35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, O-4.034 (2008)

Dimensionless pedestal identity plasmas on Alcator C-Mod and JET

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1. Introduction and global regimes

Properties of the H-mode pedestal are crucial for standard ($Q = 10$) operating regimes envisaged for ITER, but their scalings remain uncertain. Conflicting evidence exists for the variation of density pedestal width Δ_{n_e}, which can be governed by particle sources on DIII-D [1] and MAST [2], but is more strongly affected by plasma transport on Alcator C-Mod [3,4] and ASDEX Upgrade [5]. Further insight has been sought by producing plasmas on C-Mod and JET in a common single-null divertor equilibrium and with identical values of dimensionless variables $\nu_{*e}^{\mathrm{ped}}, \rho_{*}^{\mathrm{ped}}, \beta^{\mathrm{ped}}$, q_{95} at the pedestal top; this ensures local plasma transport is the same [6,7] while stringently testing other susceptibilities through a ratio $a_{\mathrm{JET}} / a_{\mathrm{C-Mod}} > 4$ in absolute size plus markedly different recycling regimes. Accurate realisation of the chosen magnetic configuration on both machines is illustrated by the overlay of scaled separatrices in Fig.1. Edge dimensionless identity then requires (as well as equal m_i / m_e, Z_{eff}) discharge parameters to be scaled [8] as indicated in Table 1. Time intervals on each device can similarly be related [8] according to $(t_{\mathrm{B}} - t_{\mathrm{A}})_{\mathrm{C-Mod}} \approx (t_{\mathrm{B}} - t_{\mathrm{A}})_{\mathrm{JET}} (a_{\mathrm{C-Mod}} / a_{\mathrm{JET}})^{5/4}$.

Global behaviour in most closely matching shot pairs is summarised in Fig.2, where JET signals are scaled onto the C-Mod time axis as just described. At the high field adopted in C-Mod, classic ELM-free H-mode phases, with monotonically rising density and radiation, were obtained. For JET, however, states were very steady despite occurrence of only small, irregular ELMs. This was probably attributable in part to a large radiated-power

Table 1. C-Mod / JET pedestal identity parameters

quantity	C-Mod	JET	size scaling
B_0 (T)	7.9	1.4	$a^{-5/4}$
I_p (MA)	1.3	0.91	$a^{-1/4}$
n_e^{ped} (10^{19} m^{-3})	20.	1.2	a^{-2}
T_e^{ped} (eV)	550.	270.	$a^{-1/2}$

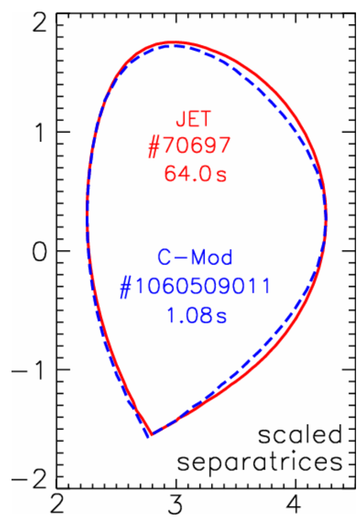

Fig.1 Scaled separatrices for identity pulses in C-Mod / JET.

fraction within the confined volume, allowing a significant difference in scaled core properties between counterpart plasmas even for equivalent pedestal heights. Hence β_t and scaled sawtooth frequencies remained distinct. Nevertheless scaled efflux power through the edge (P_{SOL}) was well reproduced and JET cases in fact reverted to ELM-free H-regime for only very small changes in conditions. Respective pedestal profiles could therefore be informatively compared.

