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EFFECTS OF CROSS-SECTION SHAPE ON L–MODE AND H–MODE ENERGY TRANSPORT

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EFFECTS OF CROSS-SECTION SHAPE ON L–MODE AND H–MODE ENERGY TRANSPORT

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INTRODUCTION

The cross-sectional shape of tokamaks is usually optimized for MHD stability or divertor considerations. This optimization has an influence on the energy confinement which is not well-characterized theoretically or experimentally. The experiments reported here attempt to isolate the effects on energy confinement of elongating the plasma while keeping the minor radius, toroidal field, and radial profiles of the density, temperature, and toroidal rotation constant. A key issue is how to vary the poloidal field. Theoretically, transport is treated as a function of safety factor q and magnetic shear, while experimentally, scaling studies use current as the independent variable. In order to compare with both approaches, scans of elongation at both constant q and constant current were analyzed.

H–MODE POWER BALANCE ANALYSIS

H–mode discharges with a lower single-null configuration were varied in elongation (κ) from 1.7–2.0. The results reported here are from the end points of this scan. To keep q fixed, the current (I) was raised from 0.84 MA to 1.08 MA. The electron density (n_e), electron temperature (T_e), and ion temperature (T_i) were well-matched as shown in Fig. 1. The

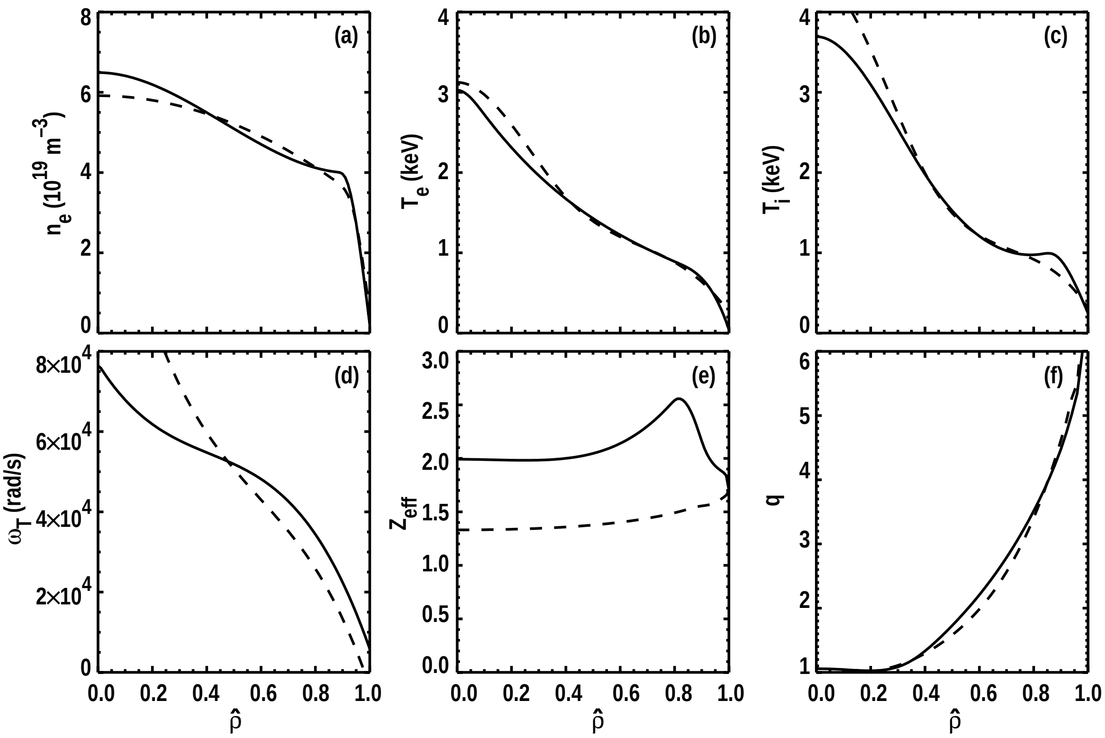

Fig. 1. Comparison of the radial profiles of (a) electron density, (b) electron temperature, (c) ion temperature, (d) toroidal rotation, (e) Z_{eff}, and (f) q for the higher elongation (solid) and lower elongation (dashed) discharges in the constant q H–mode scan.

toroidal rotation (ω_T) and effective ion charge (Z_{eff}) are less well matched, but are assumed to have weak dependencies for these discharges. The q profiles are somewhat different in the region of interest. It is straightforward to show from the flux-surface-averaged energy conservation equation that, for an experiment which perfectly matches the density and temperature profiles, $\chi_2/\chi_1 = (P_2/H_2)/(P_1/H_1)$ where P_j is the conducted power. H_j is the incremental volume of a toroidal annulus of thickness $\delta\rho$ compared to a circular cross-section annulus at the same value of the square root of normalized toroidal flux (ρ). H is close to 1 over the radial range of interest in all plasmas discussed here. Therefore, if the diffusivity is independent of geometry, the powers will also be unchanged as κ is varied. The sum of the electron and ion powers will be used in this paper since no error analysis has been performed to validate the separation into electrons and ions.

