Thèse / PhD
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Optimisation de la cinématique de pales
Physics-based optimisation of blade kinematics

Localization : INSTITUT PPRIME, ISAE-ENSMA

Duration : 36 month

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Project description

The well-know circulation theorem of lord Kelvin (1869) states that within an inviscid, barotropic flow, the circulation around any closed material curve will remain constant at all times. Evidences of this theorem can be found in many practical applications, the most known for aerodynamicists being the starting vortex shed when setting a lifting wing in motion from rest. In this specific example, the wing is initially static within a resting fluid, producing no lift nor circulation around its own solid boundary. Imparting a forward motion to the wing in a lifting configuration results in imposing a non-zero circulation of the fluid around it, that is compensated by a reversed swirling motion generated at the trailing edge. Another well-know example concerns the established flow over an airfoil, Changing either smoothly or abruptly of angle of attack will eventually result in the shedding of a vortex that compensates for the change of circulation. More generally, any arbitrary motion of an airfoil is likely to modify the flow circulation and may trig the release of isolated or multiple vortices.

Another view to the constant circulation paradigm is given in the early works of Couchet (1945). Formulating the unsteady potential flow around an airfoil profile in arbitrary plane motion, he derived mathematical relationships allowing the airfoil to either maintain or alter the circulation associated to its own kinematics. The main features of the Couchet theory involve the instantaneous angle of attack, the relative in-plane velocity of the airfoil and, most importantly, the Magnus effect associated to the airfoil's pitching rate. Using this framework, Gorle et al. (2019) successfully attempted to optimize the operating cycle of a cross-flow turbine by imparting theory-based pitching laws to its blades.

Based on these results obtained in the Couchet framework, a more systematic study is proposed in this PhD project. Three axes of investigation will be developed.

First, the applicability of the constant circulation paradigm will be numerically studied through several families of motion, from the simplest galloping, plunging or pitching motions to more complex kinematics involving combinations of these. The objective of this approach is to assess the range of parameters over which a constant circulation can be maintained around a given airfoil evolving in a real fluid. The outcome of this preliminary part will then be validated in the experimental facilities of PPRIME and ISAE-ENSMA using a 6-d.o.f robotized arm.

In a second approach, motions applicable to propulsion, sustentation, maneuvers or energy harvesting will be selected and incorporated in optimisation loops. In doing so, simple predefined motions will evolve into more efficient kinematics under the constraint of respecting a constant circulation while possibly allowing localized circulation changes. This protocol will first be explored numerically, then experimentally by programming the robotized arm within the optimiser.

In a last part, the particular dynamic stall phenomenon will be specifically investigated by combining the two latter approaches based on either predefined or optimized kinematics. Dynamic stall is closely linked to wing motion, and – in two dimensions - can be seen as the result of ill-conditioned kinematics in which the Magnus effect and instantaneous relative angle of attack compete to modify the circulation value. Consequently, it is proposed here to revisit the dynamic stall phenomenon by separating the influence of the motion parameters by manipulating the constant-circulation constraint. Therefore, and compared to previous studies imparting arbitrary kinematics to the wings, the investigation will focus on the physical reasons that bring an unsteady flow to evolve between an attached flow and a detached one.

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Candidate requirements:

Master 2 or 3rd yr engineering school

Proficiency in theoretical, computational and experimental fluid mechanics

References

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