Verification and Validation of the European Transport Solver

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Introduction

The European Transport Solver (ETS) [1,2] is the 1-D transport code developed within the Integrated Tokamak Modelling (ITM) Task Force [3]. It adopts a modular approach, where standalone physics modules provide the ETS with equilibrium, transport coefficients, sources through standardised interfaces linked with the ITM data-structure. The open source Kepler software is used to compose and manage scientific workflows, where physics modules are integrated into the ETS workflow as precompiled actors.

Several workflows have been developed to perform 1-D simulations with ETS. These include: equilibrium actors, such as three moments, EMEQ, SPIDER and Helena solvers; transport actors, such as Bohm gyro-Bohm model, ETAIGB model, Coppi-Tang model, Weiland model, GLF23 model and RITM model as well as neoclassical solver NCLASS; source actors, such as Gaussian sources, wave codes for LH, ICRH and ECRH, NBI-deposition codes and Fokker-Planck solvers for ions and electrons; impurity actor and neutrals actor.
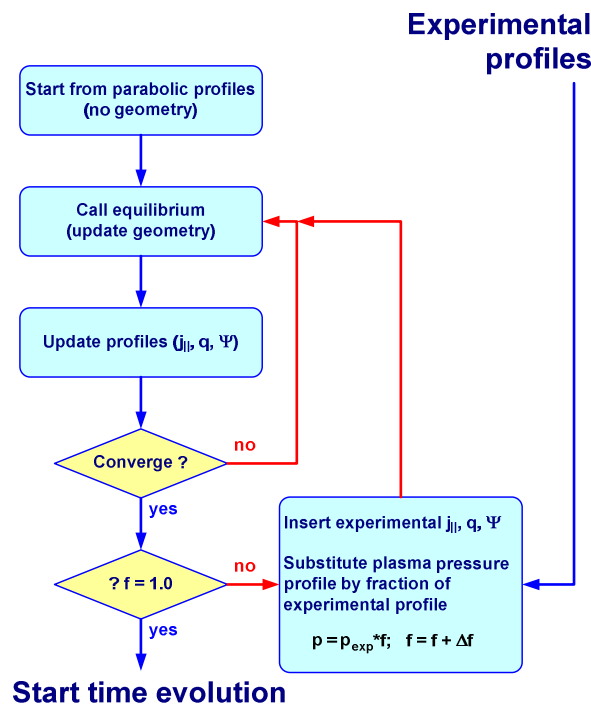

Fig.1 Schematic algorithm of adopting current profiles

Verification and validation of compiled workflows is a central activity of the developing team. Before applying the workflow for analysis of particular discharge, it is necessary to demonstrate that all the actors used in the workflow are verified, that their implementation is done properly and does not cause numerical instabilities, that the workflow goes through a minimum set of benchmarks against existing codes.

