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VALIDATION OF 1-D TRANSPORT AND SAWTOOTH MODELS FOR ITER

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VALIDATION OF 1-D TRANSPORT AND SAWTOOTH MODELS FOR ITER

ABSTRACT

In this paper we describe progress on validating a number of local transport models by comparing their predictions with relevant experimental data from a range of tokamaks in the ITER profile database. This database. the testing procedure and results are discussed. In addition a model for sawtooth oscillations is used to investigate their effect in an ITER plasma with alpha-particles.

1. INTRODUCTION

Assessments of the ignition capability of ITER usually rely on the extrapolation of empirical scaling laws for the global energy confinement time [1]. Reliable local transport models would allow more precise predictions. In this paper we describe progress on validating a number of local transport models [2] by comparing their predictions with relevant experimental data from a range of tokamaks in the ITER profile database. This database is described in Section 2, the testing procedure in Section 3 and results are discussed in Section 4. In Section 5 a model [3] for sawtooth oscillations is used to investigate their effect in an ITER plasma with alpha-particles.

2. ITER PROFILE DATABASE

The profile database is organized through the Confinement Modelling and Database expert group which collects inputs from data providers and users. The structure adopted for the profile database is that all the information required for detailed transport analysis is supplied for each discharge in the form of four text files:

1) A file containing comments and a discharge description;
2) A file containing a list of global quantities (such as plasma composition, neutral beam energy) at a selected time point during a discharge;
3) A file containing 1D time traces such as plasma current, line average density or heating power; and finally
4) A file containing profiles of quantities such as electron and ion temperatures, densities, safety factor and heat deposition at the specified time point (and as a function of time where possible).

Profile information is given as a function of 'minor radius' ρ, the square root of the normalized toroidal flux; geometrical quantities such as the surface averaged quantities $\langle|\nabla\rho|\rangle$ or $\langle|\nabla\rho|^2\rangle$ are also provided. All energy and particle sources are given as a function of ρ and time to allow detailed transport analysis.

A standard file format has been agreed. All sets of files for each available discharge are on an ftp server which also contains the profile database manual listing all the details for the file format, as well as the lists and definitions of the physics quantities to be included for each discharge. The database used for this validation exercise contains fully documented discharges from: DIII-D, JET, TFTR, JT60-U, ASDEX-U, T-10, TEXTOR, TORE SUPRA and RTP. The experimental data in the database includes data from a wide variety of experimental regime: Ohmic, L-mode, H-mode (ELMy and ELM-free), hot-ion modes, and ECH-heated hot-electron as well as high power DT discharges. Of particular interest are series of discharges over which various parameters were individually varied: scans over current, shaping, isotope, ρ_*, ν_* and β.

3. MODEL TESTING PROCEDURE AND SIMULATIONS DATABASE

Eleven transport models [2] are being tested by twelve modellers, see Table I. These models have been made available on the profile database server by their authors so that other modellers can also use them.

Table I Models and Modellers

Model	Modeller	Physics
Turner	M. Turner (EU) S. Attenberger (US)	Semi-empirical
Turner-IFS/PPPL	M. Turner (EU) S Attenberger (US)	Semi-empirical
Itoh	A.Fukuyama (JAP) S. Attenberger D. Mikkelsen R. Waltz (US)	Current Diffusive BallooningModes
T11 / SET	A. Polevoi (RF)	Semi-Empirical
RLW B	D. Mikkelsen (US) D. Boucher (JCT)	Semi-Empirical
Waltz	R. Waltz (US)	ITG
mixed	A. Taroni (EU)	Semi-Empirical
mixed-shear	G. Vlad/M. Marinucci (EU)	Semi-Empirical
IFS/PPPL	M.Turner (EU) S. Attenberger B. Dorland D. Mikkelsen R. Waltz (US)	ITG
Weiland	J. Weiland(EU) D. Mikkelsen R. Waltz(US)	ITG
Multi-mode	J. Kinsey (US)	Drift waves RBM