The effective diffusivity inferred from the conducted power required to match the profiles at constant q is reduced with increasing κ as shown in Fig. 2(a). For elliptical cross-section plasmas, the ratio of the normalized toroidal flux to the minor radius squared of flux surface ρ is approximately the elongation and therefore will be used in this paper as an estimate for $\kappa(\rho)$. The reduction in power at higher κ indicates the transport is reduced. Writing $\chi \propto \kappa^{\alpha}$, this implies a strong reduction of transport with κ ($\alpha \simeq -2$) shown in Fig. 2(b).

In strong contrast to this result is the analysis of the constant current case shown in Fig. 3. The elongation was varied over the same range as the constant q scan (κ = 1.7–2.0). The quality of the profile match is comparable to that for the constant q scan shown in Fig. 1 with the exception of the q profiles. The conducted power increases at higher κ [Fig. 3(a)] implying that transport increases at higher κ ($\alpha \simeq 1.5$) [Fig. 3(b)].

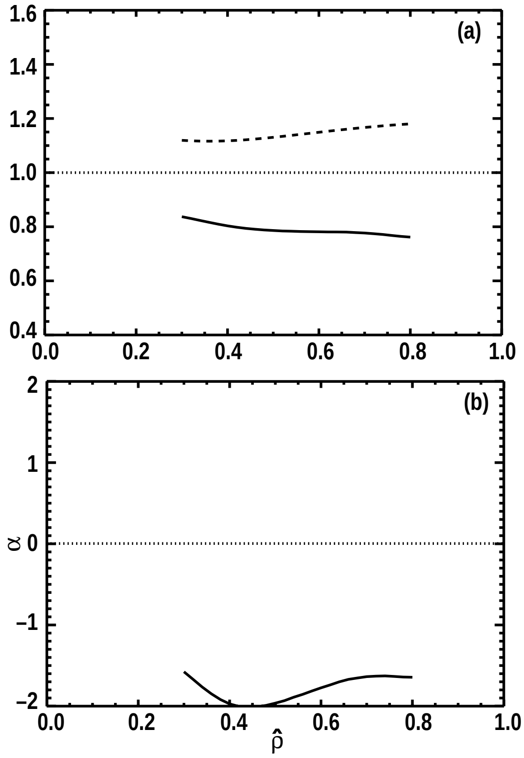

Fig. 2. (a) Ratios of the effective diffusivity χ (solid) and κ (dashed) vs. normalized radius and (b) κ-scaling exponent of χ vs. normalized radius for the constant q H–mode scan.

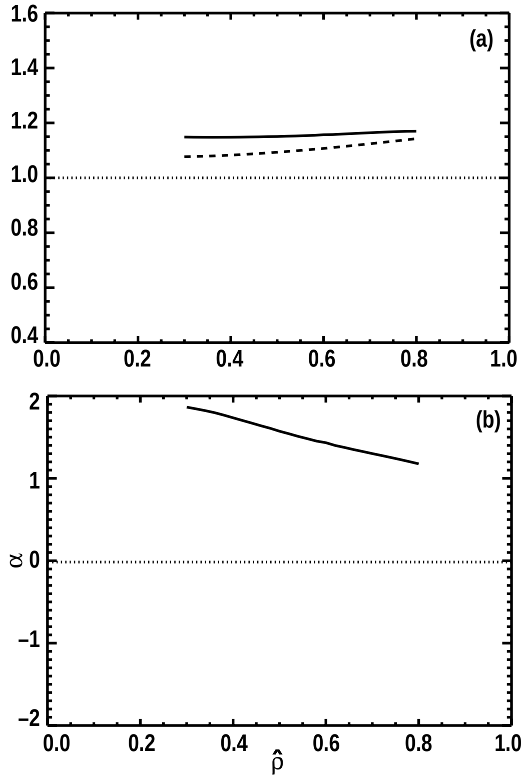

Fig. 3. (a) Ratios of χ (solid) and κ (dashed) vs. normalized radius and (b) κ-scaling exponent of χ vs. normalized radius for the constant current H–mode scan.

