Plasma movement at ELMs in JET

S. Ali-Arshad, A. Edwards, J. Lingertat, S. Puppin, J. Wesson

JET Joint Undertaking, Abingdon, Oxon. OX14 3EA, UK

INTRODUCTION

In JET giant ELMs can give rise to a sustained degradation of plasma confinement, and in some cases control of the vertical position of the plasma is lost following a giant ELM, leading to a major disruption. An example of such a case is given in fig. 1.

A variety of measurements suggest that during the ELM the scrape-off layer and bulk plasmas move rapidly. This paper presents these observations, and addresses implications for the vertical stability of the plasma.

DATA ANALYSIS

Magnetic diagnostics show a short-lived perturbation appearing during the ELM, typically in the range 10-100 Gauss. The example in fig. 2 shows the amplitudes of the modes with toroidal mode number n=0,1,2,3, calculated from a toroidal array of coils at a poloidal position of $\theta \sim 60°$. The poloidal structure of the perturbation is shown in fig. 3 at two time slices. A dominant m=1 structure is seen. The amplitude of this structure is a factor of ~3 larger than the level of perturbation observed on each of the coils in the toroidal array at $\theta \sim 60°$, suggesting a principal mode with m=1, n=0. Thus during the ELM the plasma shifts downwards, reaching its lowest position in several hundred microseconds, and then it moves upwards reaching its highest position in about a millisecond. Interpretation of soft X-ray data during ELMs is complicated by transient, highly local radiation sources. However, supporting evidence for the plasma movement is given by lines of sight not intercepting such sources. The position of the plasma current centroid, as determined from the current moment method, is shown in fig. 4. This supports the observation of a downward movement followed by an upward movement, and indicates the size of the movement is ±1cm. Fig. 4 also shows that during the downward movement little poloidal flux penetrates through the vessel. The plasma boundary displacement can therefore be calculated from flux compression between the plasma boundary and the wall: $\delta z_{down} \approx \Delta Z_0 \, \delta B_\theta / B_{\theta 0}$, where ΔZ_0 =initial plasma-wall distance, δB_θ = change in B_θ at top of vessel, $B_{\theta 0}$ = equilibrium field at top of vessel. The upward movement can also be estimated by this method, but is only accurate to a factor of ~2, due to partial flux penetration (see fig. 4). Such estimates give agreement with the centroid calculation, so that the perturbation might be approximated with a 'rigid body' displacement. In addition, this procedure allows the movement to be determined from more abundant dB_θ/dt data. Fig.5 shows such estimates for several ELMs plotted against the D_α light intensity. These suggest that larger ELMs can produce larger displacements, and that the upward overshoot is typically larger than the downward movement, by a factor of ~2.

Fig.6 shows infra-red camera data on the divertor target before and during an ELM, showing an increase in the strike zone separation during the ELM. The change is too large to be a result of the bulk plasma movement described above, so the existence of SOL currents is suggested. This is supported by Langmuir probe measurements of SOL currents of order 10kA, intercepted by the divertor target during ELMs [1]. A toroidal current of order 10kA, transferred from the main plasma current is also predicted by consideration of spilling of hot electrons into the SOL during an ELM [2].

INTERPRETATION

The vertical speed of the JET plasma is stabilised by a control system. A simplified model for this has been given [3], [4]. This has the form $I_p Z_p \approx \frac{C_1 V_R}{s(s-\gamma)} + \frac{C_2 f_z (s + 1/\tau_{eff})}{s-\gamma}$, Z_p = plasma current centroid vertical position; V_R = voltage to radial field coil, proportional to plasma speed, allowing for amplifier characteristic (±10kV max., 9 levels); γ = natural instability growth rate; τ_{eff} = effective radial field penetration time with divertor configuration; f_z = arbitrary vertical force applied to plasma. For an ELM with a 1:2cm down:up movement ratio, the model suggests a force waveform f_z as in fig. 7 (The plasma position is restored by a position control system on a time-scale of several milliseconds. This is not included in the simulation.) Scaling up this f_z waveform by a factor of ~3 produces a vertical instability in the model as shown in fig. 8. The forces on the plasma might arise from toroidal current transferred to the SOL during an ELM. Away from the X-point, to first order, this does not produce a force on the plasma. However, in the X-point region a downward force would be produced, as illustrated in fig. 9. If the SOL current then decays faster than the current recovers in the confined plasma, e.g. due to an impurity influx, an upward force could be generated due to the weaker poloidal field near the X-point compared with the top of the plasma.

