PREDICTIVE SIMULATIONS OF HIGH PERFORMANCE AND DIMENSIONLESS SCALING EXPERIMENTS ON JET*

P. Strand, H. Nordman, J.Weiland, A. Jarmén
Chalmers University of Technology, Göteborg, Sweden

J. P. Christiansen
JET Joint Undertaking, Abingdon, UK

Abstract

Predictive simulations have been performed on JET dimensionally similar discharges together with high performance hot-ion H-mode and optimised shear discharges. The first-principles drift-wave model used in the simulations predicts global scalings in reasonable agreement with the scalings observed in the collisionality, isotope and β–scans of JET ELMy H-modes. In contrast to the weak dependence on β found in the ELMy H-mode discharges, effects of finite-β are shown to be important in the simulations of high performance discharges such as the ELM-free hot-ion H-modes on JET.

1. INTRODUCTION

JET has performed a series of dimensionless scaling experiments in ELMy H-mode [1,2]. The dimensionless quantities studied in these scans were the normalised gyroradius, ρ_*, collisionality, ν_*, and magnetic β. The findings of these similarity experiments can be summarised in terms of the scaling of confinement time with the dimensionless quantities as in

$$B\tau_{TH} \propto \rho_*^{-\alpha_\rho} \nu_*^{-\alpha_\nu} \beta^{-\alpha_\beta} \tag{1}$$

where α_ρ=2.7, α_ν=0.27, and α_β=0.05. Similar results have also been obtained in the D-IIID tokamak [3,4]. The results agree with the global scaling laws except for the scaling with magnetic β which is much stronger in the global scaling law. For instance the ITERH93-P scaling has α_ρ=2.7, α_ν=0.28, and α_β=1.20. In addition, recent isotope scaling experiments on JET indicate that the core plasma has an isotope scaling consistent with gyro-Bohm models whereas the edge plasma has a much stronger mass dependence which is reflected in the global scaling of transport with isotope mass number [5]. The gyro-Bohm behaviour of the ρ_*-scan in ELMy H-mode, as well as the Bohm-like dependence in L-mode plasmas, have been reproduced previously in simulation codes and will not be discussed further here [6-8].

The study of tokamak transport in advanced confinement regimes is a high priority issue in present day fusion research. In contrast to the ELMy H-mode regime, these improved confinement regimes are generally not stationary in character. The advanced regimes are often associated with the formation of a transport barrier in the plasma. In the transient ELM-free hot-ion VH-mode discharges, the transient ELM-free phase leads to the formation of an edge transport barrier resulting in a transient increase of edge pressure and thermal energy. The detailed physics behind the formation of transport barriers is not well understood, however the suppression of turbulence by flow shear play a major role in most theories [9]. This mechanism has also been advanced as the cause of the development of the internal transport barriers in optimised shear discharges.

In the present paper, a gyro-Bohm transport model [10,11] is used in predictive transport simulations of the similarity scans in collisionality and β. Results from simulations with a varying isotope mass is also presented together with simulation results of hot-ion H-mode experiments and optimised shear discharges.

* Work partly performed under JET Task Agreement NFR/TA4

2. PREDICTIVE TRANSPORT SIMULATIONS

The time-dependent simulation code predicts ion and electron temperatures as well as density profiles for electrons, main ions and a single impurity species. The simulations are based on a first-principle gyro-Bohm transport model for ion-temperature-gradient (ITG) modes, collisionless trapped electron (CTE) modes and ideal MHD ballooning modes, incorporating effects of finite beta electromagnetic perturbations, fast particle dilution and plasma elongation. Initial profiles, boundary conditions and source terms are obtained from data processed by TRANSP. The outer boundary condition is taken on top of the density pedestal, usually between a normalised minor radius of r/a=0.8 and r/a=0.9 depending on discharge parameters. The simulation code predicts profiles extending from the axis to the chosen outer boundary condition. Neoclassical estimates are used for the inner core transport together with artificial diffusivities on the electron channels, to simulate the effects of sawteeth. These artificial diffusivities are implemented as ramp functions covering the innermost 20-30% of the plasma radius. It has been shown previously that the effects of this inner core modelling on the bulk plasma is very weak [7]. In the simulations performed here, the impurity temperature is assumed equal to the main ion temperature and the energy evolution equations have been summed over the ionic species. Due to the lack of dependable impurity deposition data, a source term for the impurity density has been prescribed as a gaussian, peaking at the point of the outer boundary. The strength of this source term is then chosen as to reproduce the measured Z_{eff}-profile within the experimental error-bars while the source strength is held fixed throughout the simulations.