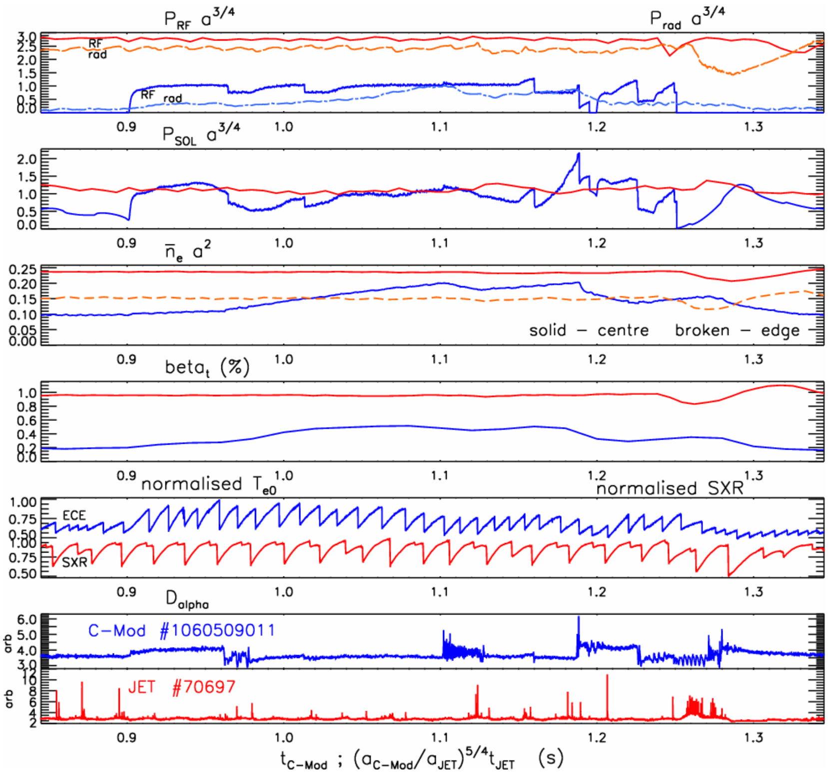

Fig.2 Global quantities (scaled powers and densities, β_t, sawtooth oscillations, Dα emission) for C-Mod / JET shot pair with close dimensionless identity at the pedestal top. JET signals scaled onto time axis of C-Mod (see text).

2. Comparison of pedestal parameters

Edge profiles were detected on C-Mod with a millimetre-resolution, 60 Hz Thomson scattering diagnostic and on JET with a new high-resolution (HRTS) system providing ≥ 1.5 cm detail at 20 Hz. To suppress random fluctuations and increase statistical significance, three consecutive time-slices were averaged in C-Mod phases with smallest $|\partial W / \partial t|$, while JET signals were averaged over their 0.5 s measurement window. Data were interpolated using an established modified tanh form [3,4], yielding consistent values of pedestal height, width and position. For JET, the instrument resolution of ≈ 1.5 cm was also taken into account, but was found to have little effect on derived parameters. Resulting electron temperature and density heights are shown in Fig.3(a), where again JET quantities have been scaled onto C-Mod ranges as indicated in Table 1 . Note C-Mod plasmas comprised a scan to higher pedestal pressure at almost constant temperature and were matched by JET partners at highest densities spanned. These conditions corresponded to moderately collisional ($\nu_{*e}^{\mathrm{ped}} / Z_{\mathrm{eff}} \approx 2$), low-pressure ($\beta^{\mathrm{ped}} \approx 0.002$) edges (NB Z_{eff} was not spatially resolved). Accompanying widths are plotted in Fig.3(b), now scaling JET figures with the size ratio, ie $\Delta' = \Delta_{\mathrm{JET}} (a_{\mathrm{C-Mod}} / a_{\mathrm{JET}})$. Thus matching profiles over the whole pedestal would imply coincidence with C-Mod points, but density widths were clearly systematically broader on JET. Its temperature widths were less reliably determined owing to only a single HRTS datapoint generally falling in the steep ∇T_e zone, so formally they were bounded between zero and interpolated shapes somewhat broader than the scaled C-Mod level.