FUTURE WORK

Further work is needed in diagnosing the SOL currents, understanding the resultant forces and the effect on the strike zones. The ELM database studied needs to be expanded, and data from soft X-ray and infra-red cameras, Langmuir probes and magnetics need to be correlated. A multi-machine scaling study of the movement would be valuable to assess implications for ITER.

ACKNOWLEDGEMENT:

ACKNOWLEDGEMENT:

The authors would like to thank Dr. P. Noll for discussions on the vertical stabilisation system.

REFERENCES

[1] J. Lingertat et. al., Studies of giant ELM interaction with the divertor target in JET, J. Nucl. Mater., to be published.

[2] J. Wesson, SOL Current During ELM, Private communication (1995).

[3] P. Noll and M. Garribba, Review of Fast Radial Field Amplifier, Private communication (1989).

[4] P. Noll, A simplified model of the stabilisation system, JET divisional note JDN/G(91)025, (1991).

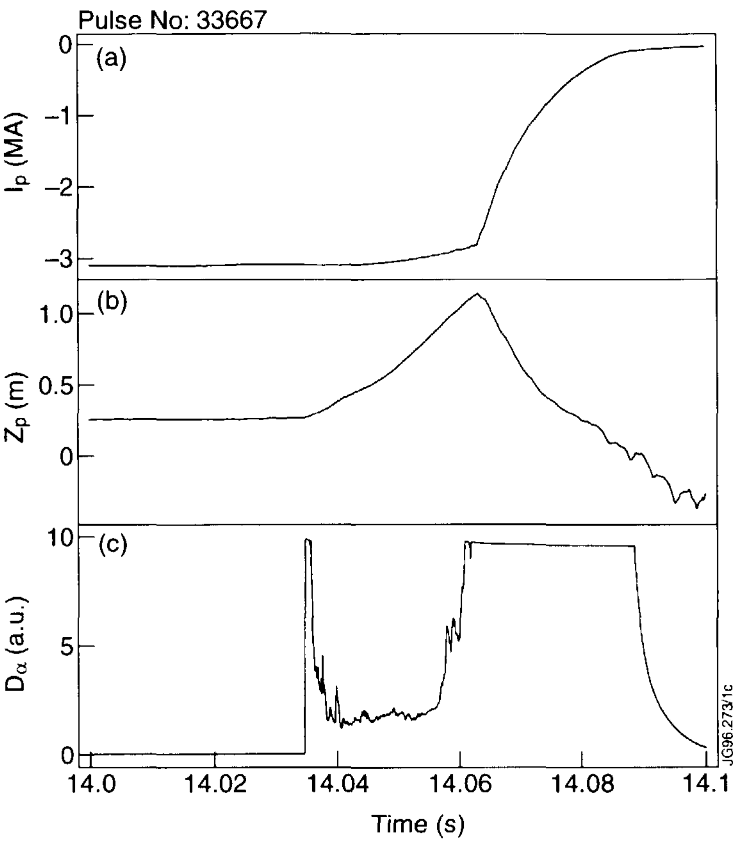

Fig. 1: Disruption of a 3MA plasma after loss of vertical stability following a giant ELM