Various tools are being used to test the transport models: these range from fully predictive codes that self-consistently model heating and particle sources and predict both temperature and density profiles, to power-balance codes that use the heat and particle sources as well as density profiles from the profile database to predict the temperature profiles for a given transport model. A benchmarking exercise, using a simple transport model, has been carried out to test the basic elements of the power-balance codes and the way the data is read. A similar procedure is under way among predictive codes but is not yet completed because of the larger range of potential differences between these codes. Therefore, we emphasise the model testing using validated power-balance codes. The simulations from power-balance and predictive codes are recorded using the same format as the experimental data and centrally stored on the ftp server. This allows modellers to compare their simulations and to apply comparison tests between simulations and experiments in a fully automated and rigorously identical fashion.

A number of tests have been chosen to compare simulations and experiment:

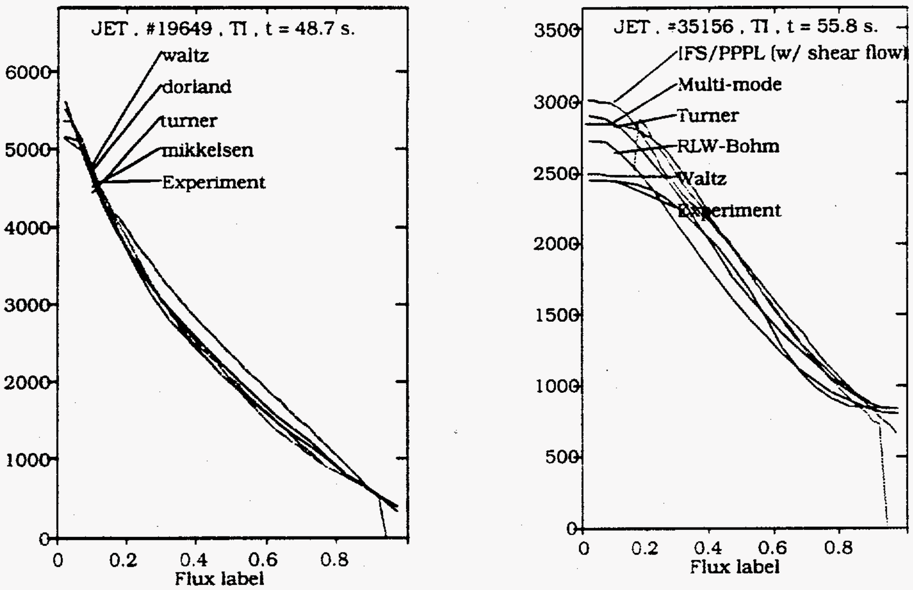
(1) Ratio of total stored energy: W_s / W_x, where $W = \Sigma(3/2)(n_e T_e + n_i T_i)dV$; (2) W_{es} / W_{ex} and W_{is} / W_{is} (same as (1) but separating electron and ion contributions); (3) $(n_{i,\rho=0.3} T_{i,\rho=0.3} W)_s / (n_{i,\rho=0.3} T_{i,\rho=0.3} W)_x$; (4) $\chi^2 = \Sigma(T_s - T_x)^2 / N\sigma^2$, where σ is the experimental error; (5) $\beta_s^{*2} / \beta_x^{*2}$ where $\beta^{*2} = \Sigma n_i^2 T_i^2 dV$; (6) STD = $\sqrt{\Sigma(T_s - T_x)^2} / \sqrt{\Sigma T_x^2}$, OFF = $\Sigma(T_s - T_x) / \sqrt{\Sigma T_x^2}$. Measures (1) - (5) are over the

range $0.2 < \rho < 0.9$, measure (6) over 3 intervals:
$0.2 \leq \rho \leq 0.9, 0.2 \leq \rho \leq 0.5, 0.5 \leq \rho \leq 0.9$

Since the simulations use the experimental edge temperature as an input boundary condition, we remove this 'pedestal' contribution in the comparison of the energies W, W_e and W_i. These 'incremental' values of W are used in Section 4.

