Internship opportunity 2023

Title: Numerical simulation and sensitivity analysis of the flow around boxfish

Supervisors :

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Boxfish get their name from the rectangular (or sometimes five-sided) shell of bony armor on the front two-thirds of their bodies. Given their shape, they could not be classified a priori among the fastest fish by any stretch of the imagination. However, it turns out that boxfish are fast, stable and incredibly manoeuvrable swimmers, so much so as to inspire human designers *[1]* (see figure 1).

Working place : Département d'aérodynamique, Energétique et Propulsion (DAEP), ISAE-SUPAERO

Duration: 6 months

Key words: boxfish, drag reduction, CFD, stability, sensitivity, shape optimisation, aerodynamics, biomechanics, biomimicry

Background

Recent studies showed that boxfish are far from being slowpokes: they can scoot over a reef at six body lengths per second which is an impressive speed by any standard. Moreover, Ian K. Bartol, a biologist at Old Dominion University in Norfolk, Virginia, and a multidisciplinary team of investigators managed to visualize the flow of water around a boxfish by placing neutrally buoyant beads in the water and filming the beads as they swept past plastic models of the fish. They found, with their models, that the drag of the boxfish is surprisingly low, as expressed by a dimensionless quantity known as its drag coefficient. The drag coefficient of the boxfish is just 0.2, which is comparable to some airfoils, and falls well below 1.5, the drag coefficient of a flat-faced box. Recent experimental measurements and Lattice-Boltzmann Method (LBM) simulations carried out in our department have confirmed these surprising results, as can be seen from figure 2.

Program of internship

The objective of this internship is to perform a sensitivity analysis of the flow around different boxfish geometries for a Reynolds number Re=3000, for which the flow is laminar (see figure 2). A previous study using experiment and LBM have revealed that aerodynamic performances are Reynolds-independent from Re≈3000 to 100000, therefore, a reduced number will be used for this internship to (i) compute the unsteady flow using DNS, and (ii) analyse the global modes that characterise the flow dynamics using a global stability approach. In particular, this internship will focus on the spatial region where vorticity is generated, as well as the wake dynamics (see figure 2 for DNS of the boxfish performed at ISAE-SUPAERO using LBM).

Below we present the <u>timetable</u> of the internship:

1. Make a structured mesh modelling the fluid control volume around the boxfish;
2. Simulate the flow around the boxfish for different Reynolds number conditions. To do so, our in-house high-order Navier-Stokes code IC3 will be used;
3. Having fixed a flow condition, perform stability analysis to determine the most unstable global mode driving the flow dynamics *[2]*;

4. Adjoint-based sensitivity analysis to identify the most sensitive flow regions and detect the most stabilising or destabilising baseflow modification *[2]*.

Figure 1: Computer-generated model of a Mercedes-Benz with design elements inspired by the hydrodynamically efficient boxfish.

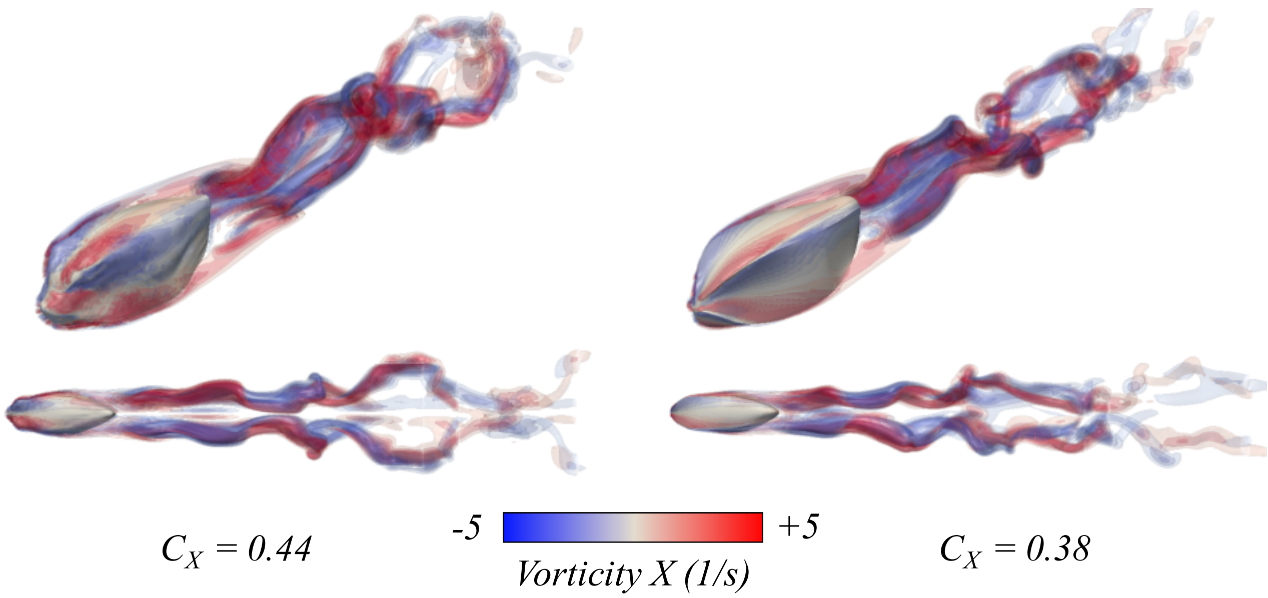

Figure 2: Vorticity field of a scanned (left) and modelled (right) boxfish geometry at Re = 3000 computed by LBM

Candidates

We are looking for candidates from engineering schools (or equivalent) with a background in computational fluid mechanics and who are highly motivated to work on a research project at the interface between academia and industry. Candidates should be comfortable with high performance computing, mesh modelling and data post-processing. Knowledge in stability and sensitivity analyses is a plus.
If you are interested, or if you know someone who might be interested, please send me by email.

Bibliography

[1] Chowdhury, H., Islam, R., Hussein, M., Zaid, M., Loganathan, B. & Alam, F. 2019
Design of an energy efficient car by biomimicry of a boxfish, Energy Procedia, Volume 160, 40-44, ISSN 1876-6102 https://doi.org/10.1016/j.egypro.2019.02.116.
[2] Nastro, G., Robinet, J.-C., Loiseau, J.-C., Passaggia, P.-Y., Baldas, L., Mazellier, N. & Stefes, B. 2022
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