Numerical investigation of the effect of motion trajectory on the vortex shedding process behind a flapping airfoil

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Long Abstract

Introduction

In aeronautics, the field of micro air vehicle (MAV), and in particular micro air vehicle with flapping wing, is one of the most studied subjects in recent years [1-6]. The remarkable interest in the study of these small crafts is linked to the many advantages which present this mode of locomotion. Unlike the fixed-wing, flapping-wing MAV are able to perform hovering flight or low-speed flying in the manner of insects or humming birds. They also have a very high manoeuvrability. They perform punctual tasks, even in small spaces. Although the rotary wings provided the same tasks, the hinging wings have an advantage related to the acoustic spectrum which is generally lower than that created by the rotors of the rotating wings. In addition to this advantage, the small size and biomimetic form of flapping wing drones favours their use in military field as an example. The drones with flapping wings take advantage of the phenomena of unsteady aerodynamics to develop a lift force higher than that of the fixed and rotating wings, in order to generate the same lift force, the latter only use the power of the actuators and thus need more energy. However, the performance of natural flying systems still far superior to artificial swing wings, due to their manoeuvrability and their propulsion efficiency. Considering the efforts established to understand the complex mechanisms used by birds and insects during flight Beaten, much remains to be explored. It is indeed difficult to reproduce technologically, the techniques developed by these animals during manoeuvres. Currently the work of research are oriented towards the discovery of better energy efficiency by increasing aerodynamic performance of micro-drones with adapting adequate technological solutions.

1. Methods

The wake structure downstream of the trailing edge plays a significant role on the forces generated by a flapping wing. In this context, the aim of this work is to study the effect of motion trajectory on the evolution of the wake behind a flapping wing. A NACA 0012 aerofoil with chord length of 100 mm is considered, undergoing combined pitching and heaving motion at low Reynolds number 11000 (figure 1). The unsteady Navier Stokes equations governing the flow around the flapping aerofoil are solved in a two-dimensional domain using the industrial CFD code STAR CCM+.

An elliptic function with an adjustable parameter S (flatness coefficient) was used to model different non-sinusoidal trajectories. The flapping motion is reproduced using the overset mesh technique available in the environment of STAR CCM+ (Figure 2). Figure 2 show the computational domain and the boundary conditions used. The reliability and accuracy of our numerical procedure was examined by comparing the computed results with the experimental and numerical results available in literature [3,7]. Figure 3 shows that the computed results are in good agreement with published results..

2. Computational Results

The results show that the nature of the motion trajectory has a great effect on the propulsive performances of the flapping aerofoil. The maximum propulsive efficiency is always achievable with sinusoidal trajectories. But, the using of non-sinusoidal trajectory improved considerably the propulsive force (about 52%), figure 4. The visualization of the flow around the flapping aerofoil allows observing that the vortex shedding process and the topological structure of the wake completely change under the effect of the motion trajectory. Depending on the nature of the motion trajectory, several modes of vortex shedding has been identified and will be presented in this paper.

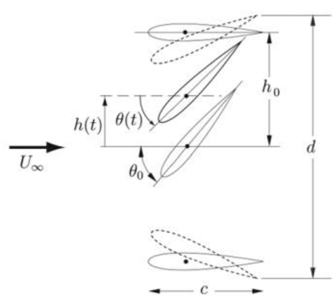


Figure 1. Flapping motion

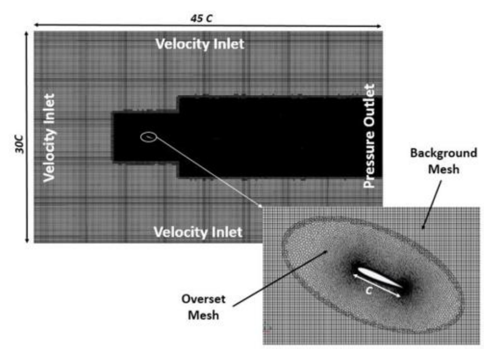
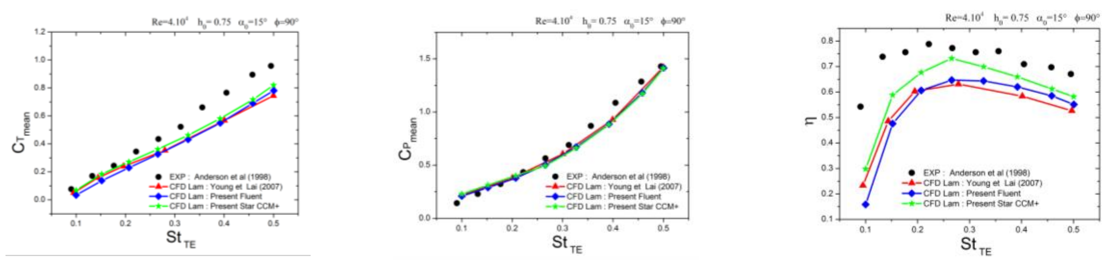


