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Implementation and Validation of Advanced Turbulence Modeling Methods for Liquid Metal Flow in Nek5000

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ABSTRACT:

Recently proposed fast reactor designs that include liquid metal cooling have necessitated CFD modeling of turbulent heat transfer in low Prandtl number (Pr) fluids. This proposed project addresses a critical need for the NEAMS program by significantly enhancing turbulence modeling capability in Nek5000 for application to low-Pr liquid metal cooling flows. The proposed collaborative effort between three universities, a national lab, and two industry partners will enhance the functionality in Nek5000 for three different turbulence modeling classes, namely URANS, LES, and hybrid RANS-LES (HRL). The research focuses on implementation and validation of existing state-of-the-art modeling techniques and investigation of potential modeling improvements. Specific methods to be implemented and investigated for URANS include temperature-gradient-based transport with variable turbulent Prandtl number (Pr_T) and advanced algebraic heat flux models (AHFM). For HRL they include modified forms of partially-averaged Navier-Stokes (PANS) and dynamic hybrid RANS-LES (DHRL) models. For LES they include variable Pr_T subgrid heat flux modeling for LES using the dynamic Smagorinsky model. Where appropriate, methods for different model classes will be integrated, for example the use of URANS and LES basis models in HRL formulations. The effort builds on substantial prior and current research collaborations between participating team members.

Verification and validation is a key component of the proposed project. Systematic validation will be accomplished by simulation of a canonical low-Pr flow test suite to include turbulent channel flow, backward-facing step flow, and Rayleigh-Bénard convection, a new DNS benchmark simulation for low-Pr flow that will be performed as part of this effort, and a reactor cooling application test case determined by National Laboratory and Industry collaborators.

Novel technical contributions include systematic investigation of several different model classes for low-Pr flow, which remains an open question for reactor cooling CFD simulations. In particular, the use of hybrid RANS-LES modeling represents the newest frontier for engineering analysis, and very few studies for low-Pr flows currently exist in the literature. The outcomes of this project will include providing Nek5000 end users with a suite of turbulence modeling options specifically validated for low-Pr cooling flow, at several different levels of fidelity. This will allow users to optimally select the most relevant options based on requirements of accuracy and computational cost. A second key outcome will be the availability of a new DNS simulation dataset that will be made available to the scientific and engineering community that may be used for future validation efforts in liquid metal and other low-Pr flows.