

---

EFDA-JET-CP(05)02-23

T. Tala, Y. Andrew, G. Corrigan, K. Crombe, D. Heading, V. Parail, A. Salmi,  
P. Strand, J. Weiland and JET EFDA contributors

# Effect of Poloidal Rotation on the Predictions for the Dynamics of the ITBs and Transport in JET Plasmas



# Effect of Poloidal Rotation on the Predictions for the Dynamics of the ITBs and Transport in JET Plasmas

T. Tala<sup>1</sup>, Y. Andrew<sup>2</sup>, G. Corrigan<sup>2</sup>, K. Crombe<sup>3</sup>, D. Heading<sup>2</sup>, V. Parail<sup>2</sup>,  
A. Salmi<sup>4</sup>, P. Strand<sup>5</sup>, J. Weiland<sup>5</sup> and JET EFDA contributors\*

<sup>1</sup>Association EURATOM-Tekes, VTT Processes, P.O. Box 1608, FIN-02044 VTT, Finland

<sup>2</sup>EURATOM/UKAEA Fusion Association, Culham Science Centre, Oxon. OX14 3DB, UK

<sup>3</sup>Department of Applied Physics, Ghent University, Belgium

<sup>4</sup>Association EURATOM-Tekes, Helsinki University of Technology, FIN-02015 TKK, Finland

<sup>5</sup>Association EURATOM-VR, Chalmers University of Technology, Göteborg, Sweden

\* See annex of J. Pamela et al, "Overview of JET Results",

(Proc.20<sup>th</sup> IAEA Fusion Energy Conference, Vilamoura, Portugal (2004)).

Preprint of Paper to be submitted for publication in Proceedings of the  
EPS Conference,

(Tarragona, Spain 27th June - 1st July 2005)

"This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts or references may not be published prior to publication of the original when applicable, or without the consent of the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK."

"Enquiries about Copyright and reproduction should be addressed to the Publications Officer, EFDA, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK."

## INTRODUCTION

Recent results from the measurements of carbon plasma rotation velocity across Internal Transport Barriers (ITBs) on JET show that the velocities are typically an order of magnitude higher than the neo-classical predictions [1]. As a consequence, the radial electric field can be very different from that calculated using the neo-classical value for  $v_{\text{pol}}$ . This gives further rise to different  $\omega_{\text{E}\times\text{B}}$  shearing rates, as normally used in transport simulations to predict the ITB dynamics, location and strength. The 1D first-principle transport models, such as the Weiland model [2] or GLF23 [3], have so far failed to reproduce satisfactorily the time dynamics, location and strength of the ITBs [4]. The Weiland model does not typically predict an ITB at all while GLF23 predicts the ITB at the wrong radial location or too weak an ITB. One of the obvious reasons is that the growth rates of the ITG/TEM modes significantly exceed the  $\omega_{\text{E}\times\text{B}}$  shearing rates calculated from the radial electric field  $E_r$ . In the present calculation of  $E_r$  in transport codes, the neo-classical value for the poloidal rotation velocity is assumed. The past explanation for the failure of the Weiland model was the oversize growth rates as compared with the  $\omega_{\text{E}\times\text{B}}$  shearing rate. However, after the recent measurements of  $v_{\text{pol}}$  in JET, the question to be addressed in this paper is whether the failure to predict ITBs could actually be caused by the incorrectly estimated  $\omega_{\text{E}\times\text{B}}$  shearing rates, rather than just the oversize growth rates.

## 1. EXPERIMENTAL AND CALCULATED CARBON POLOIDAL ROTATION VELOCITIES ON JET

The time traces and the profiles of one of the ITB discharge with the carbon poloidal rotation measurements are shown in figure 1. The poloidal velocity increases by a factor of up to 5, and even in some cases changes its sign within the ITB layer around  $t=5.8\text{s}$  when the ion ITB forms. Unfortunately, within the present time and spatial resolution of the  $v_{\text{pol}}$  measurements, it is impossible to resolve the causality, i.e. whether the changes in  $v_{\text{pol}}$  occur before ITB forms or whether the changes in  $v_{\text{pol}}$  are caused by the changes in the ion temperature profile, when the ITB has already been triggered. However, it seems to be very difficult, unless impossible, to obtain carbon poloidal rotation velocities significantly over 10km/s within the framework of neo-classical theory, even by using artificially modified, extremely large main ion density and temperature gradients as well as carbon density gradients.