3. RESULTS AND DISCUSSION

In general the pulses are well reproduced by the simulations; the predicted thermal energies as well as the profiles are within or close to the estimated error bars. The simulations have been performed in a time-dependent setting where time-slices from the stationary phase of the ELMy H-modes have been used for the analysis of the dimensionless scaling experiments whereas the intrinsically non-stationary high-performance discharges have been followed from L-mode to the enhanced confinement regime in question. For the parameter range studied here the transport model has no intrinsic transition mechanism between L- and H-modes and the change in confinement properties in this transition is due to the time-dependent change in the temperature and density boundary conditions.

3.1 DIMENSIONLESS SCALING EXPERIMENTS

In the collisionality scan ν_* was varied a factor of 2.6 between the two discharges 37718 (2T, 2MA) and 37728 (2.6T, 2.6MA). In order to fulfil the similarity scalings the heating power was changed from 10MW to 16MW between the two discharges and the volume average density was held fixed at $5\times10^{19}\,m^{-3}$. Analysing the collisional dependence in the ν_* -scan a scaling similar to the experimentally observed $B\tau_E \propto \nu_*^{-0.27}$ is obtained. This is shown in Fig. 1. where the diffusivity ratio is given assuming a one-fluid approximation. The scaling of χ_i and χ_e separately on the other hand, seem to depend on how well the boundary conditions conform to the similarity scalings. In particular the electron channel show a stronger collisionality dependence than expected from the model. The one-fluid result however, is maintained on average through the stationary phase of the discharges. The transport model used here is mainly collisionless, the collisionality scaling obtained in the simulations has to be caused by edge transport mechanisms entering the simulations through the boundary conditions, causing slightly different profile shapes between the two discharges. Similar edge effects have previously been found to be important in simulations of ρ_* experiments at JET [6,7].

The experimental profiles in the β -scan are also well reproduced by the simulation code with root-mean-square deviations of the predicted profiles within 10-15%. Global quantities such as thermal energy and confinement time are close to those experimentally observed indicating a weak confinement degradation of transport with increasing β. In this scan β had a range of 1.6 between the two discharges, 38407 (1.5T, 1.5MA) and 38415 (1.7T, 1.7MA). The global dependence, although still fairly weak, is somewhat stronger than the experimental results and depends slightly on where in the relative phases of the ELM cycles in the two discharges the analysis is performed.

In addition to the collisionality and β−scan described previously, the simulation code has also been run on 12 ELMy H-mode discharges with main plasma varying from pure hydrogen to tritium giving a range of 3 in the ion mass dependence. However the gyro-Bohm transport model has a √m dependence effectively reducing the testable range to √3. This factor will enter as a multiplier on the diffusivities and due to the stiffness of the model this will have a fairly weak impact on the confinement time ($\tau \propto m^{-0.125}$ in L-mode). In general, the agreement between experimental and simulated profiles are good with RMS errors < 10% with impurity profiles being slightly worse. Further analysis is however necessary in order to quantify the isotope dependence.

