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ABSTRACT

In JET, strong flows towards the inner divertor are observed in the Scrape-Off Layer (SOL) which peak just outside the separatrix [1]. It is known that flows can be driven by ionisation source imbalance, neo-classical drifts [2] and poloidal asymmetries in radial particle transport but there are quantitative and qualitative discrepancies with code predictions. Given that ion orbit losses appear to be a prime candidate for explaining the narrow power deposition profiles in JET, we address the question as to whether the coupling of momentum from these ions into the SOL can drive significant flow in the SOL.

1. INTRODUCTION

It has been recently demonstrated that ion orbit loss of ions born just inside the separatrix may offer a consistent explanation for the narrow power deposition profiles seen in JET [3,4,5]. These ions are believed to carry 30-40% of the power flow to the SOL in typical JET H-mode plasmas. Orbit losses are intrinsically asymmetric and are strongly dependent on the direction of the ion grad B drift. Simulations of this process with the ASCOT code and a realistic edge plasma have shown that these lost ions can interact strongly with the divertor plasma when the collisionality is sufficiently high [3] due to ion-ion and ion-neutral collisions. ASCOT follows the guiding centres of ions originating in the pedestal and computes the self-consistent electric field inside the core. We have computed the orbit losses with the ASCOT code for a realistic edge plasma generated by the EDGE2D-U/NIMBUS multi-fluid code [6] for a high density H-mode plasma where interactions of orbit lost ions with the SOL are at a maximum. The momentum and energy sources computed by ASCOT have been mapped onto the EDGE2D/NIMBUS grid and the perturbation they cause to the fluid EDGE2D solution evaluated.

2. EFFECT OF ORBIT LOSSES ON POWER BALANCE

It has long been apparent in the application of EDGE2D/NIMBUS to unfuelled ELMy H-modes in JET (n/n_{GW} ~ 0.6) that the divertor plasma parameters cannot be reproduced if the power flow to the SOL is assumed to be $P_{SOL} = P_{heat} - P_{R,core} - dW/dt$. For example Pulse No: 50401 [3,5], which was heated with 12.5MW of NBI, P_{SOL} is evaluated to be ≥9MW. EDGE2D simulations can only match the inter-ELM electron density and temperature profiles if P_{SOL} = 3-4MW and even then the favourable assumption has to made that twice as much power flows in the ion channel. ASCOT/OSM2 computations for this pulse [3] indicate that ~ 7.3(±0.5)MW of power may be removed from inside the separatrix due to ion orbit losses. This power is then transported as follows: 2.3MW go to the target, 1MW is transferred to plasma ions through collisions and 4MW is lost as charge exchange neutrals. In high density H-modes with strong fuelling (n/n_{GW} ~ 0.9) the discrepancy in the power balance disappears and we can simulate the divertor parameters with EDGE2D using the expected power flow to the SOL.

This decoupling of ion power flow from the SOL is the dominant effect of ion orbit loss on EDGE2D simulations. Its practical consequence is that there is a justification for reducing the input power flow to the SOL assumed in 2D edge fluid simulations below the value implied by the experimental power balance. Effect of ion orbit losses on power and momentum distribution ASCOT simulations based on OSM2 (onion skin model) [3] plasma backgrounds have shown that as the density is increased, the momentum and energy transfer to ions in the SOL also increases. We have therefore used a high density H-mode (Pulse No: 50402) as the test case for evaluating the effect of the momentum source on SOL flow. The radial electric field in the SOL also affects ASCOT results and is not computed by EDGE2D so scans have been carried out using ASCOT with OSM2 backgrounds [3]. In the results presented here, a radial electric field of 75kVm^{-1} was assumed for the SOL which is considered the maximum reasonable value and maximises asymmetries in the losses.

The EDGE2D solution chosen as target had a good match to the outer divertor parameters. However, the input power to EDGE2D which should have been ~ 8.5MW from experimental power balance was reduced to 5MW to give a best fit to divertor Langmuir probe data (n_e and T_e). A reasonable fit to experimental pedestal data was also achieved by adjustment of the radial profile of the transport parameters [7]. Table 1 summarises the momentum and power source terms as computed by ASCOT for this case:

Plasma Zone	**Power source (MW)**	**Force (N) +ve = towards inside**
Core / pedestal	−2.6	10
Main SOL	0.2	1.7
Outer divertor	0.42	−0.86
Inner divertor	0.17	1.44
Totals for SOL	0.79	2.28
All Zones	−1.8	12.5

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Table 1: Power and momentum sources for high density H-mode case Pulse No: 50402 (E_{rSOL}=75kV/m) from EDGE2D/ASCOT.

EDGE2D was reconverged with the above external sources of momentum and energy imported from ASCOT. These were added separately so the effects could be isolated.