The experimentally measured carbon poloidal rotation velocities are compared with the neo-classical estimates calculated with NCLASS code [5] in figure 2 (left frame). The discrepancy between the measured and neo-classical carbon poloidal rotation is largest within the ITB layer, which is shown by the  $\rho_{\text{Ti}}^*$  (defined as the ion larmor radius divided by the ion temperature length) contour plot in the right frame. Within the ITB region (4 innermost chords), the measured poloidal rotation exceeds the neo-classical one by an order of magnitude. The measured  $v_{\text{pol}}$  seems to be also elsewhere larger than the neo-classical one.

Due to the poloidal velocities being significantly larger than the neo-classical ones, the actual radial electric fields and further the  $\omega_{\text{E}\times\text{B}}$  shearing rates may be very different†from those used in transport simulations assuming neo-classical  $v_{\text{pol}}$ . The effect of using the measured  $v_{\text{pol}}$  instead of the

neo-classical one on  $E_r$  and  $\omega_{E \times B}$  is studied in section 3 and on the predictive transport simulation with the time dynamics of the ITBs in section 4.

## 2. COMPARISON OF THE RADIAL ELECTRIC FIELD AND THE $\omega_{E \times B}$ SHEARING RATE

The definitions for the different components in the calculation of the radial electric field are

$$E_r = E_{\nabla p} + E_{pol} + E_{tor} = \frac{1}{eZ_i n_i} \frac{\delta p_i}{\delta r} - v_{pol, i} B_{tor} + v_{tor, i} B_{pol}, \quad (1)$$

where  $Z_i$  is the charge number,  $n_i$  the density,  $p_i$  the pressure,  $v_{pol, i}$  the poloidal velocity and  $v_{tor, i}$  the toroidal velocity of the ion species  $i$  and  $B_{tor}$  and  $B_{pol}$  are toroidal and poloidal components of the magnetic field. In this paper, the species  $i$  is either deuterium or carbon. The  $\omega_{E \times B}$  flow shearing rate is calculated from the radial electric field as

$$\omega_{E \times B} = \left| \frac{(RB_{pol})^2}{B} \frac{\nabla \Psi}{RB_{pol}} \frac{E_r}{RB_{pol}} \right|. \quad (2)$$

The radial electric field with its three different components are illustrated in figure 3. Three different ways, originating from the different ion species (carbon versus deuterium) or different source for  $v_{pol}$  (experimental versus neo-classical), have been employed to calculate  $E_r$ . In the case of experimental  $v_{pol}$  (blue curves), the radial electric field is calculated from the measured carbon poloidal and toroidal rotation and the measured carbon pressure. In the case of neo-classical  $v_{pol}$  calculated with NCLASS, there are two options to calculate the radial electric field. a) Use the calculated deuterium poloidal rotation together with the measured deuterium pressure and carbon toroidal rotation assuming deuterium and carbon  $v_{tor}$  to be the same (red curves) or b) use the calculated carbon poloidal rotation together with the measured carbon pressure and measured carbon toroidal rotation (green curves). The black curves in toroidal and pressure gradient terms denote that at least two of the curves are identical.

The radial electric field and the  $\omega_{E \times B}$  shearing rates are very different depending on whether the experimental or neo-classical poloidal rotation velocities are used (blue versus green curves). On the other hand, taking the different ion component from NCLASS (green, carbon versus red, deuterium) gives roughly the same radial electric field, indicating that the toroidal rotation velocity of deuterium should be rather similar to that of carbon.

