plasma profiles are specified as follows: the pressure is defined by, $p = p_0(1 - \psi^\beta)^\alpha$, with $\beta = 3$ and $\alpha = 2$. The diamagnetic term in the Grad-Shafranov equation is given by $ff' = 1.505\psi^5 - 2.846\psi^4 + 2.387\psi^3 - 2.926\psi^2 + 0.874\psi + 1.0$. The toroidal field is set so that the vacuum field is $B_t = 0.3Tesla$ at $0.85m$ and the plasma current, $I_p = 1.0MA$. Figure 1 is a composite of the plasma profiles for different values of ψ_{frac}. It also shows the changing geometry in the vicinity of the X-point.

This choice of profiles results in safety-factor profiles such that $q_{axis} > 1$ and $q_{edge} \sim 7$ even when ψ_{frac} approaches unity. Avoiding the $q = 1$ surface is important as it eliminates any ambiguities associated with the $m/n = 1/1$ mode and allows us to isolate the physics of the external kink. Here m refers to the poloidal mode number. The pressure profiles was chosen to avoid internal modes and minimize the drive at the plasma edge. Later we will discuss a variation where a small pressure gradient is added to simulate an edge pedestal typical of a H-mode discharge. We refer to the present set as L-mode profiles.

Stability analysis. The stability is determined using the PEST-2 code[4]. In Figure 2 we show the variation of the growth-rate as ψ_{frac} is varied for a selected equilibrium with $\beta = 24\%$. Note that as ψ_{frac} is increased from 0.95 to 0.999 q_{edge} increases from about 6.5 to a value greater than 10.0. It is interesting to note that the growth-rate decreases in steps as each rational surface is crossed and the mode is eventually stabilized when $\psi_{frac} = 0.999$ and $q_{edge} > 10.0$.
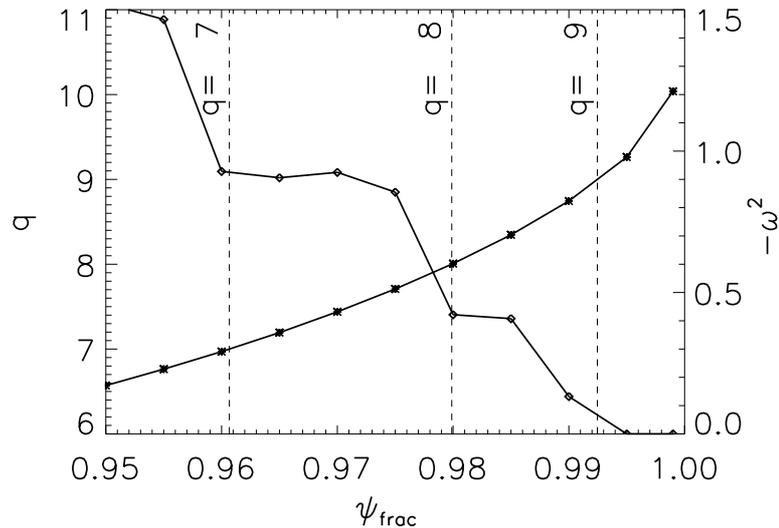

Figure 2: *The safety-factor, q and the growth-rate, $-\omega^2$, for different values of ψ_{frac}. Note the sharp drop in $-\omega^2$ when q_{edge} changes through rational values, also marked.*

H-mode profiles. We modified the pressure profile to make p' finite at the plasma edge to simulate an H-mode discharge. This also results in a finite edge current density, see
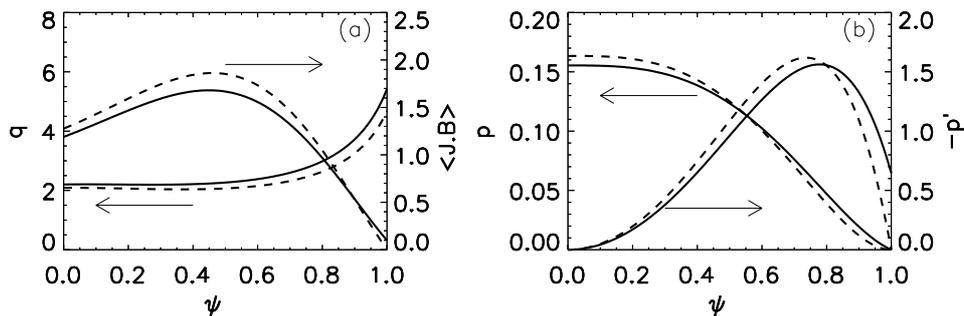
Figure 3: *Comparison of H-mode(solid) and L-mode(dashed) profiles. The total current is kept constant. a) there is a small pedestal in the current, a) and there is a finite pressure gradient at the plasma edge, b).*

