Validation of modelling of JT-60SA tokamak scenarios with METIS code

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The integrated modeling code METIS [1] is a faster than real-time scenario simulation suite which can be applied to a significant variety of plasma modelling activities due to its comprehensive list of physical models. It allows analyses of current diffusion and heat and particle transport and sources including tungsten. Recently, in the framework of the construction of JT-60SA, it has been adapted for JT-60SA scenario preparation and development. We have used METIS to optimize the scenario development of JT-60SA [2] especially during the ramp-up phase, with the aim of saving flux consumption, which is a key point to achieve longer duration discharges (the available poloidal flux is limited due to the maximum current allowed in central solenoid coils) [3,4]. METIS simulations have already been compared to experimental data for JET, DIII-D, EAST, Tore Supra, TCV and have proven to be able to predict with good accuracy, if properly tuned, most of the scenarios [1 and references therein].We present here the activity of validation carried out in view of assessing reference scenarios developed for JT-60SA.

The activity of validation has consisted, firstly, in a benchmark of METIS results against CRONOS [5] simulations of JT-60SA scenario based on models tuned on JET and JT-60U experiments [6]. This work is based on simulation of JT-60SA scenario described in details in reference [6]. These simulations have been tuned on experiments made on JET and JT-60U presenting similarities with planned JT-60SA scenarios and then extrapolated to JT-60SA scenarios. We have selected two CRONOS simulations: the first one addresses scenario 2 (Inductive H-mode, high density) using the GLF23 core transport model and the Cordey scaling law for pedestal pressure (line 4 of table 3 in [5]); the second one is scenario 4.2 (HybridGLF23 + CDBM) using both GLF23 and CDBM and Cordey scaling law for pedestal pressure (line 1 of table 3 in [5]). For the benchmark, we start from the catalogue of METIS simulations prepared for JT-60SA, based on research plan experiment descriptions [2] and joined to customize METIS distribution [7]: METIS parametrization is chosen to take into account information contained in the research plan, such as H-factor, NBI configuration and EC system capabilities. Nevertheless this leaves some freedom to choose some parameters, as the density profile shape or the pedestal pressure. Based on its internal parameters, METIS predicts all the profiles, including densities and temperatures profiles which are computed self-consistently with sources provided by METIS internal models and MHD equilibrium which is based on moments of the Grad-Shafranov equation and morphing to describe the shape close to X-point. Then, we modified the minimum set of parameters to take into account specific features of CRONOS simulations. The first benchmark is the simulation of scenario 2. It has been done by changing METIS simulation density and pedestal pressure to match the CRONOS one, which were done with slightly different parameters.Then, the simulation of scenario 4.2 has been done by changing the METIS simulation density to match the CRONOS one. In both cases METIS and CRONOS simulations share the same LCFS. We first compare 0D parameters between CRONOS and METIS predictions. Next, we compare profiles computed by CRONOS and by METIS for kinetic profiles, sources and quantities linked to equilibrium and current diffusion. These comparisons show the ability of METIS to simulate JT-60SA scenario flattop at a level of precision similar to CRONOS (details can be found in [7]). Even with this minimal tuning, we obtain quite good reproduction of CRONOS simulations (figure 1). Sensitivity checks for Z_{eff} and EC deposition width have also been carried out and showed a negligible impact of these parameters. It would be possible to obtain a quasi-complete matching of CRONOS results with METIS simulations by tuning more parameters in METIS. The only limitation will come from the equilibrium computations, based on HELENA code in CRONOS and moments and morphing in METIS, which show some deviations (within 15%) for the equilibrium parameters at the plasma edge ($\rho > 0.8$) for high β_P scenario (figure 2 & 3).

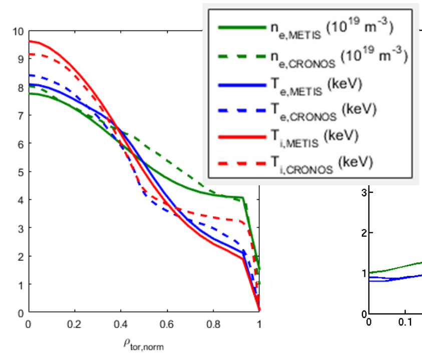

Figure 1: kinetic profiles (JT-60SA scenario 4.2)