## 3. PREDICTIVE SIMULATIONS OF THE ITB DYNAMICS USING THE EXPERIMENTAL $V_{POL}$

Two predictive simulations with the Weiland transport model are compared. The only difference between the two simulations is that the first one (red curves) uses the neo-classical poloidal velocity from NCLASS whereas the second one (blue curves) takes the experimentally measured  $v_{pol}$  in the calculation of  $E_r$  and  $\omega_{E \times B}$  flow shearing rate.

In the case when the experimental poloidal rotation is used, the Weiland model predicts the ion ITB just at the right radial location and right instant with roughly the same ITB strength as measured in the experiments when. On the other hand, otherwise an identical simulation except with  $v_{\text{pol}}$  from NCLASS does not exhibit any sign of an ITB.

## CONCLUSIONS

If the experimental poloidal velocity is used instead of the neo-classical one to calculate the radial electric field and the  $\omega_{E \times B}$  shearing rate,  $E_r$  and  $\omega_{E \times B}$  are found to be even qualitatively significantly different. This is most pronounced within the ITB layer. As a consequence, the simulation predictions for the dynamics, strength and location of ITBs change and may improve significantly, as shown here in the case of the Weiland model. In addition to changing the predictive transport simulation results, the non-neo-classical poloidal rotation velocities might raise the need for further assessment of the neo-classical transport theory in the presence of turbulence.

## ACKNOWLEDGEMENT.

The authors are grateful to Wayne Houlberg for providing us the NCLASS code and for many fruitful discussions on this topic.

## REFERENCES:

- [1]. K. Cromb e et al., “Poloidal rotation dynamics, radial electric field and neoclassical theory in the JET ITB region”, submitted to Phys. Rev. Lett. (2005).
- [2]. J. Weiland, “Collective modes in inhomogeneous plasmas”, Institute of Physics Publishing, Bristol (2000).
- [3]. R.E. Waltz et al., *Phys. Plasmas*, **4**, 2482 (1997).
- [4]. T. Tala et al., IAEA Fusion Energy Conference, Portugal, November 1-6 2004, TH/P2-9.
- [5]. W. Houlberg et al., *Phys. Plasmas* **4** 3231 (1997).

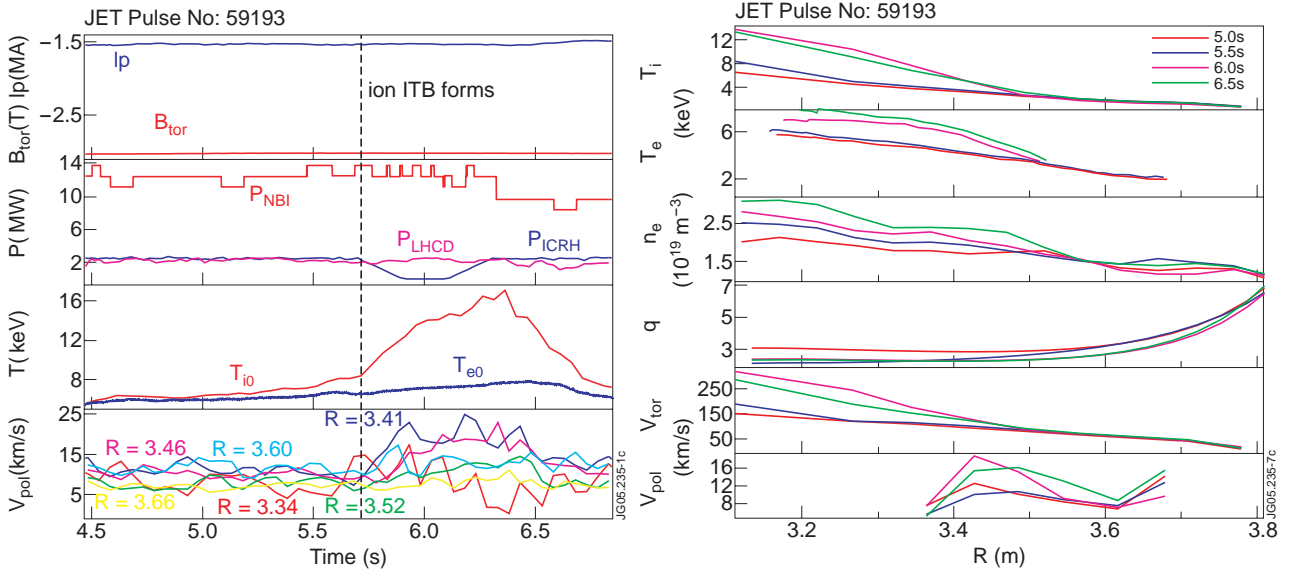


Figure 1. Time traces and profiles at four instants of one of the JET ITB discharges with poloidal rotation measurements. The poloidal velocities are measured at 6 different radii.

