Project Title: Immersed Boundary Methods for Modeling of Complex Geometry: A Leap Forward in Multiscale Modeling using NekRS

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ABSTRACT:

Generating body-fitted meshes around complex 3-D geometries is a time-consuming task that requires considerable meshing expertise. Generating a quality mesh is a complicated balance between resolving all important flow features, and element count, which scales with runtime. Recent developments in image processing techniques and three-dimensional (3D) scanning technologies provide an opportunity to generate surface representations of complex objects. If these scanned images of surface representations can be directly embedded in the computational domain for flow analysis, it can tremendously reduce the threshold of the intimate knowledge of mesh generation tools in addition to reducing the human time and effort for analysis of complex industrial grade problems. This embedded image technique has triggered great interest in Immersed Boundary Method, which is a mathematical technique where a 3-D Computer-Aided Design (CAD) geometry is embedded within a simple "background" mesh, capturing the effect of the structure with weak, residual-based boundary conditions. We propose incorporating immersed boundary methods in the NekRS CFD code to eliminate the need to generate body-fitted meshes, dramatically simplifying modeling of complex 3-D structures and facilitating a new paradigm for CFD-informed reactor analysis.

The goal of this project is to capitalize on this transformative merger of high-end scanning with massive parallel computing and develop numerical method, integration algorithm and computer code for immersed boundary analysis that promises to significantly reduce the overhead associated with mesh generation around complex geometric shapes that are typically encountered in nuclear reactor applications. This objective is accomplished via four essential ingredients that help reduce the requirements for expertise in CFD meshing and lower the level of knowhow of the CFD equations and methods that are placed upon the modeler: (i) Development of immersed boundary method for NekRS, (ii) Implementation of immersed boundary method in NekRS, (iii) Verification of implementation by comparing against Argonne National Laboratory (ANL)'s inhouse data, and (iv) Application of immersed boundary method to a challenging, elliptically-twisted salt HX.

The research efforts in this project will be directed to Immersed Boundary Method in the context of Spectral Element Technology, and development of numerical algorithms and computational code. This will be coupled with image processing techniques and three-dimensional (3D) scanning technologies that will automate the pre-processor for immersed boundary method. Ray-tracing algorithms for complex geometric configurations will be tested and implemented in conjunction with numerical integration technique for cut-cells, in parallel computing environment. The method will be tested on elliptically-twisted salt HX geometries.