Plasma Flow in the JET Scrape-Off Layer

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1. Introduction

Plasma flow in the scrape-off layer of JET L mode, Gas Box divertor discharges has been measured using a Mach Reciprocating Probe near to the top of the torus. The Mach probe, which has separate Langmuir probe elements facing the outer and inner divertor, recorded ion saturation current ratios to each side as high as $j_{sato} / j_{sati} = 4$, figure 1.

This corresponds to a flow with Mach Number M ~ 0.5, (Hutchinson [1]). Similar high Mach numbers have been recorded at the mid-plane of JT-60U, (Asakura [2]).
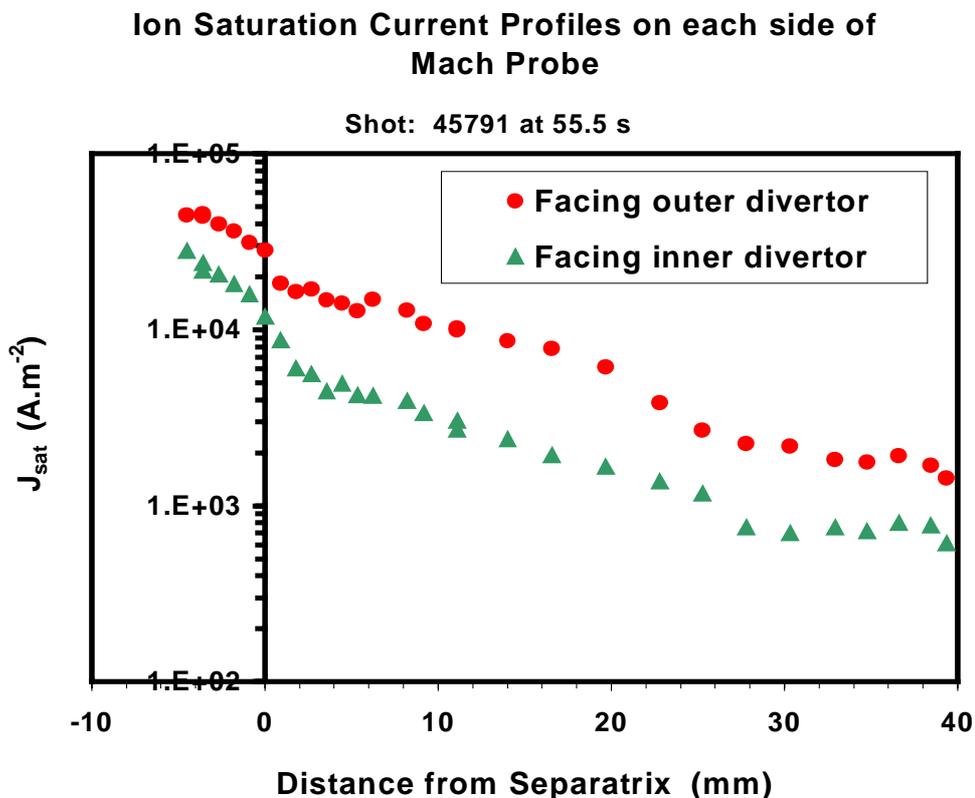

**Ion Saturation Current Profiles on each side of
Mach Probe**

*Fig. 1: $j_{sato}(r)$ and $j_{sati}(r)$ on each side of Mach probe. ($I_P = 2.4$ MA, $B_T = 2.5T$
$<n_e> = 2.1\ 10^{19}\ m^{-3}$, 2 MW of NBI heating)*

The flow is from outer to inner divertor in the normal JET B_T and I_p configuration (both clockwise, viewed from above), and is suggested as a possible mechanism for the large carbon build up observed in the inner divertor region, [Coad et. al, this conference], as impurities are swept around the SOL.

In this paper we examine the possibility of various mechanisms for the observed flow, including ballooning driven transport, flow reversal due to ionization, Pfirsch-Schlüter flow and co-current toroidal momentum in the SOL.

2. Measurements

A Mach reciprocating probe head, consisting of 2 pairs of 3 probe tips, each equidistant from the separatrix, is positioned at the top of the torus just to the outside of the plasma centre. The voltages on the probes are swept to allow measurement of radial profiles of both j_{sat} and T_e. It is found that radial profiles $T_e(r)$ are identical looking towards each divertor. Furthermore, the ratio j_{sato} / j_{sati} falls to unity far out in the SOL of limiter discharges, suggesting that the effective area of the probe elements on each side of the probe have been calculated correctly.

