MAIN CHAMBER NEUTRAL PRESSURE IN ALCATOR C-MOD AND JET

C S Pitcher, S K Erents*, W Fundamenski*, B LaBombard, B Lipschultz, G F Matthews*, G M McCracken*, P Morgan*, M F Stamp* and contributors to the EFDA-JET workprogramme[1]

MIT, Plasma Science and Fusion Center, NW17, Cambridge, MA 02139, USA
*Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB,UK

1 Introduction

Main chamber gas in a divertor tokamak arises due to recombination of plasma ions either directly in the main chamber (e.g. on limiter/wall surfaces) or indirectly in the divertor. In the case of the main chamber, a certain amount of scrape-off-layer (SOL) plasma interaction with limiters/walls is inevitable, despite the diverted nature of the magnetic topology in the boundary. Such interaction has been recently demonstrated in C-Mod [2]. In the case of the divertor, recombination can occur either at the divertor plate surface or in the volume, followed by leakage to the main chamber either through the mechanical baffle structure [3] or through the divertor plasma itself. The latter will occur when the divertor plasma is transparent for the transport of neutrals, e.g. at low discharge density. In this paper we present experimental evidence from Alcator C-Mod and JET which is consistent with a significant fraction of the main chamber neutral pressure resulting from divertor leakage.

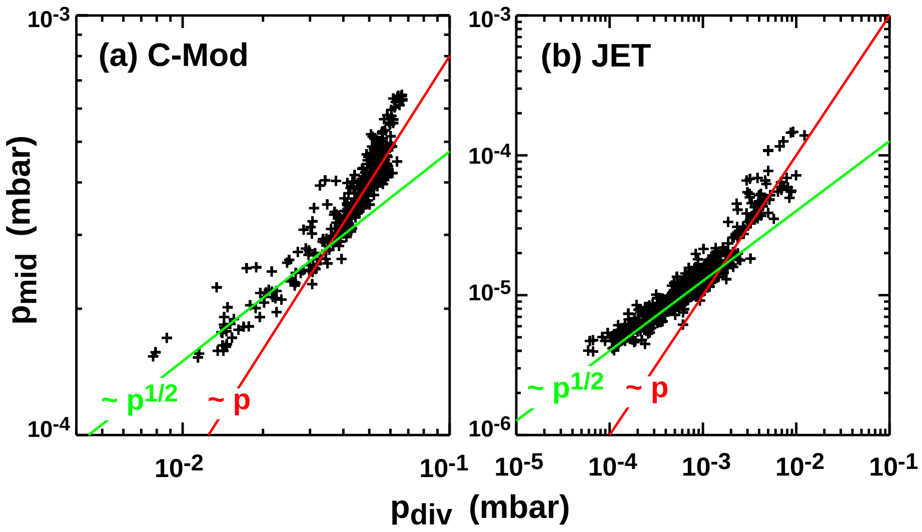
2 Experiment

We present data here from experimental campaigns in C-Mod (1999) and JET (2000). Although different in absolute size, $R_0 \approx 0.7$ m in C-Mod compared to $R_0 \approx 3$ m in JET, these two machines have many features in common including, single-null divertor geometry, vertical target plates, significant mechanical leakage conductances between the outer divertor and main chamber ($\approx 20\ \mathrm{m^3s^{-1}}$ in C-Mod, $\approx 100\ \mathrm{m^3s^{-1}}$ in JET) and large “vacuum” regions on the low-field side of the plasma, i.e. with antennas/limiters that protrude far from the vacuum vessel wall.

3 Relationship between Mid-Plane and Divertor Pressures

Figure 1 gives the (outside) mid-plane gas pressure p_{mid} as a function of divertor gas pressure p_{div}. In the case of JET, these results include data from a wide range of plasma currents, fields, plasma densities, input powers, confinement modes (L and H), outer gaps, but with fixed X-point and strike-point geometry (i.e. vertical plate configuration). In the case of C-Mod a more limited data set is used—Ohmic discharges at fixed field and current, varying regimes, including detached discharges. There is a strong correlation between the mid-plane pressure and divertor pressure. In particular, two regimes are observed (similar to [4]). First, at high pressure, an approximate linear relationship between mid-plane and divertor pressures is observed in these data sets, with $p_{mid} \approx 0.008\, p_{div}$ in C-Mod and $p_{mid} \approx 0.01\, p_{div}$ in JET. If the main chamber pressure was maintained by leakage through

Fig. 1



the mechanical baffle structure, then indeed a linear relationship would be expected dependent on the relative "pumping" speeds of the mid-plane and divertor regions. In fact, the scatter in these data sets (and others) is sufficiently large that the precise dependency in the high pressure regime is uncertain and may be influenced by a hidden parameter, e.g. machine "condition". In particular, a stronger than linear dependency can be seen in some C-Mod data.