Departure from linear scaling suggests Δ_{n_e} was subject to influences other than plasma transport. Particle sources have been estimated for best-matching shot pairs using the 1-D kinetic KN1D code [9]. This includes ionising and dissociative reactions, as well as multiple generations of charge-exchange events and elastic collisions on both ions and neutral particles. Influx onto a set plasma background is specified from measured gas pressure at the vessel wall. Typical values were $> 100\times$ higher on C-Mod (~ 0.3 mtorr) than on JET (~ 0.002 mtorr), reflecting higher plasma densities on the former. Calculated ionisation rates differed proportionally by a factor ~ 100, though decay-lengths ℓ_S within the respective density pedestals were themselves closely in proportion to their widths Δ_{n_e}. Further support to such results was obtained from separate computation of one JET case with the 2-D EDGE2D-NIMBUS fluid-plasma / kinetic-gas code suite [10], which replicated very similar source decay-length both poloidally averaged and at the outboard mid-plane. Equivalence of scaled neutral-particle penetration into the pedestal is illustrated for a pedestal-top identity shot pair in Fig.4, where sources normalised by their maxima are superimposed versus a coordinate with origin at each density pedestal foot (defined as the central position + ½Δ_{n_e}) and in turn normalised by Δ_{n_e}. Hence the shaded region denotes the steep ∇n_e zone of each profile. Evident correspondence of source fall-off behaviour against this abscissa strongly suggests Δ_{n_e} and ℓ_S are related for the plasma conditions addressed. It is likely $\approx 16\times$ lower n_e^{ped} in the JET case allowed for a deeper source distribution, and so a wider density pedestal of $\Delta_{n_e}^{\mathrm{JET}} / \Delta_{n_e}^{\mathrm{C-Mod}} \approx 7\text{-}9$, relative to simple identity scaling as $a_{\mathrm{JET}} / a_{\mathrm{C-Mod}} \approx 4$.