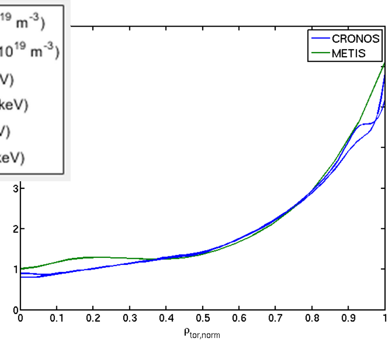

Figure 2: safety factor (JT-60SA scenario 4.2)

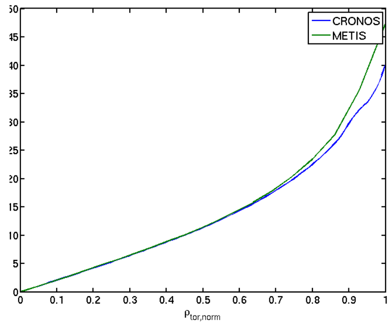

Figure 3: $\langle\frac{|\nabla\rho^2|}{R^2}\rangle$coefficient (JT-60SA scenario 4.2)

The second part of the validation has consisted of studies of the capability of METIS to simulate ramp-up of selected JET experiments: L-mode C-wall discharge, ICRH He^3 minority heating + NBI with current ramp up to 1.9 MA in 3s (73221, 73224) or up to 1.9 MA & overshoot to 2.4 MA in 4s (78834,78842); Ohmic C-wall discharge with 1 MW NBI and current ramp to 1.7 MA is 4 s (79649) [8]; Ohmic ILW discharge with late NBI and current ramp at 2.6 MA in 10 s (89723) and NBI (up to 15 MW) C-wall discharge and current ramp to 2.7 MA is 9 s (72516). METIS has been run with default tuning for JET (hard coded in METIS interface to JET MDS+ data). Plasma current, line averaged electron density, effective charge, toroidal magnetic field and plasma geometry are read from the JET database. Additionally, if used in the discharge, NBI and ICRH power and configuration are also read from JET database. METIS results are compared to the following scalar data measurements: l_i, β_p , W_{MHD} and V_{loop} from EFIT; $n_{e,0}$, $\langle n_e \rangle$, $T_{e,0}$, $\langle T_e \rangle$ from LIDAR; P_{rad} from bolometers (figure 4) and the following profile data measurements: LIDAR electron density and temperature; ECE electron temperature; HRTS electron density and temperature;

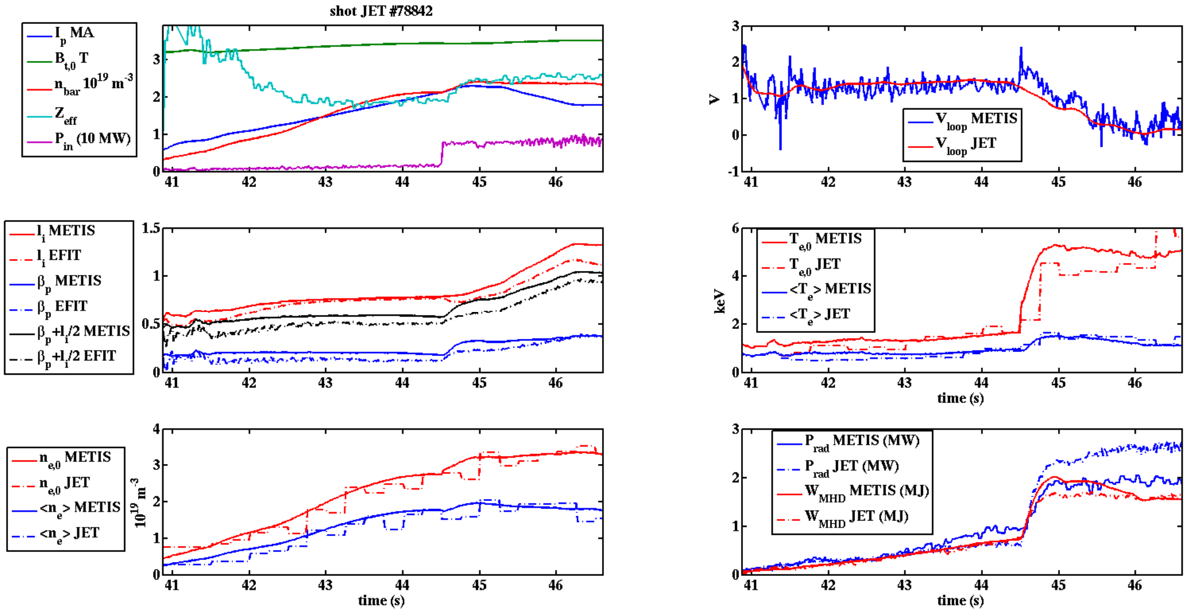

Figure 4: Comparison of 0D data between METIS predictions and measurements for JET shot 78842

