Numerical modeling of an in-vessel flow limiter using an Immersed Boundary Approach

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The increasing performance and safety requirements for the third generation of nuclear reactors led to new Research and Development studies. In this context, new innovative systems are designed to prevent or soften potential accidental or incidental situations. For instance, a passive system to postpone the core dewatering, in the case of a Large-Break Loss Of Coolant Accident in Pressurized Water Reactors, has been imagined and patented by CEA [1]. This passive flow limiter is composed of fins which, in accidental behavior (for instance fluid coming out from the vessel due a break on the cold leg), force the creation of a large vortex of fluid and so reduce the flowrate going outflow of the vessel (*i.e.* postpone the core dewatering). For more information about the background, the interested reader can refer to [2]. Of course, the pressure drop induced by the device (in both nominal and accidental situations) is greatly influenced by the shape of the fins. Thus, in order to optimize its geometry, a fast and robust numerical tool, able to faithfully model the flow limiter, is needed.

The main problematic, in developing such a tool, concerns the modelling of the effect of obstacles on the flow, regarding pressure and velocities orders of magnitude, and turbulence induced in their vicinity. The complex geometry of the fins and the large scale ratio between the fins' thickness (∼cm) and the characteristic length of the flow (∼m), added to the need of fast numerical simulations, tends to rule out a "body-fitted" approach. Indeed, fictitious domain methods, originally introduced by V.K. Saul'ev [3], seem more adapted to the problem thanks to their capability to use simple structured (often Cartesian) meshes while preserving accuracy. However, those methods fall outside the scope of standard applications of usual turbulence models, requiring a deep investigation. Aside from fictitious domain methods, the space discretisation, which notably influences the interpolation process for the variables at the vicinity of the obstacles, is also a major issue. Here, the fins can be considered as infinitely thin. In that case, the eXtended (or Generalized) Finite Element Method (X-FEM), which is often used in the field of fracture mechanics [4], can give some answers: it is capable to deal with discontinuous quantities (typically tangential velocities on each side of an infinitely thin obstacle) while preserving the standard Finite Element properties elsewhere.

In this context, an Immersed Boundary Method (IBM) called Penalized Direct Forcing and developed by M. Belliard *et al.* [5] has been chosen. The purpose is, in one way, to extend this method to weakly compressible flow models and, in another way, to adapt it to a Finite Element formulation. Moreover, as the turbulence play an important role, the interaction between IBM and different turbulence models – such as RANS, LES or DES – has to be investigated. The future IBM models would be implemented in TRUST which is an open-source CFD plateform developed by the CEA.

Références

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