L-mode plasmas analyses in view of realistic ramp-up predictions for JT-60SA and ITER

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Predicting plasma performance is an essential activity for assessing future campaigns in present day tokamaks as well as in future devices as ITER or JT-60SA. In particular, predictions for the ramp-up phase are of special importance, as successful plasmas in the flat-top phase critically depend on the initial configuration. This is particularly the case for the so-called advanced scenarios for which the plasma shape, flux consumption reduction or the control of the q profile during the ramp-up is mandatory [1, 2, 3]. However, prediction and simulation of the plasma behavior during the ramp-up is a complex activity due to the combination of several challenges involving for instance, the lack of a heat transport model valid close to the separatrix or the inadequacy of neoclassical resistivity in the prediction of q profiles. Therefore a precise computation of the turbulent transport and current diffusion in L-mode is needed in order to accurately predict the q profile evolution in ECRH assisted ramp-ups.

In this contribution, L-mode analyses have been performed combining plasmas from different tokamaks in order to assess and to provide a credible modelling framework for the predictions of ramp-up phase for JT-60SA and the initial phase of ITER for which ECRH is planned to be used. We have compared two turbulent transport models (CDBM [4] and TGLF [5] in CRONOS [6]) in order to evaluate their predictive capabilities. To this end we have run simulations of the ramp-up phase in a JET plasma without auxiliary heating and in a flat-top L-mode TCV plasma with applied ECRH. Parameter scans in Z_{eff} and in the edge electron temperature (within the experimental uncertainties) have been performed in order to assess the simulation sensitivity to these quantities.

A good prediction of q profile and li evolutions is found in JET ramp-up if edge electron temperature is well captured validating the neoclassical resistivity assumption for tokamak ramp-ups. Our sensitivity scan showed a strong impact of the edge electron temperature on q profile and li evolutions. In both studied tokamaks, results with CDBM showed better agreement with experimental measurements. Finally the impact of ECRH injected power on JT-60SA ramp-up is assessed. For a hybrid scenario a significant amount of *off-axis* ECRH power (3.5 MW) is needed to maintain q profile above unity in almost all the plasma radius.

Neoclassical resistivity and turbulence model validation

In the sensitivity study we vary the Z_{eff} profile and the edge electron temperature. The ramp-up analized is JET 72516 pulse. This shot is selected because MSE constrained equilibrium reconstruction (EFIT) is available. Therefore the accuracy of q profile reconstruction at the plasma core is improved.

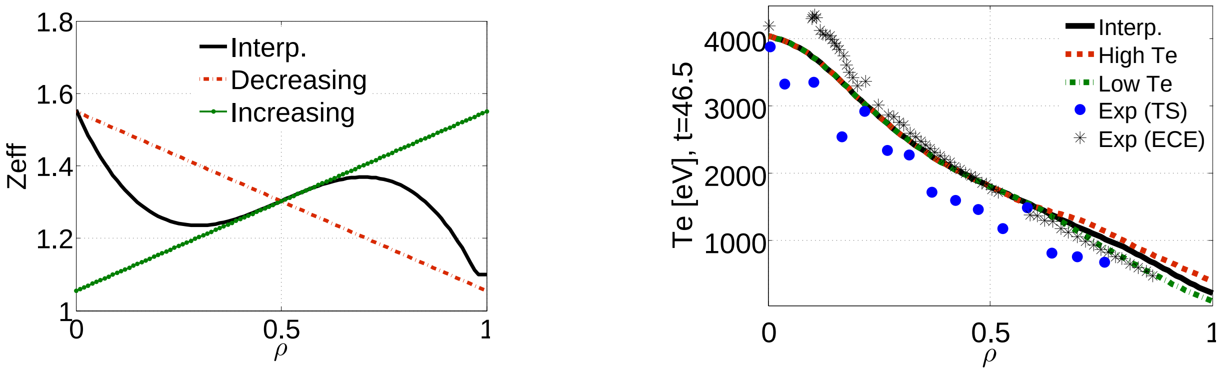

Figure 1: Illustration of different Z_{eff} profiles (left) and electron temparatures profiles (right) considered for the sensitivity analysis.

Interpretative simulations (solving current diffusion equation only) are performed for the sensitivity study. Three Z_{eff} profiles are tested, we take the measured value, decreasing and increasing linear functions (Fig. 1 *left*). For the edge electron temperature we consider a variation of ±15% at $\rho = 0.8$ (Fig. 1 *right*). The impact of these changes are illustrated on Fig. 2. In this last figure we observe a larger effect of edge T_e variation on q profile evolution. If we decrease the edge T_e by 15% (within experimental uncertainties) we are able to match the EFIT reconstructed values.

