Towards scale-resolving simulations of raceboat hydrofoils

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ABSTRACT

The E1 Series is the world's first and only all-electric raceboat championship. Pilots compete using the RaceBird, a high-speed motorboat that employs hydrofoil technology to reach speeds of up to 50 knots. Beyond entertainment, the Series aims to promote electric marine mobility and drive innovation in sustainable maritime technologies. A partnership between KAUST and the E1 Series has been formed to pursue joint R&D initiatives, targeting advancements in the RaceBird's hydrodynamic efficiency and acoustic performance.

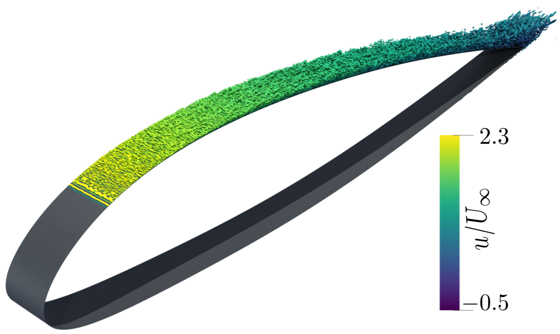

Figure 1: Turbulent structures developing on the suction side of the foil. U_∞ is the freestream velocity and u the windward.

As an initial project, we intend to conduct scale-resolving simulations of the boat's front hydrofoils. Due to the high Reynolds number of the flow, wall modeled LES (WMLES) is selected as the prime candidate for turbulence modeling. However, achieving accurate WMLES predictions for foils remains a challenge, necessitating further advancements and rigorous validation. To address this, we simulate the Aerospatiale A-airfoil at a chord Reynolds number of $Re_c = 10^7$ and an angle of attack of 13.3 degrees (Figure 1). This case benefits from recently published wall-resolved LES reference data by Tamaki et al. (2023), providing a robust benchmark for validation.

We perform the simulations with two codes, Nek5000 and OpenFOAM. The former is based on the high-order (here, 7th) spectral-element method (SEM) and the latter on the finite-volume method. Both solvers are based on the incompressible Navier-Stokes equations and employ the Vreman (2004) subgrid scale model for closure. For wall modeling, the profile developed by Spalding (1961) is used. The results differ between the two codes, with Nek5000 struggling with accuracy in the laminar region, whereas OpenFOAM appears to underpredict the effect of the APG on the flow. Both of these issues lead to an incorrect growth rate of the boundary layer. However, in outer scaling, the accuracy of the velocity profiles from Nek5000 is very good.

To improve the initial results, we will incorporate a newly-developed transition sensor for the wall model, and also consider finer grids. Ultimately, we will also explore combining WMLES with cavitation modeling, as it is likely to become relevant when exploring new hydrofoil designs.

References

Spalding, D. B. : A single formula for the 'law of the wall', *Journal of Applied Mechanics*, **28:3**, 455–458 (1961).

Tamaki, Y., Kawai, S. : Wall-resolved large-eddy simulation of near-Stall airfoil flow at $Re_c = 10^7$, *AIAA Journal* **61:2**, 698–711 (2023).

Vreman, A. W. : An eddy-viscosity subgrid-scale model for turbulent shear flow: Algebraic theory and applications, *Physics of Fluids*, **16:10**, 3670–3681 (2004).