Measurements were made using the JET MkIIA divertor for both L-mode and H-mode discharges, and maximum flows of between M = 0.3 and M = 0.6 (in H-mode) were recorded. In these measurements an indistinct maximum in the flow was found at between 10 and 20 mm from the separatrix, (all distances referred to the outer mid-plane). Using the recent Gas Box divertor configuration, much cleaner radial profiles of j_{sat} and T_e have been recorded in L-mode discharges. Here a strong maximum in the flow has been confirmed some 10 – 20 mm from the separatrix for medium to high density discharges. Low density discharges tend to have a maximum flow at the separatrix, again of magnitude M ~ 0.5.

Fig. 2:Mach number profiles across the SOL for normal and reverse B_T and I_P.

Measurements have also been made using reversed field and plasma current to that normally used on JET. In such discharges the flow is reversed, i.e. from inner to outer target, but the general shape of the radial profile is asymmetric about zero. The flow is now a minimum at 10 – 20 mm from the separatrix. The Mach number profiles for normal and reversed B_T and I_P are shown in figure 2.
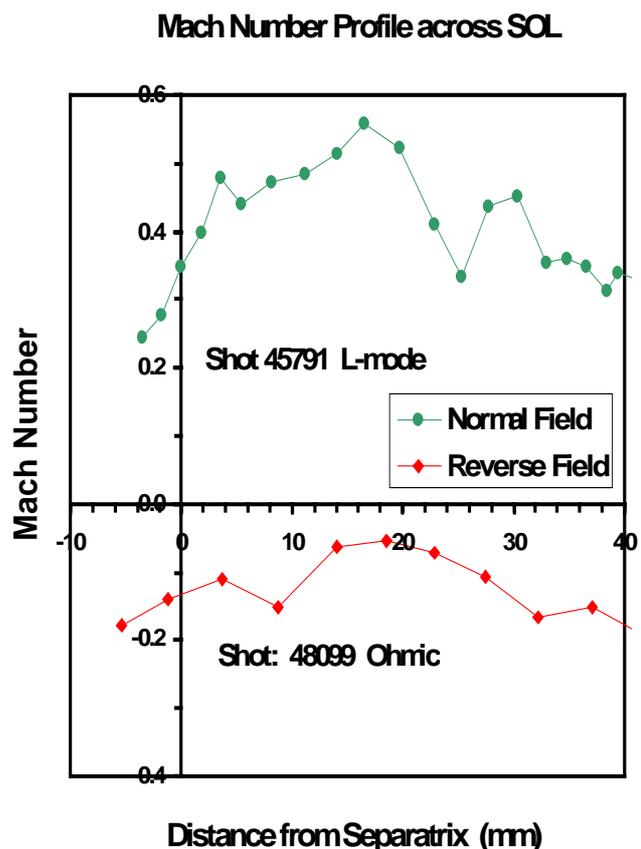
## 3. Possible candidates for explaining the flow

3(a) Ballooning Transport

Preferential perpendicular transport through the outer mid-plane (ballooning type transport) can lead to a higher pressure at the outside mid-plane. This will induce a flow pattern from the outer to the inner mid-plane. This may also explain the average direction of the flow (between the two B_T directions) towards the inner target, as the ballooning is higher at the low field outer than the high field inner mid-planes. This mechanism is independent of the B_T direction, however, so cannot be the whole explanation. It is also difficult to predict a maximum flow in the SOL using this mechanism.
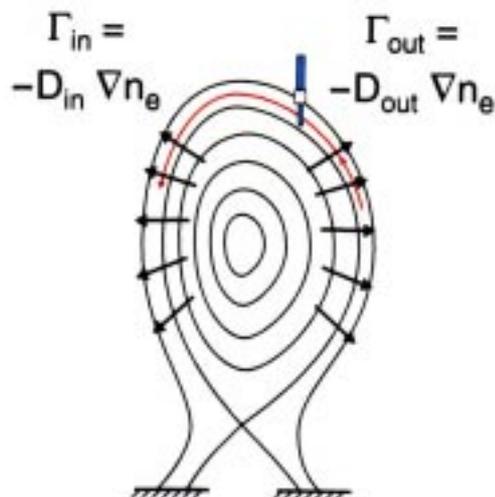
3(b) Flow Reversal