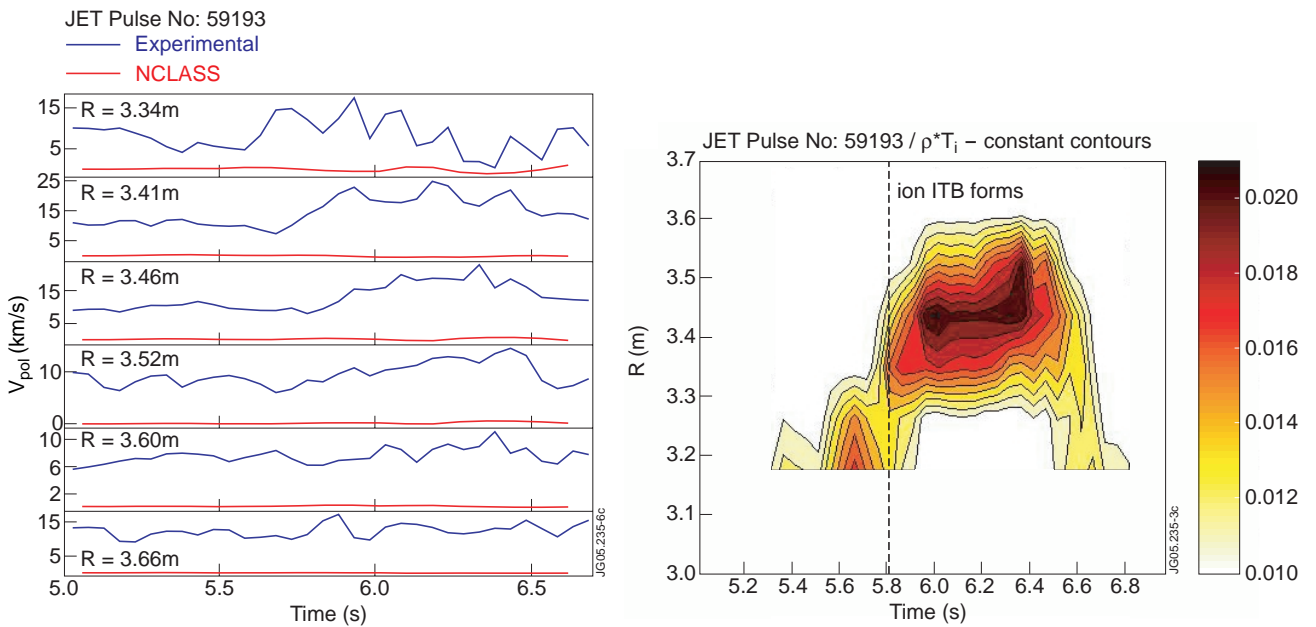


Figure 2. Experimentally measured carbon poloidal rotation velocity compared with the calculated (neo-classical) one at each 6 measured radii (left frame). Location and strength of the ion ITB as a function of time and major radius (right frame).