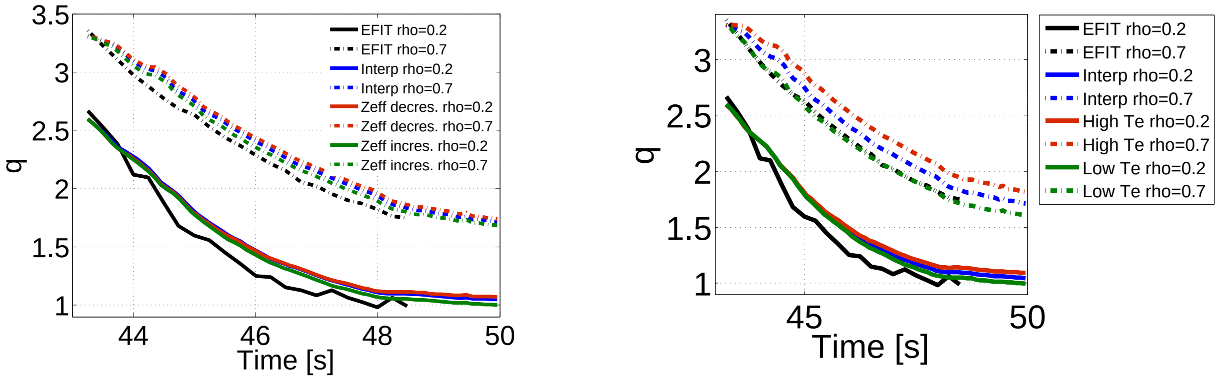

Figure 2: (Left) effect of different Z_{eff} profiles on q profile evolution at $\rho = 0.2$ and $\rho = 0.7$. (Right) effect of edge T_e variations on q profile evolution for the same ρ.

Predictive simulations (evolving ψ, T_e and T_i) are performed to evaluate the precision of turbulence models. In Fig. 3 (*left* and *center*) the computed T_e and T_i profiles are compared. CDBM model gives a good prediction of electron and ion temperature profiles. TGLF with a boundary condition (BC) at $\rho = 0.9$ gives also a good prediction but an artificial pedestal forms when the BC is at $\rho = 1$ (see NoBC profiles in Fig. 3). The accuracy of CDBM is also verified when comparing the safety factor evolution with EFIT reconstruction (Fig. 3 *right*).

The previous results allow us to validate the neoclassical resistivity computation and CDBM turbulence transport model.

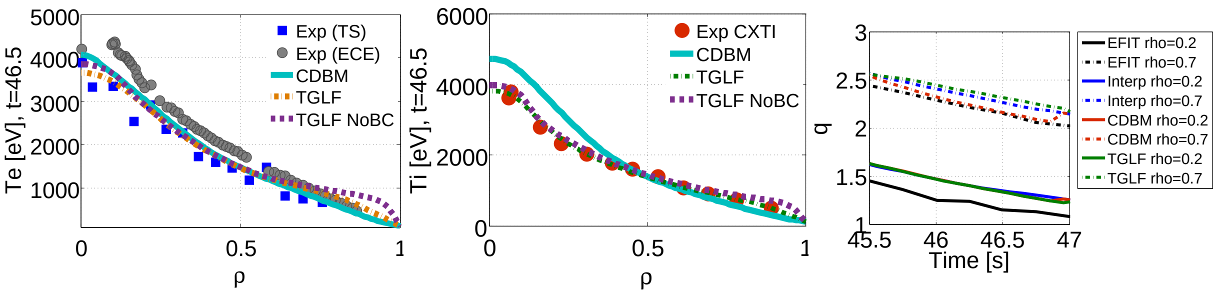

Figure 3: (Left) predicted T_e for CDBM and TGLF models. For TGLF NoBC acronym means that the model is used until $\rho = 1$, otherwise the model prediction stops at $\rho = 0.9$. (Center) predicted T_i. (Right) predicted q profile evolution for CDBM and TGLF models.

ECRH source code validation

TCV pulse 58375 is used for the validation of REMA ECRH source code and CDBM turbulence model. To this end we take into account two instants: at $t = 0.88s$ where X2 and X3 EC waves are injected and at $t = 1.40s$ where we have X2 and NBI. In Fig. 4 we show ray tracing of EC waves and absorption ratio at $t = 0.88s$. Full absorption of X2 and 80% of X3 are found.

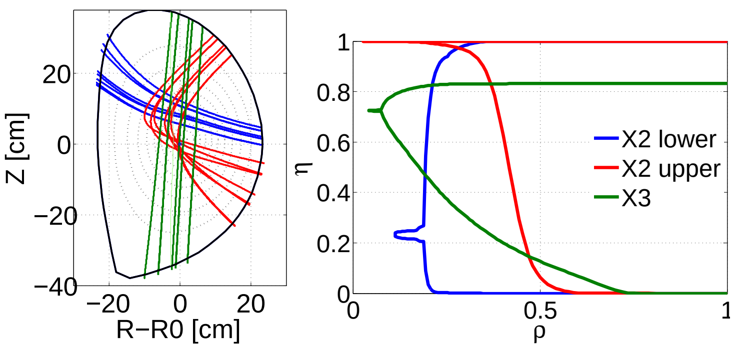

Figure 4: (Left) EC waves ray tracing. (Right) absorption ratio as a function of plasma radius ρ.