figure 3. A similar stabilization of the external kink is observed. In order to get a better understanding of these effects, we have determined the β -limits using the conventional B-field scaling method. Figure 4 shows the dependence of the β -limit for both the L- and H-mode profiles. It is interesting to note that even with the finite edge current density and pressure gradient the improvement of the β -limit with increasing ψ_{frac} is still observed, in fact the resulting β -limits are slightly higher.
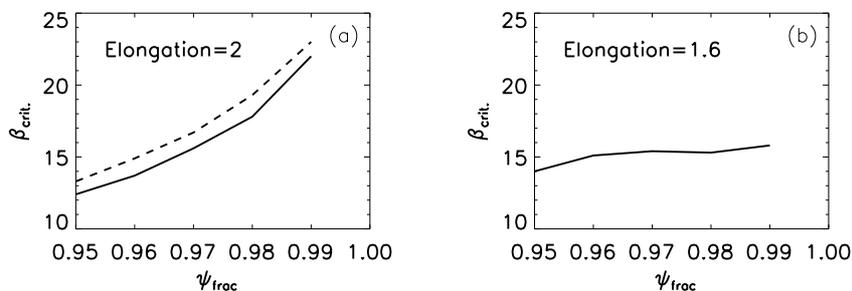

Figure 4: *β limits for the L-mode(solid) and H-mode(dashed) profiles in the $\kappa = 2$ case, a) and for the L-mode profile with $\kappa = 1.6$.*

Geometric effects. In order to study the effect of varying the plasma shape, we vary the geometry while maintaining the L-mode profiles.The shapes are shown in Fig. 5a, the stability limits are shown in Fig. 4b. We note that in contrast to the higher elongation case there is only a modest rise in the β -limit as ψ_{frac} is increased towards unity. Also note that the change in the geometry strongly affects the gradient in q, see Fig. 5b. Since the shear plays an important role in stabilizing the external kink the reduced gradient results in a weaker improvement of the β -limit as seen in Fig. 4b.

Discussion. In this study we have to attempted to understand the role of the different features of a diverted plasma on the external kink instability. In order to do this we have carefully selected profiles which will highlight the role of the seperatrix. The two important features of a diverted plasma are, the rapid rise in the safety-factor as the
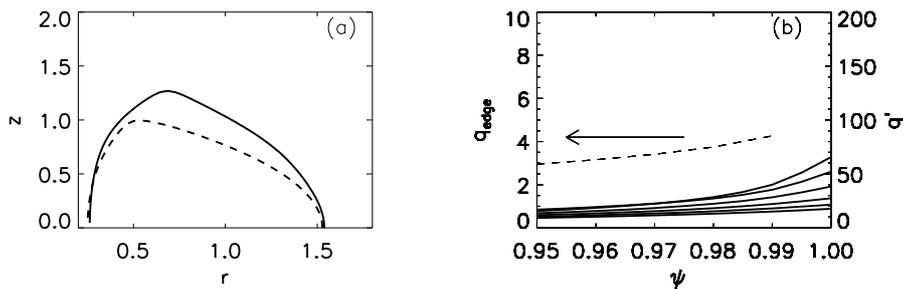
Figure 5: *a) Comparison of two geometries considered here, i) Elongation=2.0, triangularity=0.35, (solid) and ii) Elongation=1.6, triangularity=0.5,(dashed). On the right the details of the q-profile near the edge are shown. Note that in contrast with Fig. 1, the maximum value of q′ is significantly lower.*

seperatrix is approached and the change in the local curvature, these are inter-related effects. In Fig. 1d we observe that while q rises rapidly, q' increases even more rapidly for this particular geometry as we approach the seperatrix. The effect of this large value of q' is to dramatically improve the stability of the $n = 1$ external kink, Fig. 2 and Fig. 4a. It is interesting to note that with a different geometry, Fig. 5a, which does not have as strong a local curvature near the X-point, the change in q' is much smaller, even though, the pressure and current profile shapes were kept the *same*. This suggests that the rise in q' is governed strongly by the nature of the flux-surface geometry near the boundary. This may cast new light on the observations of improved stability with increased shaping. The other interesting feature is the rather dramatic sensitivity to the value of q_{edge} , displayed in Fig. 2. In fact a systematic study, not shown here, of this effect shows that there may be islands of stability associated with having q_{edge} equal to an integer value. This also reflects the experimental observations of increased MHD activity shortly after q_{edge} passes through an integer value. In passing we also note that these equilibria are stable to high-n ballooning modes. Further studies with different plasma profiles are needed to determine the best operating regimes for diverted plasmas.

References

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