3. EFFECT OF THE EXTERNAL ENERGY SOURCE TERMS ON EDGE2D

Provided input power is increased by 1.8MW (the net sink) there is negligible change in the SOL solution due to changes in the source distribution. This adjustment makes power input to the model more consistent with experimental power balance. However, due to the fact that most the power loss is in the core the SOL effects are neglible.

4. EFFECT OF THE EXTERNAL MOMENTUM SOURCE TERM ON EDGE2D

The effect of the momentum source is as you would expect. The sign of the force is directed towards the inner target and therefore increases the SOL flow in this direction both inside and outside the separatrix. The inner divertor plasma is compressed and there is a rise in the static pressure there which is mainly the result of a rise in ion density. The Mach number at the location of the reciprocating probe is increased in the direction of the inner divertor but the effect is also very small. To illustrate the changes the magnitude of the sources has been increased by a factor 4, see figures 1-4. This is not completely arbitrary since the SOL force computed by ASCOT in conjunction with OSM2 "onion-skin" model backgrounds is 10N [4] (4 times the value given in table 1) so the results shown represent the maximum effect anticipated.

5. DISCUSSION

Analysis of the parallel force balance shows that the dominant terms are the ion parallel pressure gradient and parallel electric field (pre-sheath), figure 2. For substantial effects to be seen on the fluid solution, the external momentum source due to ion orbit interaction must approach the magnitude of these intrinsic terms. In JET H-modes the threshold for significant effects is around 10N total force on the SOL. It is easy to show that we would expect about 5N of force for each 1MW of in/out power asymmetry (assuming 0.5KeV ions). In practice however, much of this torque acts on the pedestal region rather than the SOL and so the effect is small.

Figure 2 also shows that the momentum source due to the orbit lost ions is highest near the inner divertor where the collisionality is highest. Since the EDGE2D solutions are less in/out asymmetric than the experiment we would expect that a more realistic solution would exhibit a higher net torque on the SOL, as found in calculations using the "onion-skin" model OSM2 for the plasma background [5]. However the effect still seems too small to be the primary cause of the plasma asymmetry.

Future work will be aimed at evaluating the significance of ion orbit effects for the ITER SOL simulations. In ITER, the combination of low collisionality pedestal and SOL with a high collisionality divertor plasma might be expected to lead to a much stronger role for kinetic transfer of power and momentum.

6. CONCLUSIONS

Our main conclusion is that orbit loss of pedestal ions is important for the SOL power balance and must be taken into account when modelling low density ELMy H-modes. The effect of orbit losses on the SOL momentum balance is of the right sign to explain the observed flows of plasma ions and impurities to the inner divertor. However, results obtained so far show that this effect is probably far too small to be a primary cause of these observations. In ITER, the large gradient in collisionality between pedestal and divertor mean that we would expect the kinetic contributions to be more significant than in JET.

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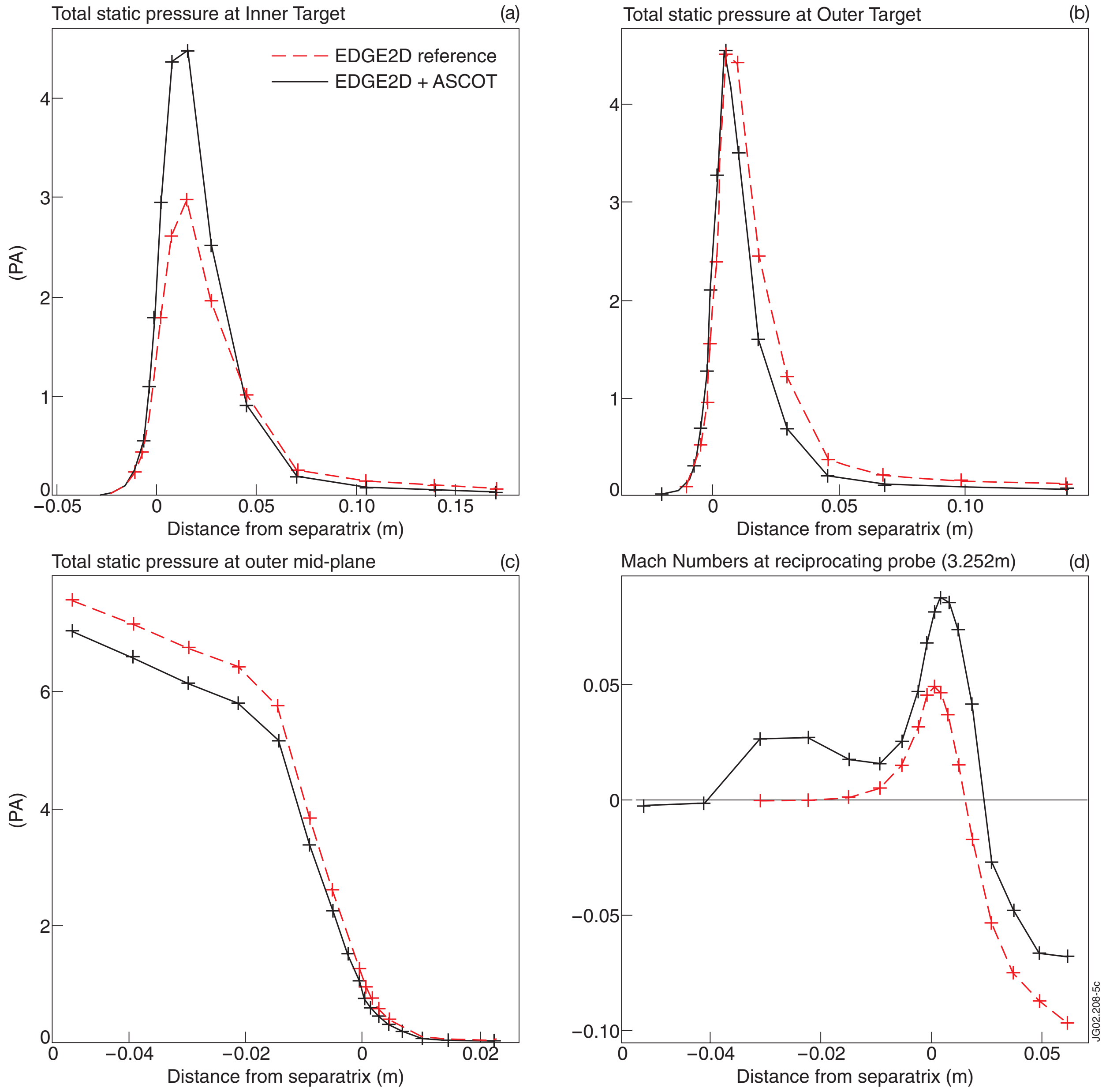