In the case of the main chamber, the plasma is a "pump" (we neglect the torus vacuum pumps) and its magnitude can be estimated based on its surface area and assuming free-streaming molecular flow conditions. This gives $\approx 1400\ \mathrm{m^3s^{-1}}$ in the case of C-Mod and $\approx 4\times10^4\ \mathrm{m^3s^{-1}}$ for JET. Thus, the expected pressure ratios for C-Mod and JET, based on these pumping speeds and the leakage conductances from the divertor only, are 0.014 and 0.003, respectively. These are of the same magnitude as those observed experimentally, making it plausible that the mid-plane pressures in both machines are (in part) maintained by leakage from the divertor. It should be noted, however, that in the case of C-Mod the main chamber recycling ion flux to the limiters [2] is comparable to the estimated leakage flux and given the sizable errors involved in the latter, we cannot be certain as to the relative contributions to the mid-plane pressure of the two sources (in C-Mod).

At low pressure, a second regime is observed where $p_{\mathrm{mid}} \propto p_{\mathrm{div}}^{1/2}$, which results in mid-plane pressures significantly higher than that associated with simple leakage through the mechanical structure. We do not dwell here on an explanation for this dependence, but it could be due to an additional leakage flux from the divertor through the divertor plasma itself at low discharge density. This awaits more detailed neutral transport modeling.

4 Effect of Limiter/Wall-Separatrix Gap

Intuitively one expects that the amount of main chamber recycling from limiters/walls depends on the "gap" between the separatrix and these structures. Figure 2 gives results at fixed divertor gas pressure ($p_{\mathrm{div}} \approx 0.05$ mbar in C-Mod and $p_{\mathrm{div}} \approx 6\times10^{-4}$ mbar in JET),

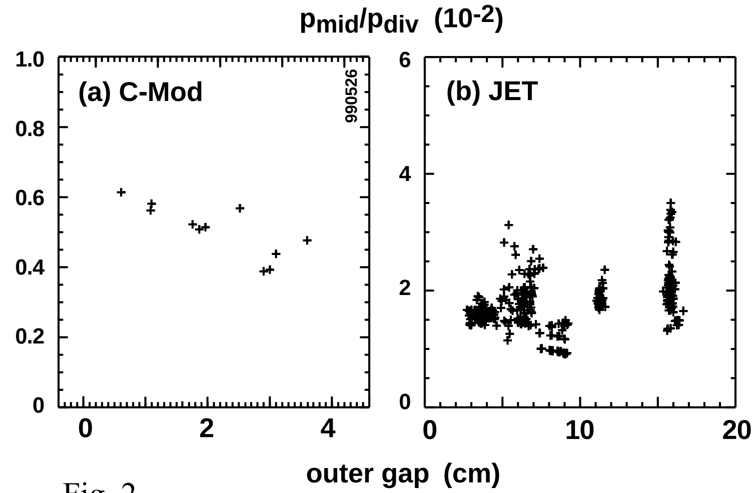


Fig. 2

with varying outer gap. Typical operating gaps are 1.5 cm and 6 cm in C-Mod and JET, which are to be compared with typical particle flux widths of 1 cm and 3 cm, respectively. In addition, in C-Mod a broad shoulder in the parallel flux density further out in the SOL is observed with a significantly longer e-folding distance [2]. In the case of C-Mod, some decrease with increasing gap is apparent and is consistent with the hypothesis that main chamber recycling contributes to the gas pressure. This is not surprising given the relatively broad SOL (in comparison to the gap distance) in C-Mod. In the case of JET, no dependence on the gap is apparent in the data, suggesting little plasma recycling in the main chamber, consistent with the relatively short e-folding width.