charge exchange ion temperature and a direct comparison to MSE angles (with the help of CRONOS synthetic diagnostic). These measurements are not available for all discharges. All shot simulations reproduce the measurements quite well: loop voltage, l_i and β_p evolutions are quite well simulated with, for some shots, an offset in β_p and some difference for l_i in the early part of the ramp-up; $\langle n_e \rangle$, $n_{e,0}$, $\langle T_e \rangle$ and $T_{e,0}$ are well simulated, but for some shots the temperature is higher than the measured one in the early part of the ramp-up; P_{rad} is correctly simulated (with larger differences than for other parameters), but not for shot 79649 and for 89723; the energy content is well predicted except for shot 79649. Most of the discharges have no sawtooth (ST) during the ramp-up; only shot 88723 has ST onset during ramp-up and METIS predicts the first ST about 0.5 s before ST can be seen on the $T_{e,0}$ signal (ECE/KK3). MSE angles (figure 5) are only available for shots 78842 & 79649 and there is a good

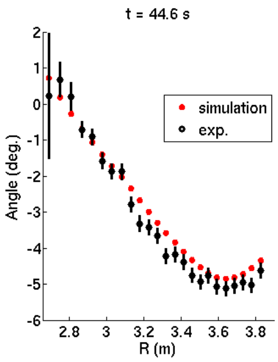

Figure 5: MSE angles for JET shot 78842

agreement of prediction with measurement for shot 78842. Interpretation of measurement is difficult for shot 79649 (there are oscillations in the experimental profiles). Electron density profiles (figure 6) are quite well simulated and electron temperature profiles (figure 7) are reasonably predicted with some discrepancies in the early ramp-up phase: values and width of profiles are not correctly predicted. Ion temperature profiles (figure 8) are generally not available during ramp-up and only shot 79649 has NBI diagnostic

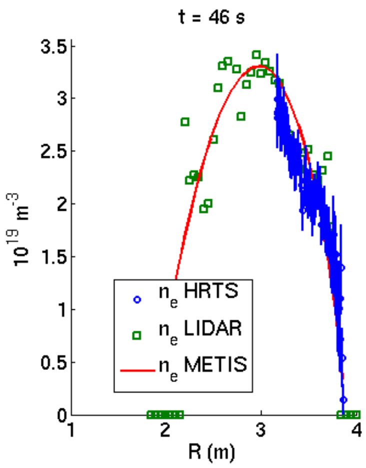

Figure 6: Electron density for JET shot 78842

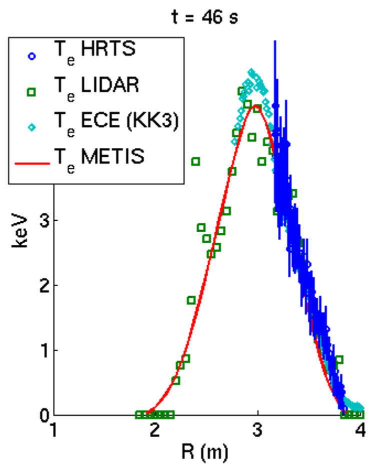

Figure 7: Electron temperature for JET shot 78842

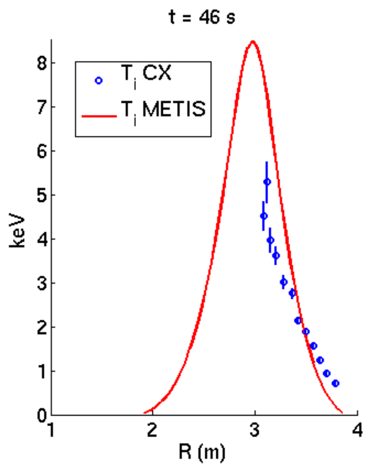

Figure 8: Ion temperature for JET shot 78842

during ramp-up (1MW). Ion temperature is overestimated compared to the first available measurement (generally after the end of the ramp-up).

In conclusion, this study allowed highlighting the capacity of METIS to simulate the ramp-up of a device with similar size to JT-60SA and to predict flattop phases of JT-60SA. Comparisons between METIS predictions and experiments show good agreement, even if some limitations appear. Differences are found, in particular, in temperature and density profiles predictions.

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