Flow reversal from a highly ionized region each side of and below the X-point can be created as a result of an ion pressure gradient away from each target. There is also a flow towards each target from this region, and from the SOL via cross-field transport. It is possible that an ionization source could have a local maximum some distance from the separatrix. Code calculations, however, suggest that flow reversal on its own is insufficient to account for the large Mach numbers observed in the SOL.
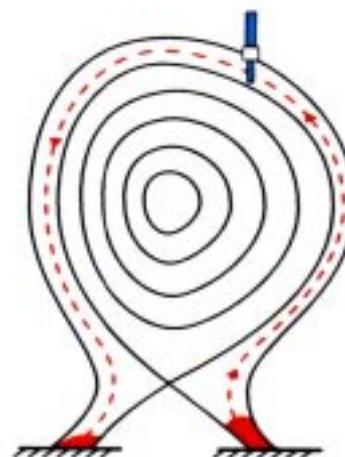
3(c) Pfirsh-Schlüter flow

Ion Pfirsh-Schlüter flow has been considered as a possible candidate for the measured flow, both by using EDGE2D [3] simulations, and from simple

analysis [2] $V_{ps} = \dfrac{2r}{RB_T}[E_r + T_{iu}(\lambda_{Ti}^{-1} + \lambda_{ne}^{-1})]$.

However, due to low $T_{iu} \sim 2T_{eu}$ and low electric field ($< 2kV.m^{-1}$), V_{ps} is too low at the top of the torus to account for the large values of flow measured in the SOL. A value of M~0.1 would be expected on the grounds of this mechanism alone. For reversed field, (B_T in to the paper) the ion ∇B drift would be up, and the flow reversed.

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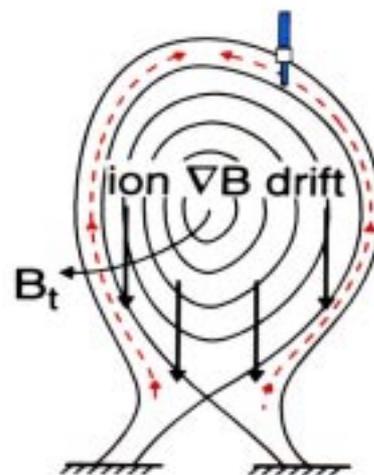
3(d) Co-current toroidal momentum

Large difference in the flow between the two B_T directions is consistent with the assumption of the existence of toroidal momentum in the SOL in the direction of the plasma current, driven by the toroidal component of $j_r \times B$ forces. Preliminary runs of the EDGE2D code with classical drifts included, reveal toroidal rotation of the SOL plasma as a whole, superimposed on Pfirsh-Schlüter flows. The Mach number of the flow at the probe position is about ±0.2, depending on the B_t direction. The flow exists inside the SOL and decays towards the separatrix, consistent with experiment. Switching off the poloidal $E \times B$ drift in the code had little effect on the flow. For reversed field, (B_T in to the paper) the flow is reversed.
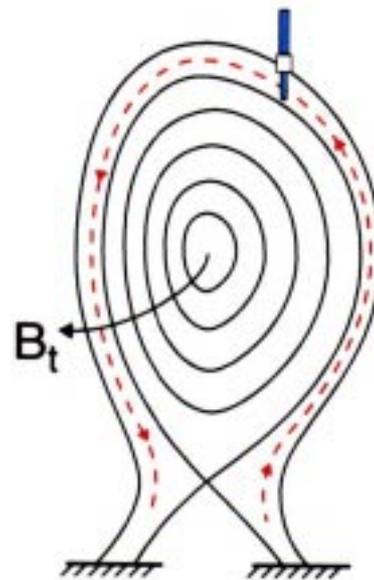
4. Conclusions

- Plasma flows with Mach number M = 0.5 have been measured in the JET SOL. These flows show a maximum some 10 – 20 mid-plane mm outside the separatrix.

- The flow reverses with reversed B_T and I_P, but is asymmetric about zero. This could be due to a contribution from ballooning transport.

- It is concluded that the major contributor to the observed flow is the co-current toroidal momentum generated in the SOL by ion ∇B and classical (diamagnetic) drifts. These account for most of the up-down pressure asymmetries which cause net radial current and toroidal acceleration in the SOL by exerting $j_r \times B$ forces. Ion Pfirsh-Schlüter flows caused by ion ∇B drifts appear to be insufficient on their own to account for the measured flows.

- Poloidal $E \times B$ drifts only increase the pressure asymmetries, and switching them off in code calculations has little effect on the magnitude of the flow.

References
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