The large change in the apparent scaling of χ with κ scaling for the different scans is consistent with previous dimensionless scaling results from DIII–D [1]. The measured scaling of χ with q at fixed cross-section shape, gyroradius, β, and collisionality is approximately q^2. Raising elongation at fixed current raises q by a significant amount, especially at large minor radius. Preliminary analysis using the q values from equilibrium reconstructions with MSE indicates that a $\chi \propto q^2$ dependence does reconcile the two cases, yielding a corrected value of $\alpha \simeq -2$ for both scans. No attempt has been made to correct for the magnetic shear dependence observed previously [1]. Clearly, a careful error analysis will be required to validate this correction. However, it is equally clear that attempting to measure the influence of geometry on transport at constant plasma current does not isolate the geometric effects. Scans done in that manner are strongly influenced by the change in q.

L–MODE POWER BALANCE ANALYSIS

The L–mode scalings of transport with κ are very similar to the H–mode results above. Both constant q and constant current scans were carried out in inside-wall limited discharges. In L–mode, a larger variation in κ (1.2–1.8) is possible. The apparent κ scaling can be characterized again by $\chi \propto \kappa^{\alpha}$. The values of α for the constant q and constant current scans are shown in Fig. 4. For the constant q scan, the transport is reduced at higher κ, while in the constant current scan, the transport is larger at higher κ. The offset between the two cases is again in qualitative agreement with a q scaling of energy transport. Experiments have been carried out recently on the q scaling in L mode which will aid the quantitative interpretation of these scans.

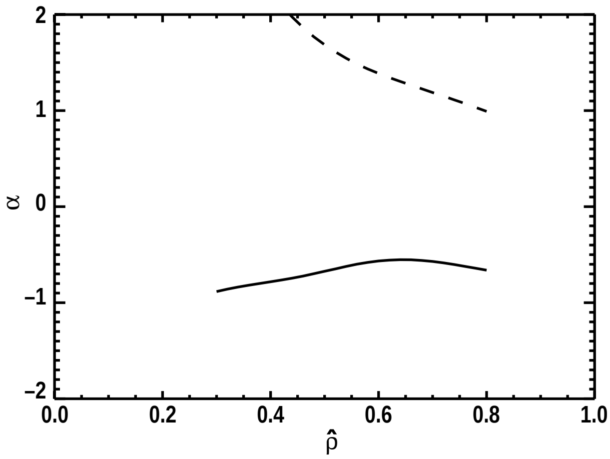

Fig. 4. (a) κ-scaling exponent of χ vs. normalized radius for the constant q (solid) and constant I (dashed) L–mode scans.

GLOBAL SCALING RESULTS

The global scaling results for both H mode and L mode are in qualitative agreement with the local analysis shown above. The expected value of the global thermal confinement with cross-section shape can be estimated using $\tau_{th} \propto \rho_b^2/\chi$, where ρ_b is the value of ρ at the plasma boundary. For elliptical cross-section plasmas at fixed minor radius with no dependence of χ on κ, the confinement should scale roughly like κ. Table I gives the thermal confinement times (τ_{th}), the separatrix elongation (κ), the boundary value of the normalized toroidal flux (ρ_b), the appropriate ITER database thermal scaling estimate (H_{98y2} for H mode, L_{IPB} for L mode) [2], and the exponent α (from $\tau_{th} \propto \kappa^{\alpha}$) for the H–mode and L–mode scans. In each entry the first numbers correspond to the higher elongation discharge of the pair. The results for the H–mode and L–mode scans described above are in qualitative agreement with the local analysis, offset by an additional factor of ~κ. Complications such as dependences of the pedestal width on q and κ suggest that the global scalings of the effect of cross-section shape may be of limited use.

Table I.

	H Mode		L Mode	
	Constant q	Constant I	Constant q	Constant I
τ_{th} (ms)	190/135	137/128	90.0/46.2	56.6/48.7
κ	2.0/1.71	2.02/1.70	1.77/1.17	1.79/1.17
ρ_b^2 (m^2)	0.63/0.517	0.604/0.513	0.73/0.46	0.684/0.462
H_{98y2}	0.99/1.20	1.15/1.20	–	–
L_{IPB}	–	–	0.69/1.12	1.23/1.18
α	2.19	0.41	1.61	0.35

DISCUSSION

The preliminary analysis presented here is consistent with strong and opposing dependencies of local diffusivity on q and κ in both L–mode and H–mode discharges. These experiments indicate that scans of cross-section shape at constant current do not isolate the effects of geometry. This implies the true influence of cross-section shape can only be seen with scans holding q fixed, unlike in previous experiments [3,4]. The strong scaling of energy transport with κ observed in these plasmas would be more consistent with the *ad hoc* geometry corrections in the Multi-Mode model [5] than with the weaker scalings found in general geometry drift-wave calculations [6,7]. Simulations of the experimental profiles with these models are now underway. The experimental analysis points to substantial benefits in energy confinement of both low q and strong cross-section shaping.

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