Starting equilibrium-transport iterations

The ETS workflow consists of three parts: *Before the time evolution* (this part initializes all working CPOs, loads starting profiles from the ITM data base and checks the consistency between current profiles and starting equilibrium), *Time loop* (this part computes evolution of plasma parameters including the equilibrium) and *After the time evolution* (this part does necessary post processing analysis, saves final results to the data base and closes the connection to the data base). Since ETS starting profiles are not necessary provided by other consistent numerical simulations, and even can be conflicting to each-other and to the starting equilibrium, before entering the time evolution it is necessary to check the consistency between current quantities like total current, profiles of poloidal flux, Ψ, safety factor, q, parallel current, $j_\parallel$, and the equilibrium. Disagreement between these quantities can lead to artificial generation of the current, which can cause the crash of equilibrium solver. Thus the iterative scheme of finding the consistent solution between current quantities and equilibrium was introduced into the ETS workflow.
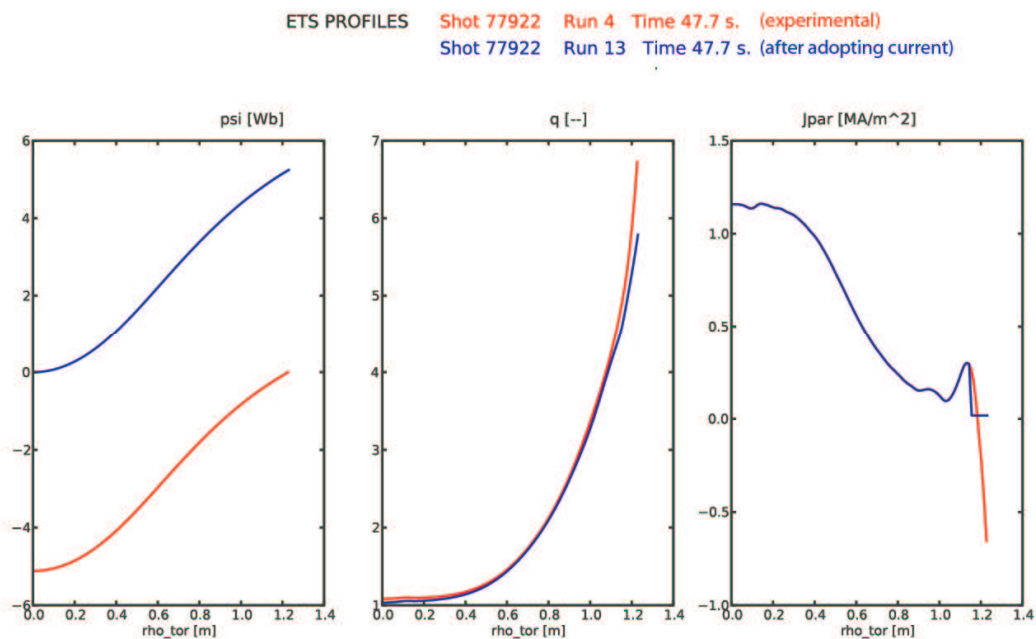

Fig.2 Profiles of poloidal flux, safety factor and parallel current before and after the check of consistency with equilibrium

Figure 1 presents the algorithm of automatic correction of input profiles before the time evolution. It starts without the equilibrium from defining parabolic profiles used for the first call to equilibrium solver. After the new equilibrium is received, profiles of Ψ, q

and $j_∥$ are renormalized using new metric and equilibrium solver is called again. This loop is repeated until the convergence is satisfied. Then, profiles of $Ψ$, q and $j_∥$ are replaced by input experimental data. User can choose the primary quantity among them. Selected quantity will be preserved by the routine and two other will be adopted consistently. To avoid a possible crash caused by high beta, the pressure can be increased slowly starting from 20-50% of experimental one. This procedure allows starting the time evolution from consistent set of current quantities avoiding the crash of equilibrium. Figure 2 compares profiles obtained from experiment and after the consistency of current profiles and equilibrium was checked. The profile of current density was selected as a primary quantity. It is preserved by the routine until minor radius ~1.1m. Outside of this position the negative current has been removed by the routine. The removal is compensated by drop of equivalent amount of positive current to fit with the defined total plasma current. As a consequence, q has been slightly lowered near the edge.

Benchmarking to other codes

The validation and verification activity for the ETS is aimed in: checking the numerical properties of the tool, such as accuracy/convergence, dependencies on $Δt$ and $Δρ$, conservation properties; and validating of physics modules, checking the accuracy, validating the applicability ranges. This is done by means of comparison with analytical results using the method of manufactured solutions [1], the self-benchmarking (reduction tests) [2] and by the benchmarking to other codes.
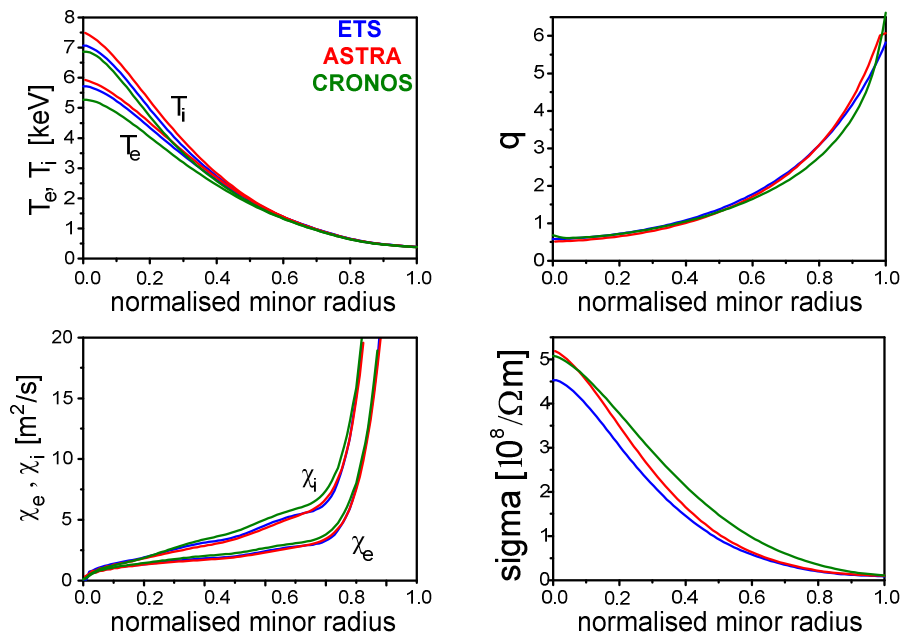