Figure 2. Computational domain with overset mesh

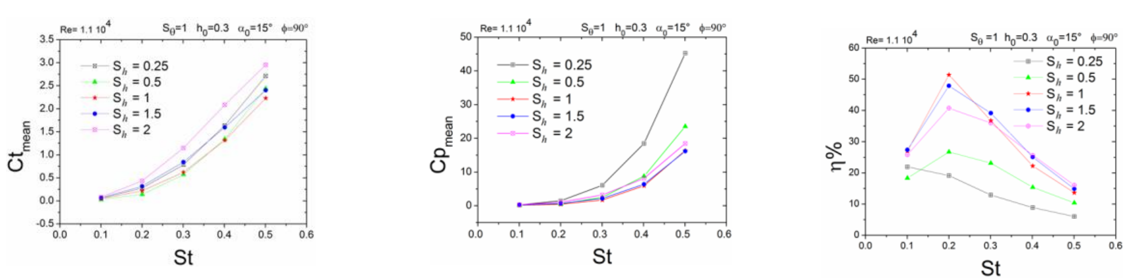


Thrust coefficient

Power coefficient

Efficiency

Figure 3. Solver validation

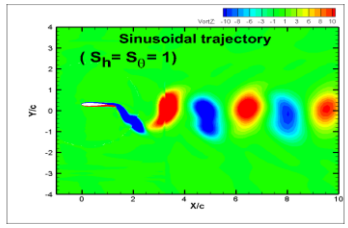


Thrust coefficient

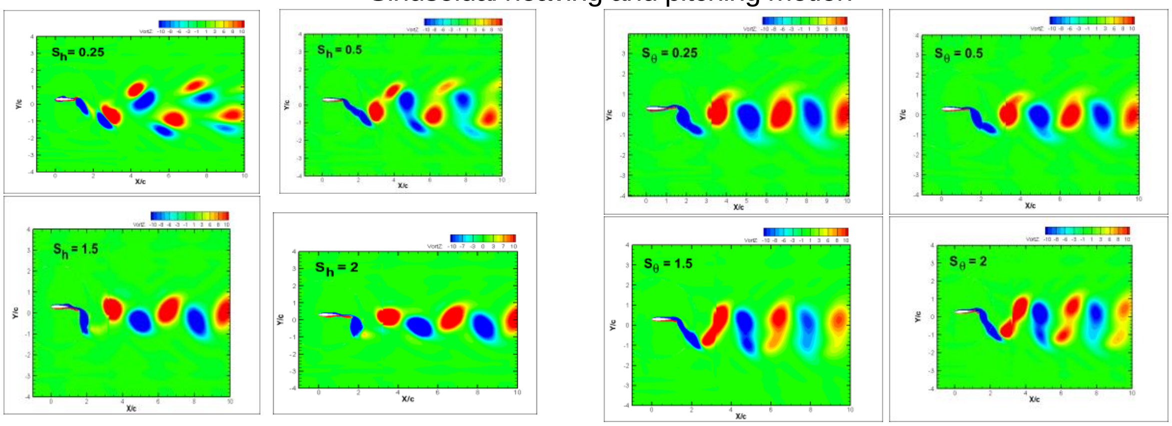
Power coefficient

Efficiency

Figure 4. Effect of non-sinusoidal heaving on the propulsive performances



Sinusoidal heaving and pitching motion



Non-sinusoidal heaving combined with sinusoidal pitching motion

Sinusoidal heaving combined with non-sinusoidal pitching

Figure 5. Effect of motion trajectory on the wake

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