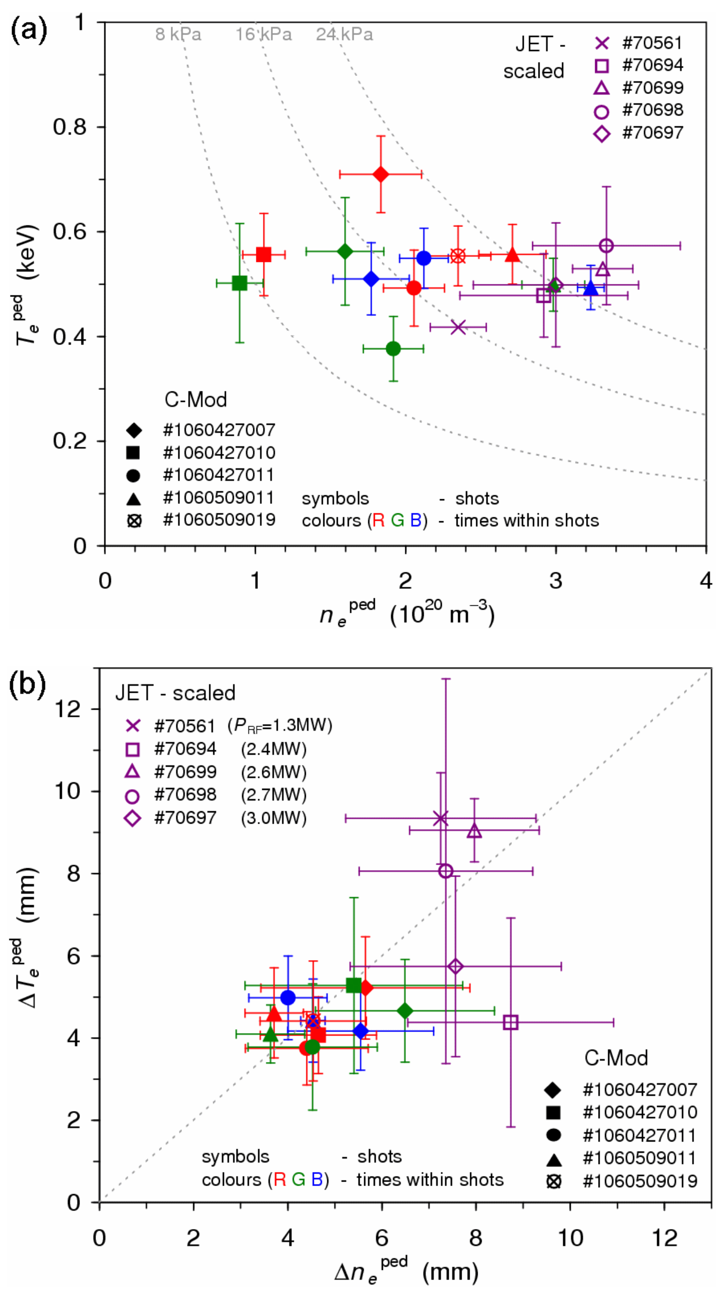

Fig.3 (a) Pedestal heights interpolated for C-Mod / JET power scans, JET data scaled onto C-Mod ranges (cf Table 1). Best matches implying edge dimensionless identity obtained for higher densities. (b) Accompanying pedestal widths, JET data scaled with size ratio.

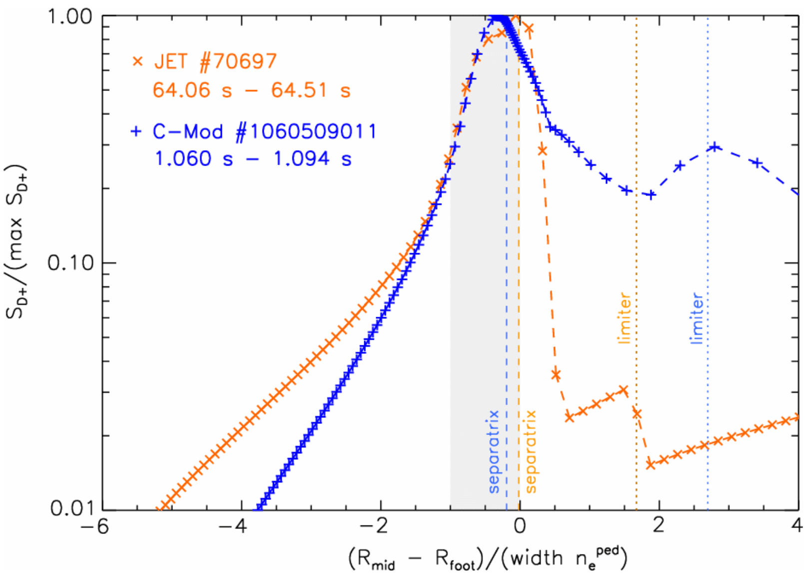

Fig.4 Normalised ionisation source rates from KN1D for pedestal-top identity shot pair. The abscissa is centred on the density pedestal foot in each case and normalised by its width, ie the shaded region denotes the main gradient zone. Separatrices and boundary surfaces ("limiter") of respective KN1D grids indicated by dashed lines.

3. Conclusion

Single-null diverted plasmas with equal values of dimensionless plasma variables at the pedestal top have been achieved on C-Mod and JET, encompassing a factor > 4 in absolute size as well as substantially different recycling regimes. For the moderately collisional, low-pressure edges investigated, electron temperature pedestal widths on JET were estimated to lie within a somewhat broader interval about scaled C-Mod extents. Density pedestal widths, however, were systematically broader in proportion to machine size on JET than on C-Mod, indicating an influence apart from plasma transport in their formation on at least one of the two devices. Calculations of edge particle sources for pedestal-top identity shot pairs with the 1-D KN1D code [9] revealed similar neutral-particle penetration for both machines compared with the respective density profile thickness, strongly suggesting they are related for the conditions tested. Such susceptibility to ionisation sources implies scaling of density pedestal width in the present experiments is not Kadomtsev-like [6], ie cannot be specified completely in terms of $\nu_{*e}^{ped}, \rho_*^{ped}, \beta^{ped}, q_{95}$. In this case, unambiguous scans could not be performed with respect to these arguments, since any changes seen could not be identified as due to the increment(s) in dimensionless variable(s) or to consequential alterations of particle sources.

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This work was funded jointly by the UK Engineering and Physical Sciences Research Council and by the EC under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission. Studies on Alcator C-Mod were supported by US Department of Energy award DE-FC02-99ER54512.