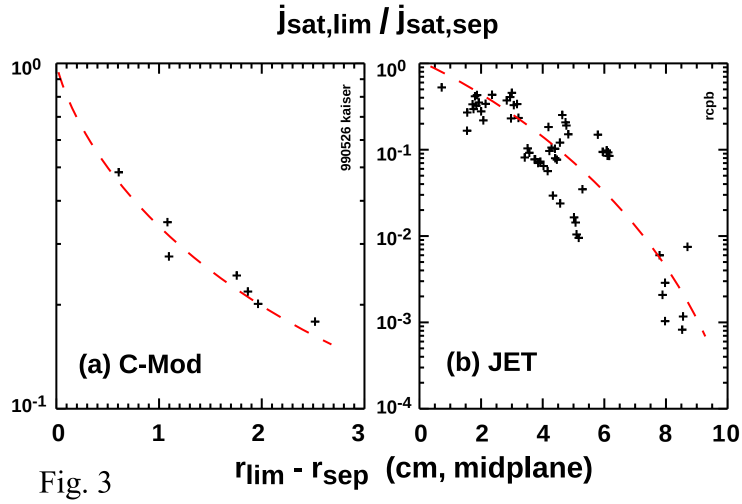


Fig. 3

The respective flux widths are reflected in Figure 3, which gives the ratio of the parallel particle flux density at the limiter radius to that at the separatrix radius, as functions of the limiter-separatrix distance. In the case of C-Mod, the parallel flux density is based on n_e and T_e measurements at the outside mid-plane using the helium beam technique, whilst for JET, a fast-moving Langmuir probe at the top of the vessel is used. One can see that over the typical range of limiter-separatrix distance, the parallel flux density at the limiter radius is significantly higher in C-Mod compared with JET. In the case of JET, a limiter-separatrix distance of 9 cm results in parallel fluxes at the limiter which are a factor of ~ 1000 less than at the separatrix. Such behavior does not occur in C-Mod.

5 SOL Return Flow

In steady-state, the neutral flux that leaks from the divertor to the mid-plane must return to the divertor as plasma flow in the SOL after becoming ionized in the main chamber. In Figure 4 we demonstrate that it is plausible that the SOL plasma conditions can support this return flow. The figure gives the parallel ion flux leaving the main chamber obtained by radially-integrating the SOL plasma profiles obtained with the helium beam (C-Mod) and Langmuir probe (JET) assuming the flow exits the main chamber with Mach speeds of M = 0.5 and M = 1.0, respectively. The results are given as a function of outer gap and are normalized by the main chamber influx of neutrals based on the mid-plane pressure assuming free-streaming conditions and a poloidally uniform source. The ratio of fluxes are clustered around ~ 1 for both machines, indicating that flux balance is possible providing the flow leaving the main chamber has appreciable velocity. We have assumed here that the main chamber influx is due wholly to divertor leakage and thus the Mach numbers quoted here would be reduced in proportion by main chamber recycling, e.g. in C-Mod an equal amount of main chamber recycling would reduce the required Mach number to M = 0.25, close to what is observed with a Mach probe at the entrance to the divertor [2].

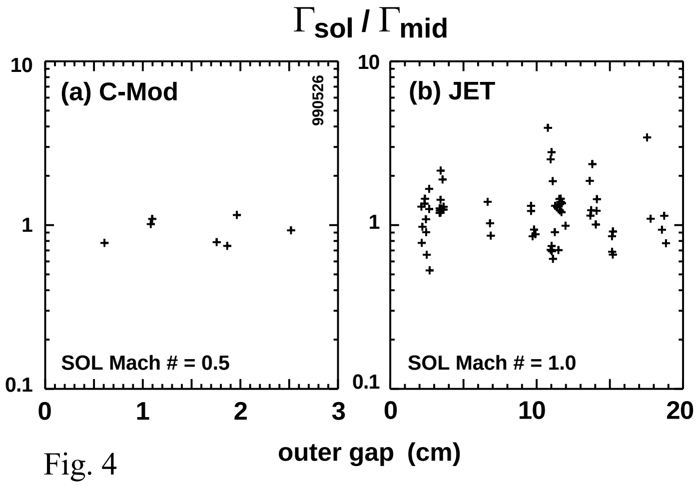


Fig. 4

6 Conclusions

These results are consistent with the mid-plane pressure in C-Mod being determined by a combination of main chamber recycling and divertor leakage. The precise balance is unclear. In the case of JET, divertor leakage appears to be the primary mechanism determining the mid-plane pressure since plasma interaction with limiters appears to be of reduced importance. The difference between C-Mod and JET is explained by the relatively broad SOL in C-Mod compared with JET.

References

1. See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001)
2. B LaBombard et al, Nucl Fusion 40 (2000) 2041
3. C S Pitcher et al, J Nucl Mat 290-293 (2001) 812
4. A Niemczewski et al, Nucl Fusion 37 (1997) 151

JET work carried out under the European Fusion Development Agreement, MIT PSFC personnel supported by US DoE Contract # DE-FC02-99ER54512