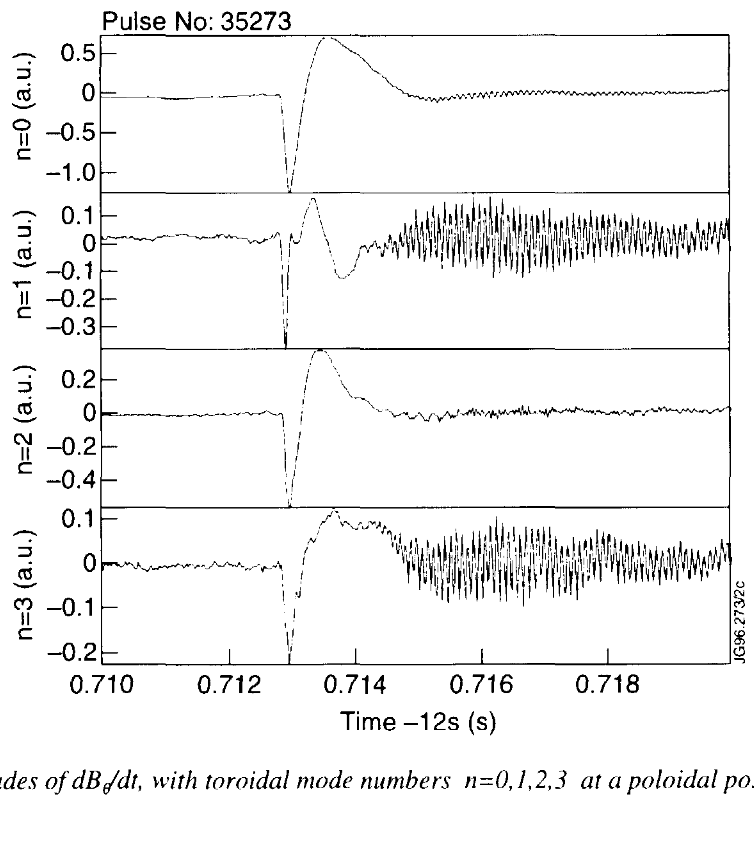

Fig. 2: Amplitudes of dB_θ/dt, with toroidal mode numbers $n=0,1,2,3$ at a poloidal position of θ~60°.

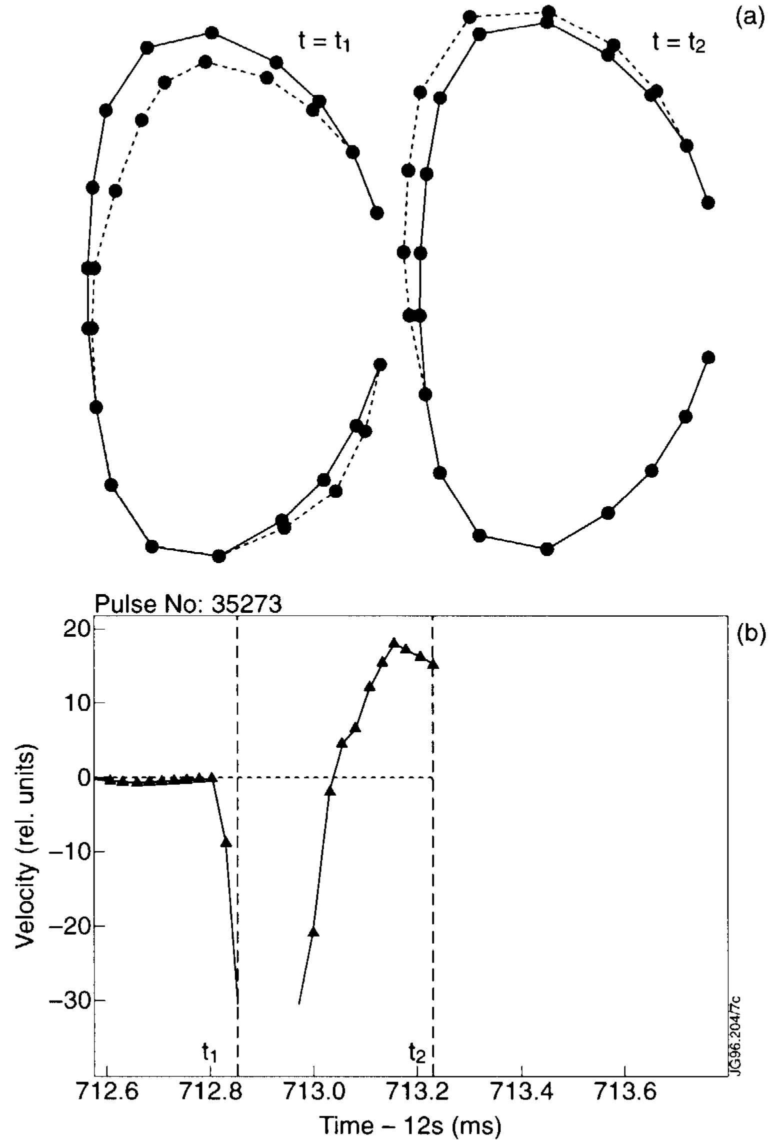

Fig. 3: (a) dB_θ/dt perturbation at two times during an ELM (see (b)). On fast time-scales (<<3ms) this is proportional to the local normal plasma speed.