The comparison of experimental temperature profiles and predictive simulation with REMA and CDBM is presented in Fig. 5. The calculation is accurate for T_e but T_i is underestimated. This can be explained by the low T_i in this pulse. CDBM model computes a single thermal diffusion coefficient for T_e and T_i. If both temperatures are different the model will predict better the temperature profile with larger gradients, in other words the channel with higher transport (in this case electrons).

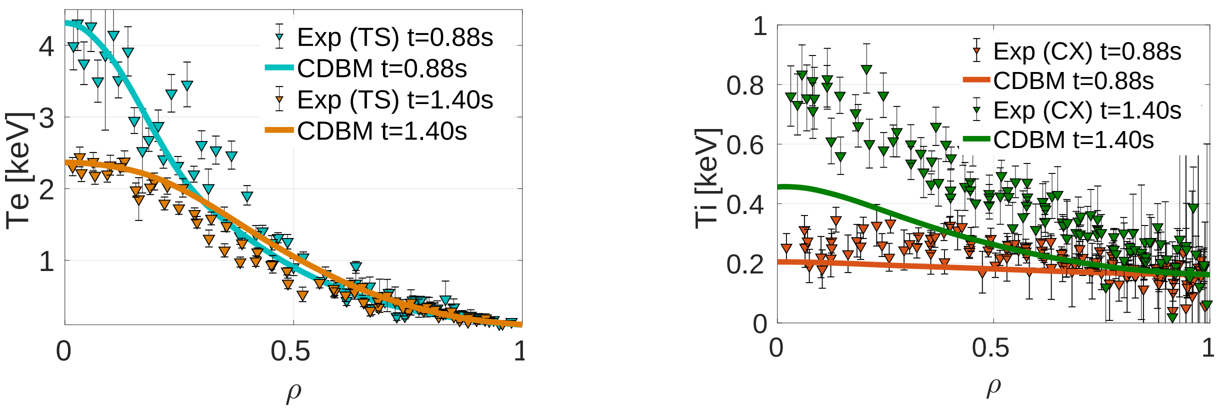

Figure 5: comparison of (left) T_e profiles, (right) T_i profiles.

Application to JT-60SA ramp-up prediction

After the validation of REMA and CDBM transport model we apply CRONOS to JT-60SA hybrid scenario #4-2 ramp-up [7]. In this study we vary the EC power injected off-axis at $\rho = 0.4$. The goal is to reach LH transition (in this case at $t = 12.45s$) with q profile above unity. This is the goal because in H mode the q profile is almost frozen therefore the hybrid scenario is more easily achieved, q is above unity avoiding the appearance of sawteeth. Three different powers are presented in Fig. 6 and an *Ad hoc* case. This last one is an artificially imposed current source that maintains q profile above unity.

From the evolution of q with power we note that EC effect is mainly visible for $\rho < 0.4$. The core q profile increases with injected power. From our study we find that to obtain a q profile above unity from $\rho = 0.1$ to $\rho = 1$ at least $3.5MW$ of EC power is needed.

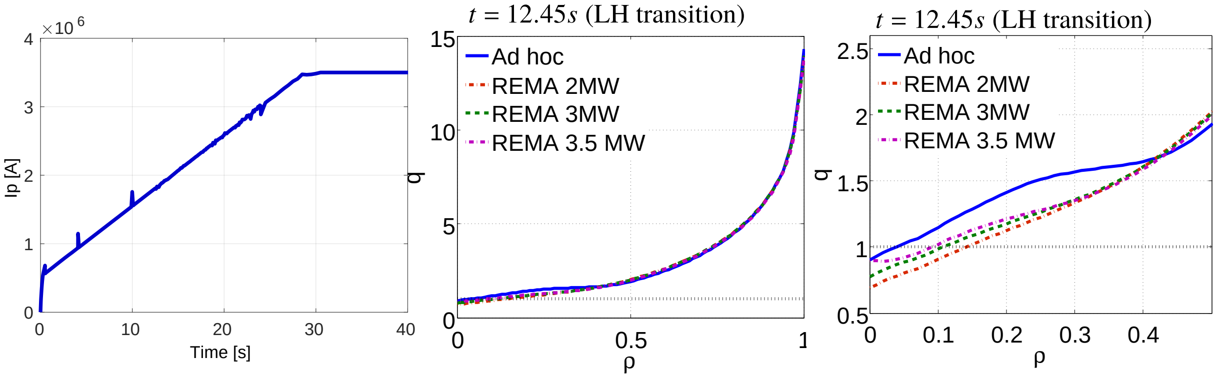

Figure 6: (Left) Ip ramp-up, (center) q profile at LH transition (right) core q profile.

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