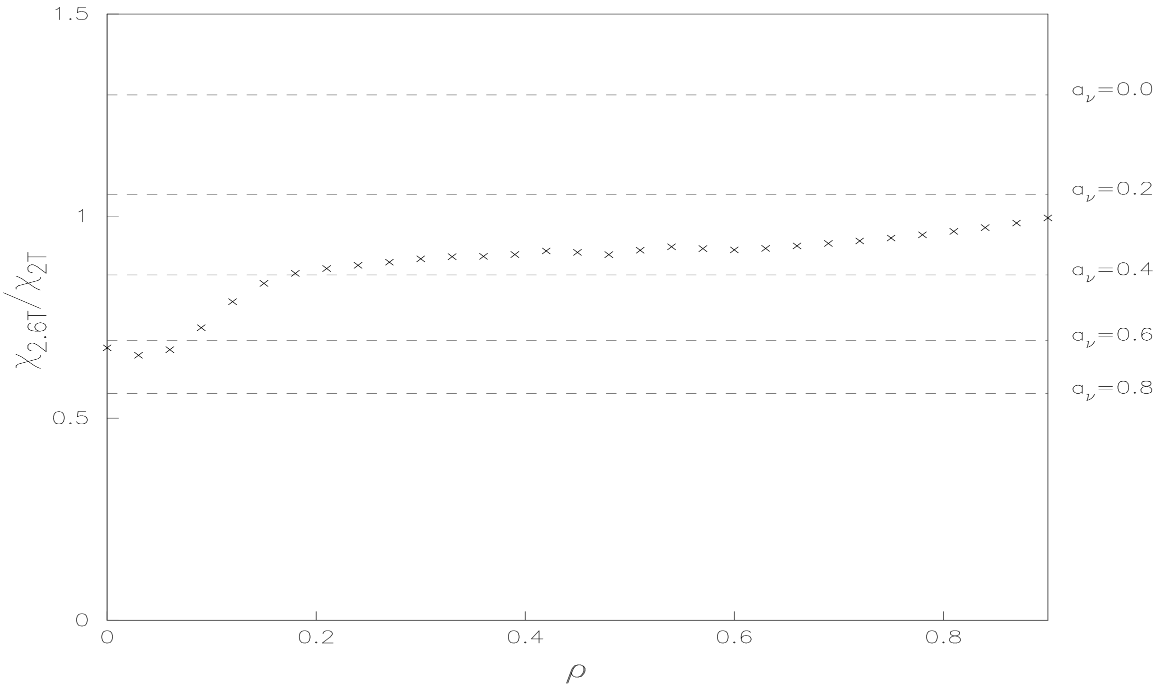

FIG. 1. Low ν to high ν* ratios of one-fluid heat diffusivities $\chi = (n_i \chi_i + n_e \chi_e)/(n_i + n_e)$ as obtained in simulations. Ratios corresponding to exponents a_ν = 0 (top), 0.2, 0.4, 0.6 and 0.8 (bottom) are indicated.*

3.2 HIGH PERFORMANCE DISCHARGES

In contrast to the weak dependence in the β-scan, the effects of finite β are important at higher β. This is manifested in simulations of hot-ion H-modes on JET. In these simulations boundary conditions are taken on top of the edge pedestal and the discharges are followed from L-mode to the stage of peak performance, before the disruption, in VH-mode. The choice of boundary conditions (taken at 80 -90% of the plasma minor radius) thus provides the transition mechanism between L- and H-mode. The simulations are found to reproduce the transient VH phase of the pulses with ion temperatures reaching 15-25 keV. In order to achieve this in the simulations, it is necessary to include the stabilising effects of finite beta, i.e. electromagnetic perturbations on the ITG-mode transport. This is exemplified in Fig. 2. It is found that the stabilising effects of fast particle and impurity dilution is subdominant in this regime. For the optimised shear discharges, the additional stabilising effects of sheared ExB rotation are important for the development of the internal transport barrier. This has been verified in simulations of optimised shear discharges on JET and one other tokamak. The ion temperature profiles are well reproduced by the simulations only when ExB rotation is included. More work is needed in order to quantify and compare the effects of sheared rotation with the finite beta stabilisation for the hot-ion H-mode discharges.

