The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5-9 June 2022, Oslo, Norway

Penalized Direct-Forcing method and power-law-based wall model for Immersed-Boundary numerical simulations of obstacles in turbulent flow

Idris Hamadache[1]*, Michel Belliard[1] and Pierre Sagaut[2]

[1] French Atomic Energy Commission (CEA), DES, IRESNE, F-13118 Saint-Paul-Lez-Durance, France, - idris.hamadache@cea.fr and michel.belliard@cea.fr

[2] Aix-Marseille University, CNRS, Centrale Marseille, M2P2, Marseille, France - pierre.sagaut@univ-amu.fr

Keywords: *Immersed Boundary Method, Penalized Direct Forcing, Explicit power-law wall model*

This work is in the context of the safety-system development for the new generations of nuclear power plants. We wish to model the turbulent flow inside an industrial passive-safety device, the in-vessel flow limiter, based on the fluidic-diode principle [1]. Our goal is to design and optimize its shape. This shape optimization would need a lot of computations, each one with a specific mesh relative to the evaluated shape, followed by a statistical treatment.
In order to avoid the time consuming phase of re-meshing, we use the Fictitious Domain approach. Using an in-house industrial software, we face the constraint to not being able to modify the physical-problem governing equations in the code. Taking into account this fact, we choose the Penalized Direct Forcing method, a merge of the Penalty and Direct-Forcing (DF) methods [2]. It consists in a penalized forcing term, written in a DF formulation, added to the governing equations for taking into account the immersed boundaries.
Considering industrial turbulent-flow problems computed by RANS approach and not-resolved boundary layers, we need an appropriate immersed wall treatment. An immersed power-law-based wall model is chosen because its ability to model the velocity profile inside the whole boundary layer [3]. This is important due to the non-uniform distribution of the forced-node distances to the immersed wall. Moreover, this wall model has the advantage to be explicit and to not rely on an iterative procedure for the friction velocity determination. Therefore, coming from our previous directional linear interpolation technique [2], we have implemented the power law approach into our PDF method.
Using a Finite-Element version of our PDF method, we validate this approach on analytical-test cases and present our results concerning the in-vessel flow limiter industrial-test case.

REFERENCES

[1] Belliard, M. Numerical modeling of an in-vessel flow limiter using an immersed boundary approach. *Nuclear Engineering and Design* (2018) **330**: 437-449.

[2] Billo, G., Belliard, M. and Sagaut, P. A Finite Element Penalized Direct Forcing Immersed Boundary Method to take into account infinitely thin obstacles in a dilatable flow. *Computers Mathematics with Applications* (2021) **99**: 292-304.

[3] Wilhelm, S., Jacob, J. and Sagaut, P. An explicit power-law-based wall model for lattice Boltzmann method-Reynolds-averaged numerical simulations of the flow around airfoils. *Physics of Fluids* (2018) **30**: 065111.