4. SIMULATION RESULTS

It is only possible to present here a few examples of the analysis of the modelling results that has been carried out using the data and software on the server. In Fig 1, as illustrations of temperature profile modelling, we compare results for the T_i profile for two JET shots. Figure 1(a) shows the agreement between the results for a number of different codes using the IFS/PPPL model; Fig 1(b) shows the results obtained for a number of different models by their authors.



(a) (b)

Fig. 1 Various predictions for ion temperature profiles for two JET shots: (a) 19649 is an L-mode and (b) 35156 is a member of an H-mode ρ_* scan

In Fig 2 we show the values for W_s/W_x for a number of models using the same power-balance code (RW); this figure indicates L and H-mode simulations.

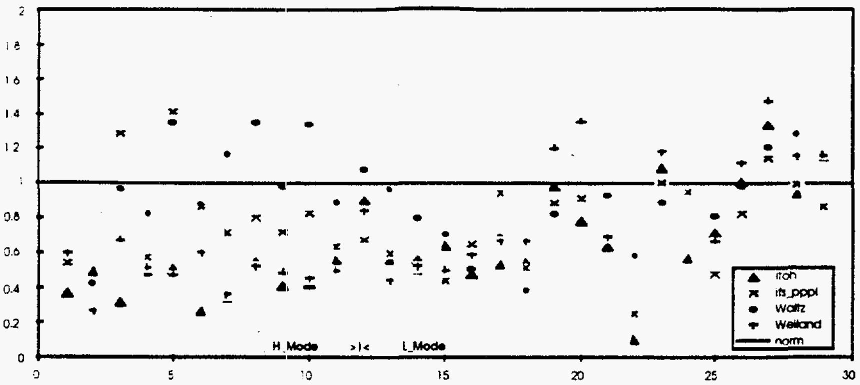


Fig. 2 Power-balance code modelling results for W_S/W_X from various models. (These preliminary results use models taken from the literature rather than the server.)

Figure 3 illustrates the variability arising from using the two different types of code to calculate W_S/W_X, with the RLWB model as an example. Figures 4, 5 and 6 show the results for W_S/W_X for a number of modellers using their own models. Figure 4 shows the semi-empirical Turner and Turner - IFS/PPPL models and the physics based IFS/PPPL model with an estimate of shear flow stabilisation; Fig 5, the physics based Itoh, Waltz, Weiland and Multi-mode models; and Fig 6, the semi-empirical mixed Bohm gyro-Bohm, its modification to take account of magnetic shear and the T11/SET models.

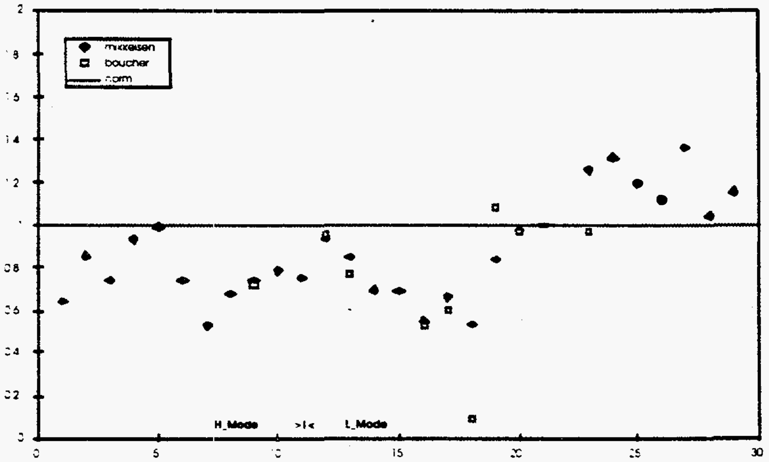


Fig. 3 RLWB model predictions for W_S/W_X using a predictive (DB) and a power-balance (DM) code