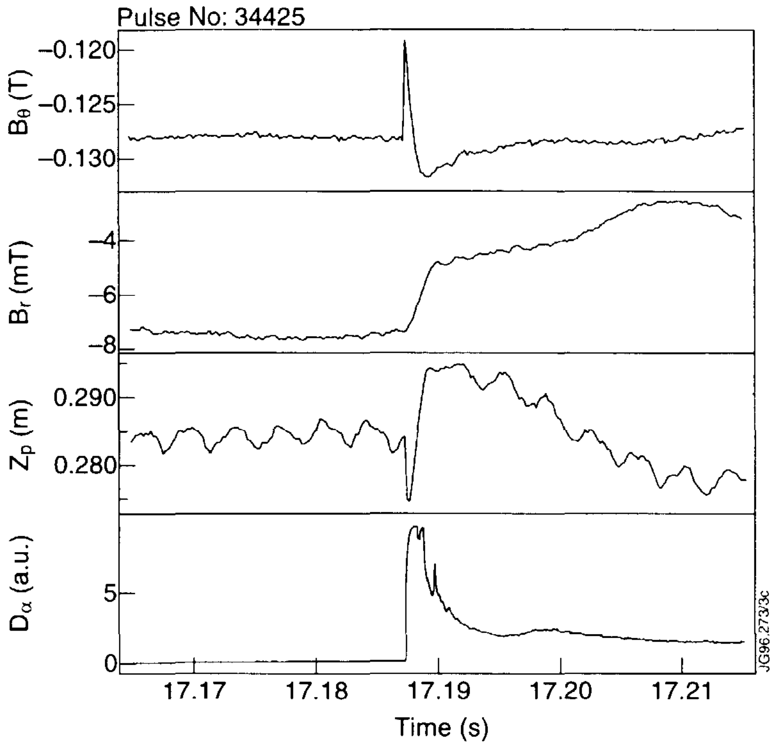

Fig. 4: (a) Poloidal field and (b) radial field at top of vessel, and the plasma current centroid (c), at an ELM.

