VRIJE UNIVERSITEIT BRUSSEL

The faculty of Engineering of the Vrije Universiteit Brussel invites you to attend the public defense leading to the degree of

DOCTOR OF ENGINEERING SCIENCES

of **Luca Damiola**

The public defense will take place on **Thursday 25th September 2025 at 5 pm** in room **D.2.01** (Building D, VUB Main Campus)

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UNSTEADY AEROFOIL AERODYNAMICS: FLOW PHYSICS AND DATA-DRIVEN MODELLING

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Abstract of the PhD research

The aerodynamic performance of unsteady aerofoils at moderate Reynolds numbers plays a crucial role in various engineering applications, including small wind turbines and unmanned aerial vehicles (UAVs). These devices frequently operate in highly turbulent and unsteady environments, posing significant challenges to their aerodynamic characteristics and overall efficiency. Addressing these challenges requires a deep understanding of the underlying flow physics. However, insight into the flow physics alone is not sufficient. Accurate and versatile mathematical models are also required for real-time performance prediction, design optimisation, and control. This research addresses two primary objectives.

First, this work provides physical insight into the behaviour of aerofoils under various unsteady conditions at moderate Reynolds numbers (O(10^5)). In particular, wind tunnel experiments of a pitching NACA 0018 aerofoil are conducted to evaluate the influence of freestream turbulence on the unsteady aerodynamic loads, considering dynamic experiments for various angle-of-attack ranges and reduced frequencies. Additionally, in a separate experimental campaign, the effect of streamwise gusts on the aerodynamic behaviour of a NACA 0012 aerofoil is examined by applying an oscillating freestream velocity. To complement the experimental results, numerical simulations are conducted under similar flow conditions, demonstrating good agreement with the experiments and offering additional flow field insights.

The second objective involves the development of fast and accurate data-driven models to predict the unsteady aerodynamic loads acting on a pitching aerofoil. A flexible black-box modelling approach integrating neural networks within a classical state-space representation is developed to account for the highly nonlinear response of aerofoils at high angles of attack. This research demonstrates that accurate data-driven aerodynamic models can be constructed using either experimental or numerical data, effectively capturing complex nonlinear relationships. The added value of these nonlinear models is demonstrated in a use case focused on flow control, where the pitching kinematics of the aerofoil is optimised to mitigate the undesired load fluctuations caused by dynamic stall.

Ultimately, this research contributes to a better understanding of the flow physics of unsteady aerofoils under pitching and surging conditions while also proposing a novel approach for the construction of data-driven aerodynamic models. These nonlinear models are particularly well-suited for integration into optimisation and control frameworks where both accuracy and rapid evaluation are essential.