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**Title**

# Effects of the reduced frequency on the aerodynamic characteristics of a pitching NACA0012 airfoil under moderate Reynolds number

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**Abstract**

Oscillations of the wing or airfoil are commonly observed in the aerospace community. Unsteady aerodynamics induced by the airfoil oscillation have drawn great attentions for decades. For applications under low or moderate Reynolds numbers, such as small unmanned aerial vehicles (UAV) powered by multiple propellers, the propeller blades that are often made of plastic or carbon composite materials may experience different levels of oscillation at high rotational speeds, causing unsteady aerodynamic loads[i] and increase of aerodynamic noise[ii]. In this paper, Aerodynamic characteristics of a pitching NACA 0012 airfoil, including the load performance and flow field features, are studied using numerical simulations in this paper. Large Eddy Simulations (LES) has been performed and the chord-based Reynolds number is set as 66000. Pitching frequency varies from 3Hz to 20Hz, corresponding to the reduced frequency ($k=\pi f_p c/U$, where $f_p$ is the pitching frequency, $c$ is the chord length, and $U$ refers to the incident flow speed) being 0.094-0.628.

As the pitching frequency increases, the maximum lift coefficient achieved in one pitching cycle decreases, and the direction of the lift hysteresis loop changes as the pitching frequency goes beyond a certain value, leading to a change in the lift of the sign at the zero-incidence moment, which is a result of the instantaneous flow patterns the airfoil surface. As the pitching frequency increases, flow unsteadiness develops less in one pitching cycle, and the time duration in which the turbulence boundary layer can be detected in one pitching cycle shrinks. As well, for the pitching airfoil, combinations of the flow patterns on the upper and lower sides, such as laminar separation and turbulent boundary layer, laminar separation and laminar separation bubble, are observed on the airfoil surface, which are not detected on a static airfoil at the corresponding Reynolds number. It is considered as another effect of the pitching motion other than the phase-lag effect.

The results correspond to the aeroacoustic measurements previously reported by the authors that the instantaneous narrow-band noise observed at a certain pitching angle gets weakened as the reduced frequency increases[iii]. According to the noise-PIV synchronization measurements, it was revealed that the narrow-band noise is induced by the large-scale coherent structures presented at the corresponding pitching angle. As the reduced frequency increases, the strength of the separation vortices reduces, leading to lower intensity of the narrow-band noise.

**References**

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