Fig.3 Benchmarking between ETS, ASTRA and CRONOS for the conditions of hybrid scenario discharge

Benchmarking of the ETS against ASTRA and CRONOS transport codes was performed for conditions of hybrid scenario discharge with current overshoot, B_{tor}=2.3 T,

I_{pl}=1.7 MA, high triangularity (0.38), 18MW of NBI, n_l=4.8e^{19} m^{-3}, β_N = 2.8. Spitzer resistivity was used for the current transport and heat transport coefficients were obtained from Bohm-gyroBohm model. The Gaussian H&CD profiles (centred at ρ=0, half-width $\rho\Delta$=0.3), with the total heating power P_{tot}=18 MW, distributed 70/30 between ions and electrons, were used with all codes. Total non-inductive current was I_{ni}=0.12 MA, neglecting bootstrap current contribution. Figure 3 shows the results obtained for steady state conditions with different codes. Satisfactory agreement has been obtained. Slight differences in profiles refer to different equilibrium solvers used within compared codes.

Benchmarking of the ETS impurity solver against SANCO impurity code was done for conditions of low confinement mode discharge, assuming interpretative parabolic profiles for density and temperature of main ions and interpretative equilibrium provided by EFIT equilibrium reconstruction code. Boundary conditions in both codes were given by the total impurity concentration at the last closed magnetic surface, assuming the coronal distribution at the corresponding ion temperature. Good agreement is achieved for carbon and argon concentration in comparison between two codes. Figure 4 compares steady state profiles of radiative power density and ion effective ion charge, obtained after 1s. of time evolution.
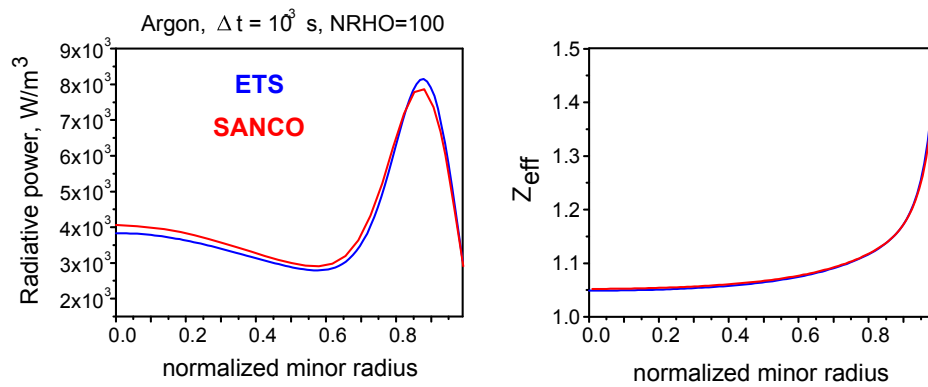

Fig.4 Benchmarking of ETS impurity solver with SANCO code for parabolic plasma profiles

Conclusions

Significant progress has been made in developing the workflows for 1-D transport simulations with ETS. Several options for the equilibrium solver as well as for transport coefficients and sources are available as a part of the workflow.

The benchmarking of the ETS to other comparable codes shows a reasonable agreement as for the steady-state conditions as for the time evolution between them.

References

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