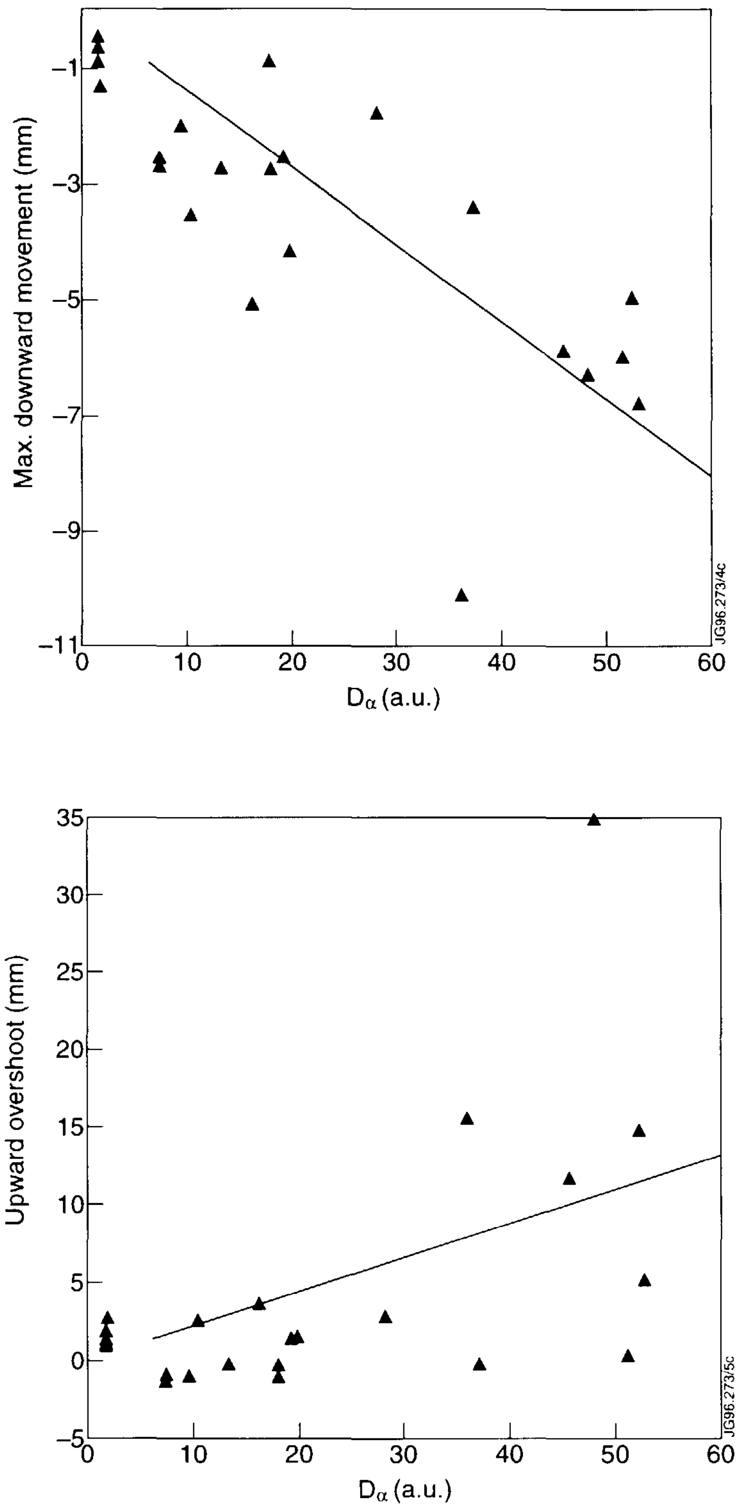

Fig. 5: Plasma displacement estimated from poloidal flux compression. The upward movement is likely to be underestimated by a factor of ~2, due to partial flux penetration.

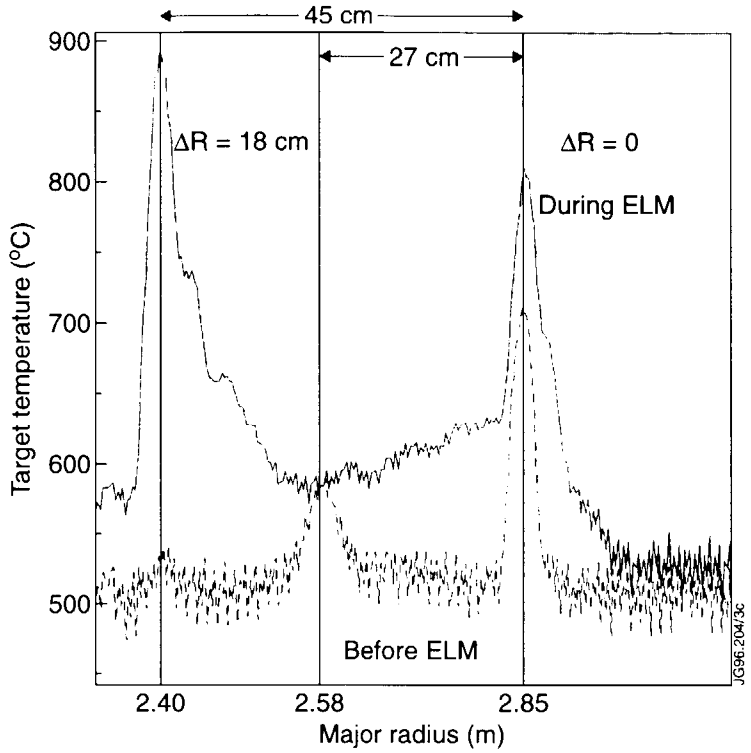

Fig. 6: Infra-red camera view of the divertor target before and during and ELM.

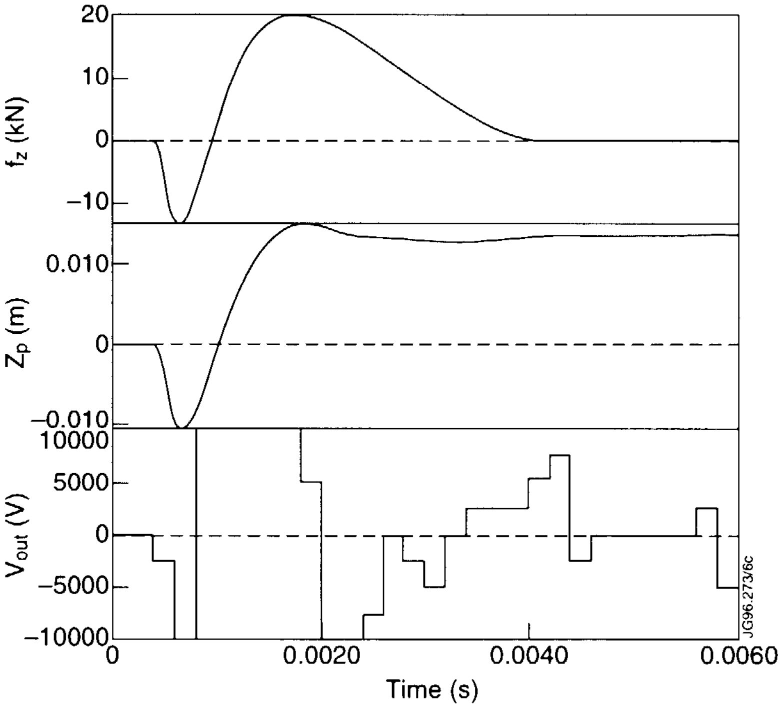

Fig. 7: Force required for typical plasma movement at a giant ELM, for a 3MA plasma with γ=700s^{-1}.