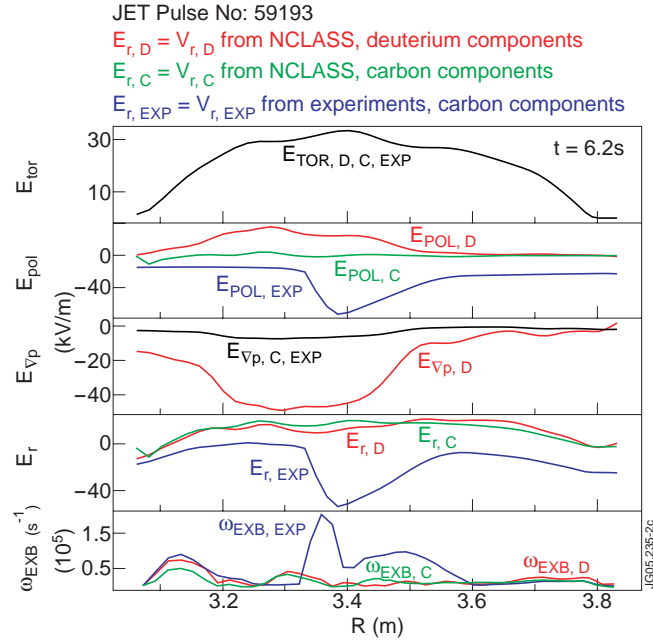


Figure 3. The radial electric field with its three components, calculated using different ion species and different sources for  $v_{pob}$  pressure gradient and density at  $t = 6.2s$ . Shown also the corresponding  $w_{ExB}$  shearing rates, respectively.

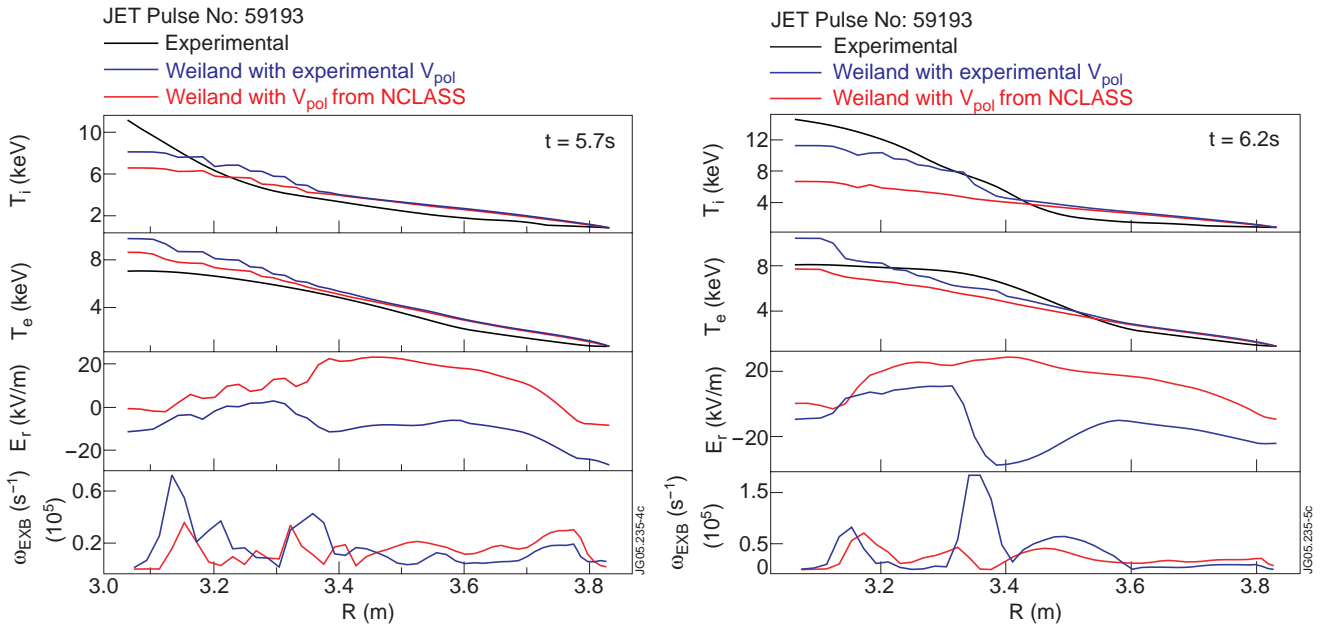


Figure 4. Predictions for the ion and electron temperatures, radial electric field and  $\omega_{ExB}$  shearing rate before the ion ITB formation (left frame) and after it (right frame).