PROPOSAL PhD Thesis DGA 2025

Data assimilation for computational-experimental coupling applied to wakes near the free surface

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Context

Context Understanding and predicting flows around fixed or moving structures is a key issue in many defence applications. In aerodynamics and hydrodynamics, fixed or rotating wings, control surfaces and thrusters are subject to fluid forces caused by complex unsteady physical phenomena that are difficult to predict and measure accurately. In most applications, these phenomena determine the fluid-structure interactions, and understanding them requires knowledge of the unsteady dynamics of the flow, the wake and the corresponding fluid forces. In particular, turbulent flows generate structures at multiple scales that strongly influence pressure and friction forces (and hence hydrodynamic performance), wakes, as well as aeration and cavitation, which in turn influence wakes.

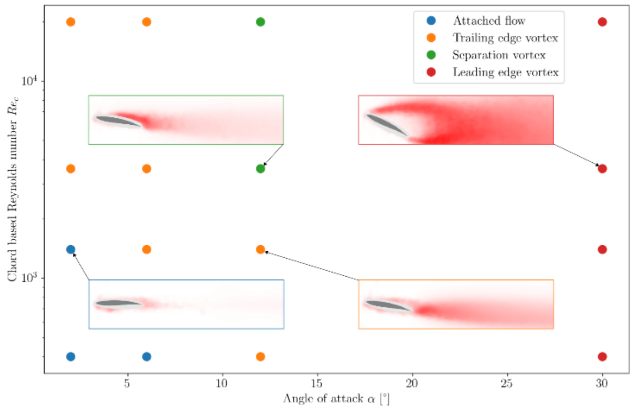
In this context, theoretical and numerical flow prediction tools are generally compared with available experimental data using statistical, modal or spectral quantities. However, it is difficult to directly compare simulation results with experimental results because the two approaches are conditioned independently and obtained on different time bases. In addition, the numerical calculation provides a detailed description of the flows close to the walls and in areas inaccessible to measurement and therefore cannot be directly compared with the experimental results. It can therefore be seen that, beyond comparison, computation and measurement must be able to enrich each other in order to provide predictions extended to the most inaccessible areas, while sharing the same conditioning.

In this thesis, we propose to develop a methodology for coupling simulation and experiment to provide predictions of flows around an Eppler profile near the free surface, the representativeness of which will be quantified using uncertainty calculations applied to both approaches. This topic follows on from the work of Hervé Bonnard (2024), who initiated this work during his PhD by building up a large database of high quality experimental and numerical data.

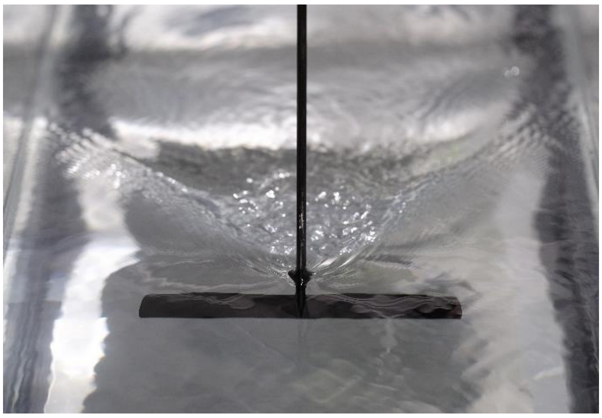
Thesis Programme :

The aim of the proposed thesis is to develop, validate and apply an operational data assimilation methodology for unsteady and turbulent flows. A first approach will be to determine the extent to which hybridisation - direct coupling with arbitrary weights (Suzuki et al. 2018) - of numerical and experimental data can be an acceptable solution. This first phase will be complemented by a stochastic estimation approach, taking into account the uncertainty levels of each data set for the coupling. Finally, a stochastic approach (Suzuki et al., 2020) will be developed in which an evolution model based on the Navier-Stokes equations will be combined with an observational model of the experimental data. The level of uncertainty in the experimental and numerical calculations will be incorporated into this approach to provide the best possible estimate of the state of the flow. The performance of these methods will be quantified by comparing the results obtained from data assimilation with those obtained from experiments on independent learning and validation databases.

Additional work will be carried out to determine the minimum data sets required for effective assimilation, with a view to reducing the volume of experimental data.



Flow regimes as a function of Reynolds number and angle of attack



Visualisation of the wake for a foil close to a free surface

Applications to laminar and turbulent flows around wing profiles (Eppler section) will be carried out. Particular attention will be paid to the reconstruction of three-dimensional structures from two- or three-component velocity data obtained on two- or three-dimensional measurement domains. The estimation of pressure fields and fluid forces will be compared with sensor measurements and with the results of conventional post-processing methods.

Skills required :

Fluid mechanics, Numerical simulation (OpenFOAM), Experimental techniques, Scientific programming

References

Suzuki, T., Chatellier, L., Jeon, Y. J., & David, L. Unsteady Pressure Estimation and Compensation Capabilities of the Hybrid Simulation Combining PIV and DNS, Measurement Science and Technology, 29(2), 2018 https://doi.org/https://dx.doi.org/10.1088/1361-6501/aae6b7

Suzuki, T., Chatellier, L., Jeon, Y. J., & David, L. A few techniques to improve data-driven reduced-order simulations for unsteady flows, Computers & Fluids, 201:104455, 2020 https://doi.org/10.1016/j.compfluid.2020.104455

Bonnard, H. Études numérique et expérimentale d'hydrofoils 2D et 3D pour différentes configurations d'écoulement à surface libre, Thèse de doctorat de l'Université de Poitiers, 2024

The position is open to European students only.