Uncertainty Quantification in Computational Fluid Dynamics
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Uncertainty Quantification of the Aerodynamics of a Rectangular 5:1 Cylinder

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Uncertainty plays a significant role in the BARC benchmark on the aerodynamics of a rectangular cylinder with a chord-to-depth ratio of 5 (Figure 1). Despite the relatively straightforward geometry, the BARC case contains most difficulties also found in realistic bluff body flows of interest in wind engineering. The flow around the stationary elongated cylinder is turbulent with unsteady separation and reattachment at the considered high Reynolds number of 40,000. The objective of the BARC benchmark is to collect different data sets for assessing the reliability and the dispersion of computational and experimental studies [1]. The comparison of these results revealed that both the numerical simulations as well as the wind tunnel tests are impacted by various sources of uncertainty. In particular, besides modeling uncertainties and numerical errors, in numerical simulations it is difficult to exactly reproduce the experimental conditions due to uncertainties in the set up parameters, which sometimes cannot be exactly controlled or characterized.

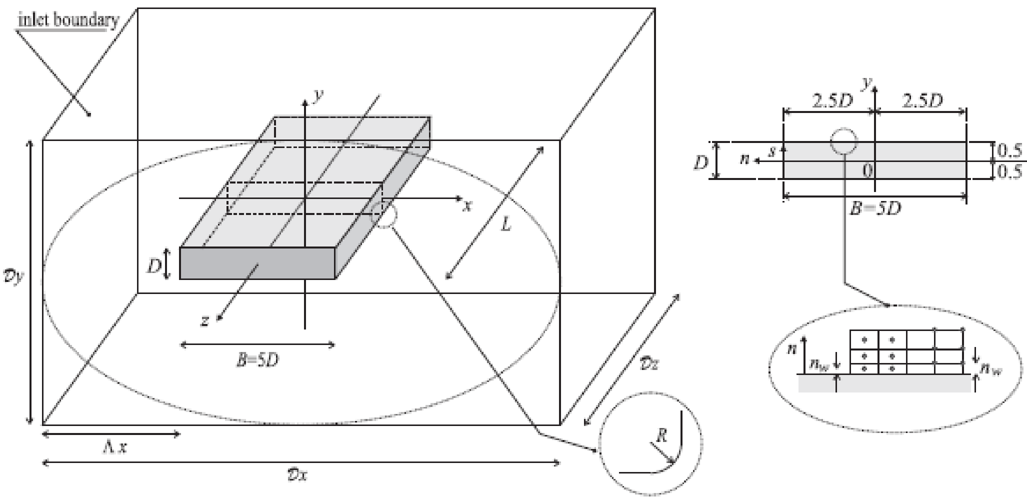

Figure 1: BARC model and domain geometry for the computational study.

In this study, a computational sensitivity analysis and UQ study to the parametric uncertainties is carried out using probabilistic methods. A decision making framework developed and tested earlier for allocating computational resources over multiple sources of error and uncertainty [2] is used. The following uncertain set-up parameters are investigated in the subsequent ranges: the angle of incidence α (0^o-1^o), the longitudinal turbulence intensity I_x (0-0.05), and the turbulence length scale (1D-5D). All these parameters have significant effects on the flow features and on the aerodynamic loads and they are often not characterized or difficult to be exactly controlled in experiments. Sensitivity analysis to small variations of the angle of incidence is also done, because it is interesting to highlight to which extent this affects the symmetry of the flow. The analysis excludes the geometrical uncertainties, in contrast to [3], to avoid re-meshing and post-processing visualization issues. Variations in the Reynolds number are not among the predominant effects and varying it would also imply to change the grid to maintain the same near wall resolution in wall units.

The computations are performed using 2D URANS simulations in order to make the computational effort feasible. A URANS model is used that has proven to give good results for the BARC case [1]. The outcomes are compared to other models and existing LES results to quantify the bias error due to turbulence modeling. The numerical error is estimated by comparing the results from computations on different mesh sizes. This step employs the experience and the spatial meshes from earlier studies [4,5]. Among the output quantities of interest are the bulk parameters: averaged lift and drag coefficient, standard deviation of the lift coefficient, and the Strouhal number. In addition, the time-averaged flow fields are considered as well as the statistics of the pressure coefficient distribution in terms of the mean and standard deviation.

The Stochastic Collocation (SC) method [6] is employed to perform the probabilistic uncertainty propagation of the three set-up parameters. This results in 25 URANS simulations based on the sparse grid extension of the level-2 Clenshaw-Curtis quadrature points. The UQ propagation error is estimated by comparing the results with those on the nested lower levels. It is also investigated whether more quadrature points with the lowest associated weights can be dropped for reducing costs, while maintaining a UQ accuracy that falls within the model and numerical accuracies. The result is a probabilistic comparison of the impact of the considered errors and uncertainties as well as quantitative recommendations for future research directions within the BARC benchmark. These computational UQ results are compared with the ensemble statistics of the available numerical and experimental data sets.

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