Project FORTE - Nuclear Thermal Hydraulics R&D for BEIS

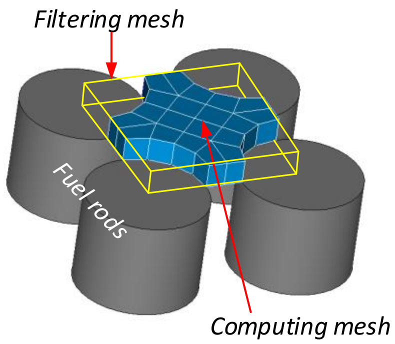
Development of Novel Coarse-Grid Sub-Channel CFD

THE CHALLENGE

Computational Fluid Dynamics (CFD) and High Performance Computing (HPC) have developed rapidly in the last few decades. However, it is still not feasible to routinely perform industrial thermal hydraulics calculations for a single fuel channel, let alone a complete reactor core, using CFD due to the high computing cost. The current design calculations and safety case development still rely on the traditional 1-D system or sub-channel codes first developed in the 1960s and 1970s. Such methods become increasingly inadequate for the safety and efficiency requirements of advanced reactor systems, where reliable predictions of 3-D phenomena and flow transients are of great importance. Consequently, a grand challenge is to develop a reliable and robust, low cost, highly flexible, full 3-D numerical tool for routine engineering calculations taking, advantage of the modern advancement in CFD.

OUR SOLUTION

The vision of this research is to develop a modern, CFD-based, sub-channel framework for nuclear power plant (NPP). Our solution is Sub-Channel CFD (SubChCFD). This is based on a standard CFD solver whilst embracing the sub-channel correlations of the current industrial standard. SubChCFD uses a two-level mesh system: (i) the filtering mesh, which aligns with the sub-channel mesh of the traditional method, enabling the use of existing engineering correlations to account for the integral wall shear and heat transfer effects, and (ii) the computing mesh, which resolves the inviscid flow with corrections for mixing using a simple turbulence model. The method is highly flexible and can be coupled directly with resolved CFD to provide locally high resolution predictions of the flow and a porous medium approach to capture the overall effects of complex structures.

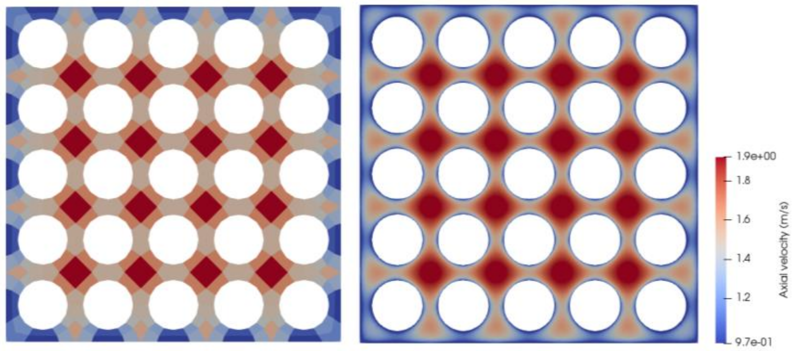


Two-level mesh of SubChCFD

The development of the baseline model of SubChCFD has been completed and validation has been carried out with a wide range of test cases. The new method has been shown to be able to predict the frictional losses and heat transfer satisfactorily in complex 3-D flows in fuel bundles, with a computing cost of 2 to 3 orders of magnitude lower than that of resolved CFD. Future developments include accounting for complex flow physics, such as buoyancy affected mixed convection and swirling flows.

OUR INNOVATION

SubChCFD is a smart mix of CFD and sub-channel methodologies, which takes the advantages of both approaches and, equally importantly, circumvents their drawbacks. Like a sub-channel code, SubChCFD is able to be calibrated, making use of existing engineering data, and can be validated and potentially licenced for specific reactor designs. SubChCFD is based on a standard CFD solver making the coupling with advanced resolved CFD an inherent feature of the method.



(a) SubChCFD (b) Resolved

Axial velocity in 5x5 rod bundle

THE BENEFITS

SubChCFD is a promising resolution to advance nuclear thermal hydraulics by modernising the system and sub-channel codes, which fall short in keeping up with the developments of NPP. It bridges the gap between advanced CFD methods and traditional 1-D approaches. By making use of knowledge accumulated in the nuclear industry, SubChCFD enables CFD to be used in a reliable and efficient way in real-world engineering. With the reduced computing cost, it will be possible to simulate very large nuclear systems and provide a full 3-D prediction with desirable level of local refinement in regions of interest.

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