Figure 1: Change in EDGE2D computed static plasma pressure with introduction of an external momentum source (see main text) in the outer divertor (a), inner divertor (b) and at the outer mid-plane (c). The change in Mach number computed at the top reciprocating probe location is shown in (d).

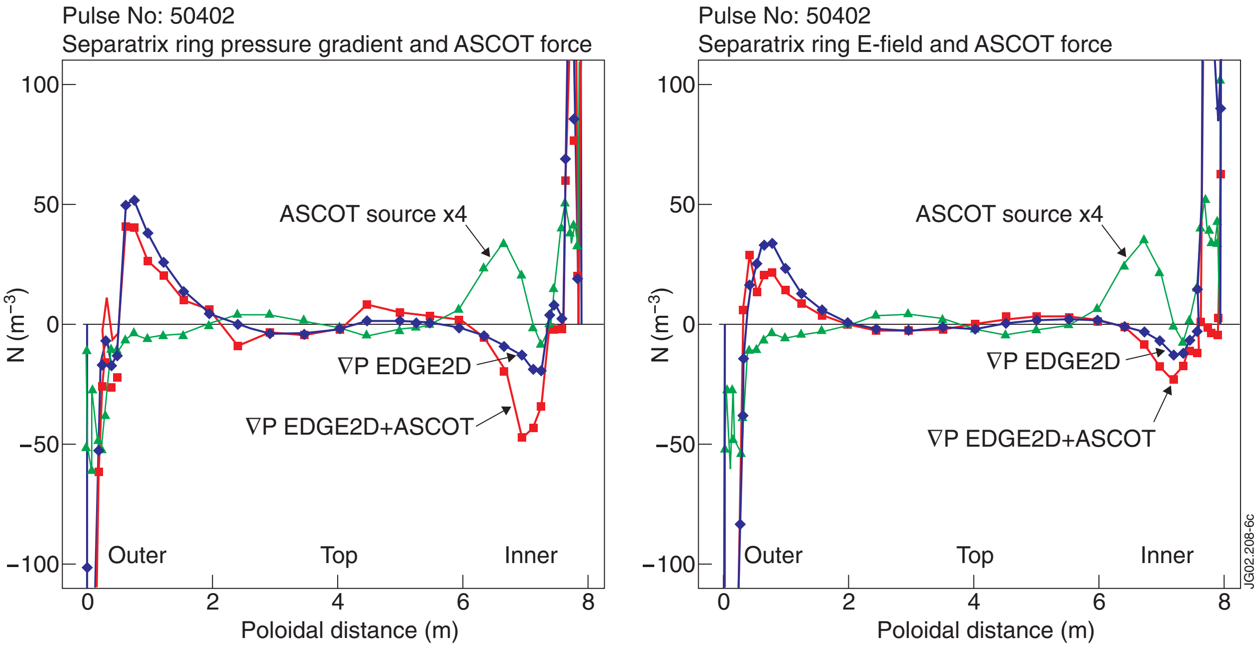

Figure 2: Poloidal plots comparing the magnitude of the momentum source predicted by ASCOT (increased by a factor 4) with the parallel pressure gradient and parallel electric field computed by EDGE2D (with and without the ASCOT source).