A physics-informed data-driven Immersed Boundary Method using online sequential Data Assimilation

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Sequential Data Assimilation based on the Ensemble Kalman Filter (EnKF)[1] is here used to infuse physical information in a continuous Immersed Boundary Method (IBM)[2]. The latter is a classical penalization method[3] which accounts for the presence of the immersed body via a volume source term which is included in the Navier–Stokes equations. The coefficients driving the performance of the penalization method, which are usually selected by the user, are optimized here using an EnKF data-driven strategy. The parametric inference is governed by local and global physical information of the flow, such as the no-slip condition at the wall and the Reynolds number.

To this purpose, an online C++ library has been designed to couple an ensemble of numerical realizations performed using the CFD open-source code OpenFOAM with EnKF-based tools for the optimization of the IBM. Such library is referred to as *CONES* (*Coupling OpenFOAM with Numerical EnvironmentS*)[4]. The analysis is performed for a classical test case of analysis, namely the turbulent channel flow with $Re_\tau = 550$. A representation of the test case is shown in Fig. 1 (a), with the sensors employed by the data-driven strategy to enforce the no-slip condition at the wall.

The ensemble simulations are run on a grid for which the size of the mesh elements at the wall is $y^+ \approx 1$, but it is rather coarse in the streamwise and spanwise directions. Results shown in Fig. 1 (b) for the normalized mean streamwise velocity U^+ are compared with data from a body-fitted high-resolution direct numerical simulation and with a coarse-grid classical IBM. The data-driven procedure exhibits remarkable accuracy despite the relatively low grid resolution, more than two orders of magnitude coarser than the mesh used for the high-resolution DNS.

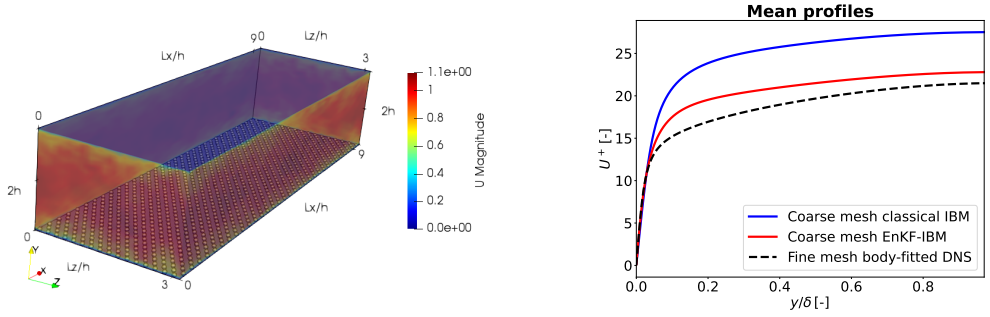

Figure 1: (a) Test case and sensors used for optimization. (b) Mean velocity obtained by the data-augmented IBM, compared with body-fitted DNS and classical IBM.

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