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Progress in edge plasma turbulence modelling – hierarchy of models from 2D transport applications to 3D fluid simulations in realistic tokamak geometry.

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Accurate modelling of cross-field turbulent transport in tokamak's edge plasma remains a challenge, many key experimental features such as edge transport barriers formation being still hard to simulate, especially for ITER size tokamaks. Being able to predict the SOL width or the power load imbalance between inner and outer divertor legs even for today's JET size tokamaks is still an open issue. First principle modelling of edge plasma turbulence is thus today a very active topic in the fusion community driving many dedicated research projects such as the TSVV "European boundary code"project in Europe.

Despite this effort towards first principle modelling of the turbulent transport, 2D transport codes where the cross-field turbulent transport is emulated by ad-hoc diffusion remain today the most popular tool for experiments analysis or engineering applications. In these codes, the prescription of the diffusion coefficients rely on empirical basis and are usually adjusted to match simulation and experimental at a given location (usually mid-plane profiles). In this empirical procedure, the nature of the turbulence behind these transport coefficients is most of the time not taken into account. The main drawback of this approach is to lack predictability by missing the basic physics of turbulence mechanisms.

In order to address both the first principle modelling of edge turbulence but also to feed information about turbulence into transport codes, a dedicated effort has been made at IRFM in the last two years to develop the new code SOLEDGE3X which aims at encompassing a hierarchy of models from standard 2D transport code to 3D first principle turbulence modelling. The development of this new code comes from the merging of the transport code SOLEDGE2D [1] and the turbulence code TOKAM3X [2] previously developed within the French fusion community. Integrating features of the two latter codes, SOLEDGE3X is able to simulate tokamak edge plasma either in 2D or 3D, including: the realistic wall geometry, neutrals since it is coupled to EIRENE and impurities since the code is fully multi-species, based on the state-of-the-art Zhdanov collisional closure for multi-component plasmas. First results of turbulent plasma in WEST geometry including the sputtering of the wall have been produced in 2019 and represent a major step for first principle modelling of tokamak plasma in realistic conditions.

However, since full 3D simulations remain expensive in CPU time, it is still profitable to use SOLEDGE3X as a transport code in 2D to run fast interpretative simulations. An original idea implemented in SOLEDGE3X to improve turbulent transport predictability and go beyond the standard empirical approach is to use a reduced model for turbulence in the same fashion as the "k-epsilon"widely used in neutral fluid community. One or two equations are added to the standard mass, momentum and energy balance to describe the evolution of the turbulence intensity "k"and optionally the evolution of the turbulence dissipation "ε". This model is used as a platform to include some ingredients of the turbulence physics - such as the interchange instability – in the framework of 2D transport codes. Of course, this reduced model is not first principle and require an empirical closure. We use the multi-machine scaling law for the SOL width $_q$ to do so, as a first approach of data assimilation. When SOLEDGE3X is used as a transport code with this reduced "k-epsilon"model for turbulence activated, the number of free parameters is drastically reduced since there is no need to prescribe transport coefficients, the "k-epsilon"model predicting a 2D map of cross-field diffusivities. Since the model is based on interchange instability, one recovers for instance the ballooning of radial transport in the low field side mid-plane. Also, since the model is closed using the multi-machine scaling law, the overall level of transport is automatically adjusted to get a SOL width compatible with this scaling law. This closure with the scaling law is thus powerful to obtain reasonable profiles, however it is also a weakness of the model since in principle, one could not reproduce an experiment where the SOL width does not follow the scaling law. This is the drawback of this kind of semi-empirical models which are not first principle and thus limited by the main assumptions behind their closure. In order to test the applicability of this reduced model for turbulence, a series of L-mode TCV shots have been simulated and the simulation results have been compared with experimental data [Figure 1]. Even if the simulation does not recover exactly the SOL width measured in the experiment, the overall agreement in term of peak heat flux, density and temperature on the target is quite remarkable. This "k-epsilon"model has shown to be a promising first step toward integration of turbulence physics inside transport simulations.

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To go further, the advantage of the SOLEDGE3X code is to be able to run also first principle turbulent simulations where the turbulence intensity can be directly "measured". The comparison between turbulent simulations and the reduced model for turbulence should in the future provide a clear path to improve these reduced models for turbulence. In that perspective, first results of full turbulent simulation in the same TCV geometry [figure 2] should help interpreting the results obtained with the reduced "k-epsilon"model and identify missing ingredients.

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[1] H. Bufferand et al., Nucl. Fusion 55 (2015), 053025
[2] P. Tamain et al., J. Comp. Phys. 321 (2016), 606-623

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Country or International Organization

France

Affiliation

CEA

Primary author: Dr BUFFERAND, Hugo (CEA)

Co-authors: Dr GALLO, Alberto (PIIM - CNRS); Dr SERRE, Eric (M2P2, CNRS, Aix-Marseille Univ., ECM); Dr SCHWANDER, Frédéric (M2P2 - CNRS); CIRAOLO, GUIDO (CEA, IRFM); Dr GIORGIANNI, Giorgio (M2P2 - CNRS); Dr FALCHETTO, Gloria (CEA, IRFM, F-13108 St-Paul-Lez-Durance, France); Mr YANG, Hao (CEA); BUCALOSSI, Jerome (CEA); Mr SCOTTO D'ABUSCO, Manuel (M2P2 - CNRS); FEDORCZAK, Nicolas (CEA, IRFM, Saint Paul Lez Durance, France); TAMAIN, Patrick (CEA Cadarache); GHENDRIH, Philippe (CEA-IRFM); Dr BASCHETTI, Serafina (M2P2 - CNRS); THE WEST TEAM; MARANDET, Yannick (PIIM, CNRS/Aix-Marseille Univ., Marseille, France, EU); THE TCV TEAM

Presenter: Dr BUFFERAND, Hugo (CEA)

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