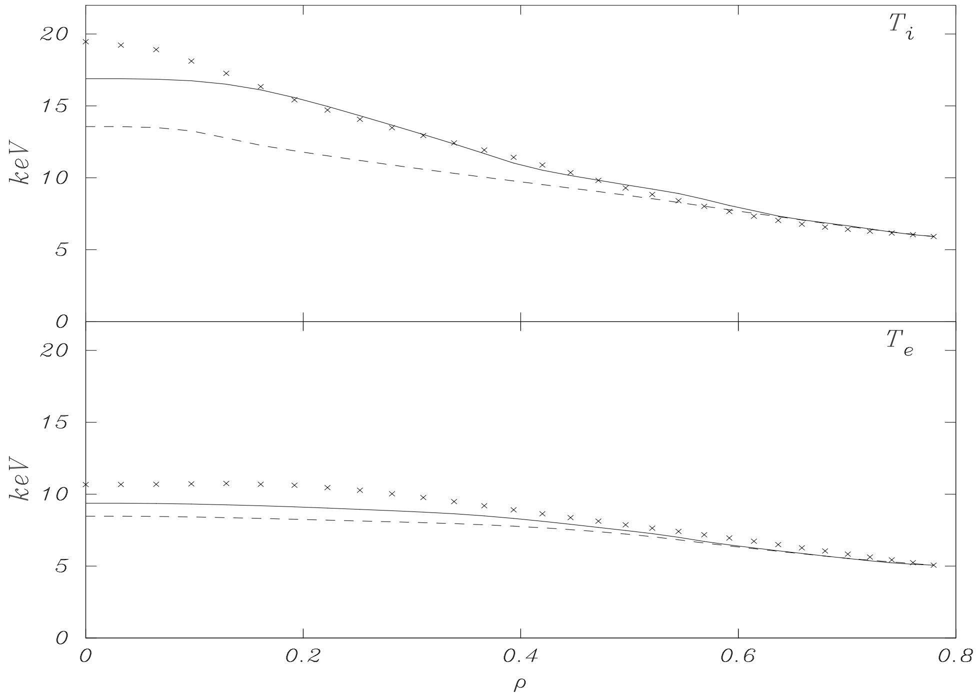

FIG. 2. Simulation results using a) the electrostatic model shown as dashed lines (- - -) and b) including electromagnetic corrections shown as full lines (—), for JET pulse 26087 at 53.3 s compared to experimental profiles (X) as a function of the square root of normalised toroidal flux.

REFERENCES

[1] Cordey, J.G., Plasma Phys. Control. Fusion **38** (1996), A67
[2] JET Team (presented by J.G. Cordey), Fusion Energy 1996 (Proc 16th International Conference), Montreal, Canada, **2** (1996), 603
[3] Petty, C.C, et al., Phys. Plasmas **2** (1995), 2342
[4] Petty, C.C, Luce T.C., 24th EPS Conference, Berechtesgarden 1997, Vol. 21 Part III, 1085
[5] Cordey., J.G., et al., "H-mode power threshold and confinement in JET H, D, DT and T plasmas", IAEA-F1-CN-69/EX7-1, 17th IAEA Conf. Yokohama 1998
[6] Nordman, H., Strand, P.,Weiland, J., Jarmén, A., Christiansen, J.P., Fusion Energy 1996 (Proc 16th International Conference), Montreal, Canada, **2** (1996), 567
[7] Strand, P., Nordman, H., Weiland, J., Christiansen, J.P., Nucl. Fusion **33** (1998), 545
[8] Kinsey, J.E., Bateman, G., Phys. Plasmas **3** (1996), 3344
[9] Burrel, K.H, Phys. Plasmas **4** (1997), 1499
[10] Jarmén, A., Andersson, P., Weiland, J., Nucl. Fusion **27** (1987), 941
[11] Weiland, J., Jarmén, A., Nordman, H., Nucl. Fusion **29** (1989), 1810