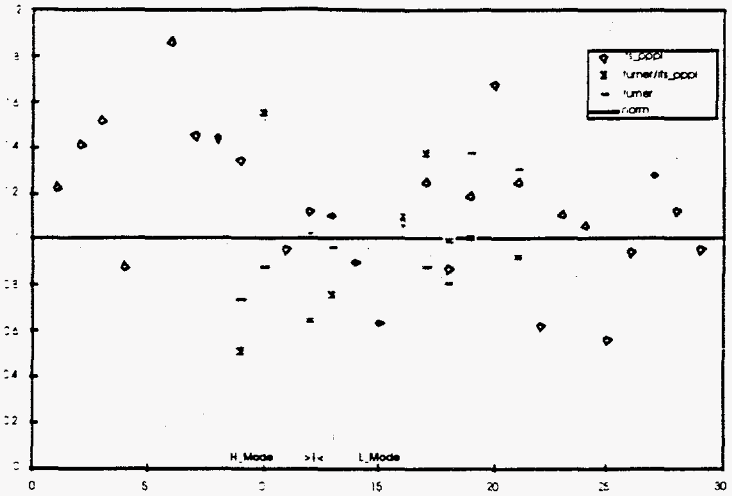


Fig. 4 Results for W_s/W_x from the semi-empirical Turner and Turner-IFS/PPPL models and the physics based IFS/PPPL model with an estimate of shear flow stabilisation

The standard deviations on the incremental W_e and W_i over the discharges in the database for a number of models and modellers have been analysed. This shows that for these measures of performance, few models achieve better than 30% success in fitting the data, which is competitive with the performance of global scaling laws. A number of the models perform comparably well. It is thus difficult, at this point, to identify a 'best' model on the basis of these particular comparisons. It is, however, worthwhile using a number of them in predictive codes to establish a range of predictions for ignition in ITER. Some models (e.g., IFS/PPPL) can be very sensitive to edge boundary conditions and the significance of this for ITER needs quantifying.

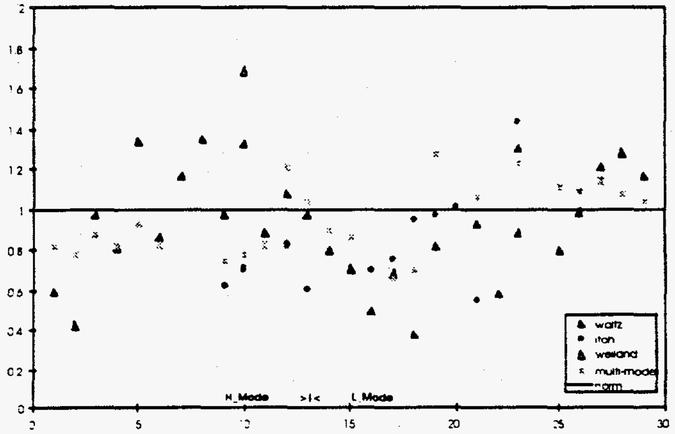


Fig. 5 Results for W_s/W_x from some physics based models: Itoh, Waltz, Weiland and Multi-mode models

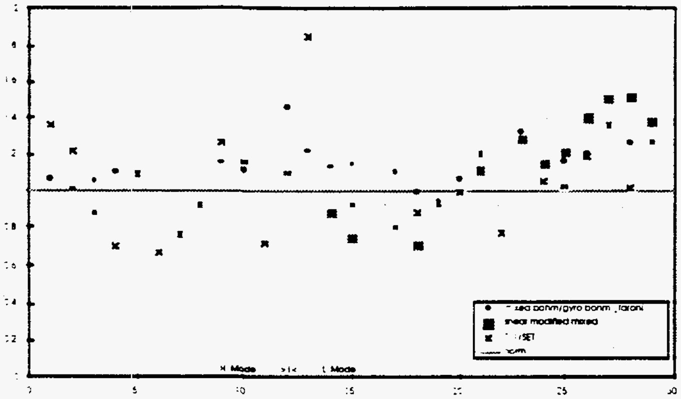


Fig. 6 Results for W_S/W_X from some semi-empirical models: the mixed Bohm gyro-Bohm (these simulations used a different edge prescription), its modification to account for magnetic shear and T11/SET models

The true importance of the work reported here is that, for the first time, an open and systematic procedure for assessing the performance of transport models against well documented data is available to all. It can be anticipated that: (i) continuing work on improving the completeness and consistency of the information in the profile database; and (ii) further developments of models (e.g., including effects of sheared rotation) and their subsequent testing, will help to discriminate between transport models. Non-steady state situations could also be particularly helpful in this regard. A transport model that performs satisfactorily can provide a capability to predict non-stationary scenarios in ITER and explore profile effects and new regimes (e.g., Internal Transport Barriers) which are beyond the power of global scaling laws.