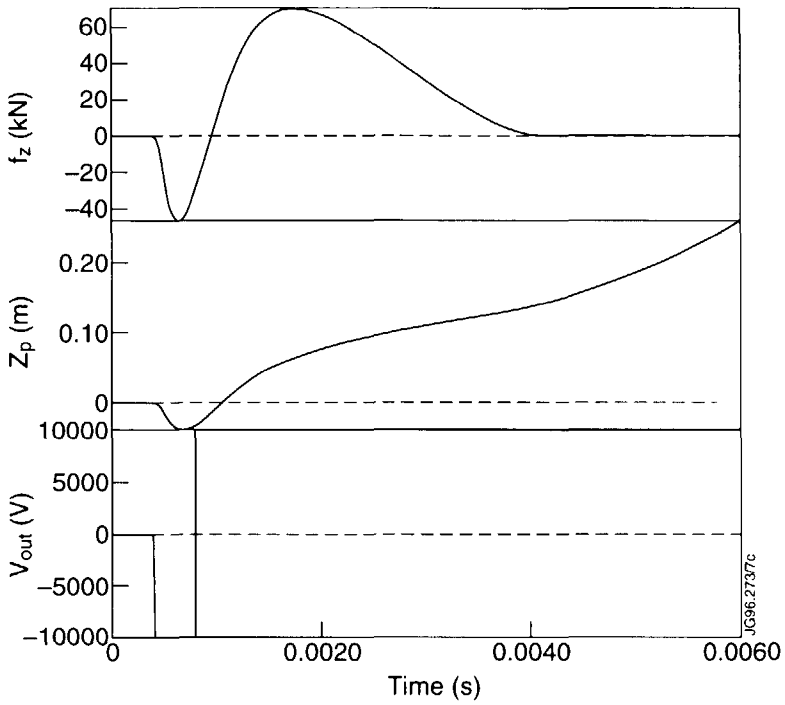

Fig. 8: Vertical instability produced by amplifying the force waveform found in fig. 7 by a factor of ~3.

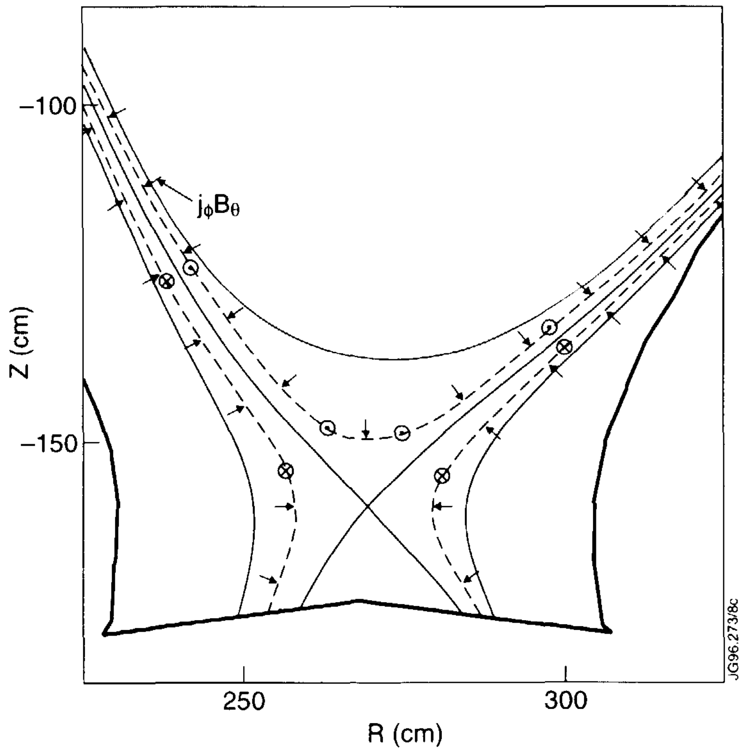

Fig. 9: Forces arising from toroidal current transfer from edge confined plasma to the SOL