Turbulence and transport simulations with Hermes-3

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The boundary of magnetically confined plasmas is a complex environment that has a critical impact on the optimization and operation of high-power fusion devices. Significant gaps in understanding and modeling capabilities remain, limiting the community's ability to extrapolate to new regimes: The spreading of heat to the divertor and particle fluxes to the first wall; the effect of detachment and divertor configuration on cross-field transport; the L-H transition and access to enhanced confinement regimes. A new generation of tools is required to fill these gaps and enable extrapolation to Fusion Pilot Plant regimes.

To address these gaps we are developing Hermes-3, a multifluid plasma simulation model of transport and turbulence in the edge of magnetically confined plasmas [1]. It is built on BOUT++ and defines reusable components to simulate 1, 2 and 3-D geometries. Hermes-3 is predictive, consistently simulating the evolution of plasma profiles, neutral interactions, and plasma turbulence given heating and fueling inputs.

An Advanced Fluid Neutral model and the immersed boundary (penalization) method [2] have been implemented in Hermes-3, enabling complex boundary shapes to be modeled using structured meshes in FPP-scale devices. We will demonstrate 2D transport simulations in C-AT geometry [3] (R = 4m), using the Cherab ray-tracer to calculate radiation heat loads. Electromagnetic effects have been added and used to simulate 3D turbulence in multiple devices. We will report progress and comparisons to experiment.

We will present a roadmap for open-source development of Hermes-3 as both a transport (2D axisymmetric) and turbulence (3D) model to address boundary modeling needs.

[1] B. Dudson et al. Comp. Phys. Comm. 296, 108991 (2024)
[2] H. Bufferand et al. J. Nucl. Mat. 438, S445-S448 (2013)
[3] R.J. Buttery et al. Nucl. Fusion 61, 046028 (2021)

This work was in part performed under the auspices of the U.S. DoE by LLNL under Contract DE-AC52-07NA27344. Supported by the FREDA SciDAC. LLNL-ABS-2003525.