5. SAWTOOTH MODELLING

Experimentally, sawteeth are often triggered as a result of the peaking of the pressure profile inside the mixing radius that follows the sawtooth reconnection event. The resulting sawtooth period is therefore related to the energy confinement time which determines how fast the temperature profile recovers after flattening. There is however a different class of sawteeth where the temperature and density profiles can reach their equilibrium value without triggering a reconnection process. For such sawteeth, known as monster sawteeth, the period between successive crashes is much longer than the energy confinement time or the slowing down time of energetic particles. The subsequent sawtooth reconnection can only occur as a consequence of the current profile evolution. The monster sawtooth period is therefore related to the characteristic current penetration time which scales like $a^2T^{3/2}/Z_{eff}$. For instance, in JET discharge #33127 which is an ITER Demonstration Discharge, the monster period was about 0.8 s with a=0.9 m, $T_e(0)$ = 6.2 KeV, $Zeff \sim 1.5$. Assuming that the same relative current variation would trigger a crash in ITER (a=2.8 m, $T_e(0) \sim 30$ KeV, $Zeff \sim 1.5$) the sawteeth period would be ~ 80 s. A model has been implemented [3] to study the stabilization of the internal kink instability in ITER by the fusion produced fast alpha-particles. The potential energy $\delta\hat{W}$ of the internal kink is estimated including the modification coming from high energy particles and thermal trapped particles. A criteria for the sawtooth crash including layer physics (represented by $\hat{\rho}$) is derived in the model and has been implemented in a local transport code that involves these quantities using ITER parameters. The predicted sawtooth period varies between 50 and 100 s depending on the current reconnection model used. Figures 7 and 8 show an example of the sawtooth oscillation and resulting T_e profiles for full Kadomtsev reconnection.

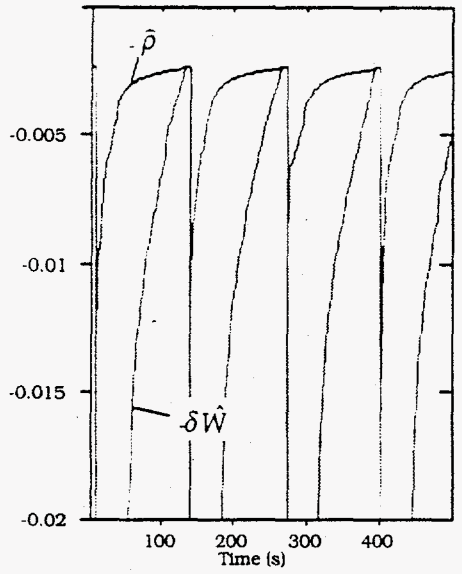


Fig. 7 A sawtooth crash is triggered when $-\delta\hat{W} = -\hat{\rho}$.

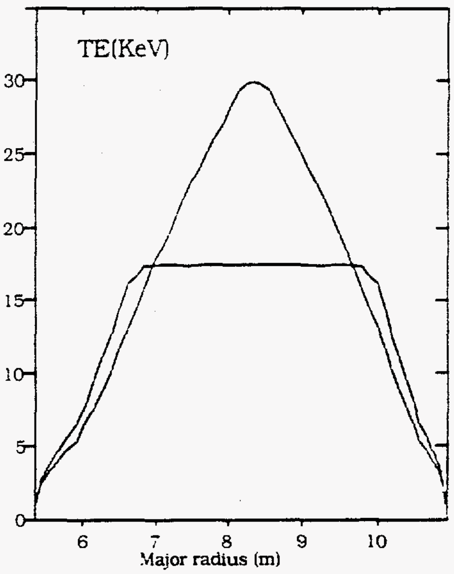


Fig. 8 Electron temperature profile before and after reconnection

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