Verification methodology for plasma simulations and application to a scrape-off layer turbulence code

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Approaching the ITER era, errors, affecting simulations that are used as fundamental tools to uncover the complex plasma dynamics in a tokamak, due both to mistakes present in the code and the implementation of a non sufficiently accurate physical model, can have far reaching consequences on costly nuclear facilities. As a consequence, there is a strong motivation to increase the reliability of the results of numerical simulations in the plasma physics domain. To assess the reliability of numerical simulation codes, a rigorous methodology has been developed, which constitutes the Verification and Validation (V&V) procedure [1]. V&V is composed by two separated tasks: the verification process, which is a mathematical issue targeted to assess that the physical model is correctly solved, and the validation, used to assess the consistency of the code results with experimental data.

Bridging the gap with the computational fluid dynamics community, in the present work we introduce a general, rigorous, and simple-to-apply methodology for both the verification of the correct implementation of the model equations (code verification) and numerical error quantification (solution verification) [2]. The proposed code verification procedure consists in using the method of manufactured solutions and executing an order-of-accuracy test, assessing the rate of convergence of the numerical solution to the manufactured one. For the solution verification, the numerical error is quantified by applying the Richardson extrapolation, which provides an approximation of the analytical solution, and by using the grid convergence index to estimate the numerical uncertainty affecting the simulation results. The methodology is applied to verify the correct implementation of the drift-reduced Braginskii equations into the GBS code [3], and to estimate the numerical error affecting the GBS simulation of plasma turbulence in the SOL. The GBS code is successfully

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verified and an estimate of the numerical error affecting the simulation results is provided.

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[2] F. Riva, P. Ricci, F. D. Halpern, S. Jolliet, J. Loizu, and A. Mosetto, "Verification methodology for plasma simulations and application to a scrape-off layer turbulence code," *Physics of Plasmas*, vol. 21, p. 062301, June 2014.

[3] P. Ricci, F. D. Halpern, S. Jolliet, J. Loizu, A. Mosetto, A. Fasoli, I. Furno, and C. Theiler, "Simulation of plasma turbulence in scrape-off layer conditions: the GBS code, simulation results and code validation," *Plasma Physics and Controlled Fusion*, vol. 54, p. 124047, Dec. 2012.