Effect of pitch rate variation on the evolution of the leading edge vortex

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Studies on biological fliers like insects and birds have shown that their inspiring flight performance can be attributed to the interactions between the flapping wings and unsteady air flows. It has come to light that the Leading Edge Vortex (LEV) plays the most prominent role in enhancing lift (Shyy et al, 2010). However, the aerodynamic consequences of changes in attributes such as kinematics and morphology of the wings are not yet entirely understood.

Investigations of model wings have shown that the same high lift mechanisms produced by dragonflies can be recreated. This was furthered by Rival and Tropea (2010), who discussed the vortex-interactions of pitching and plunging motion in airfoils. Even though the unsteady characteristics have been studied for different aerodynamic profiles, a detailed topological analysis for variations in kinematics of a simple but encompassing motion such as pitching, like in case of hovering, is desirable. The current study revolves around improving our understanding of the dependency of model wing aerodynamics on the rate of change of angle of attack. Keeping the amplitude and time period constant while varying the temporal evolution for the angle of attack (α), comparisons between different cases are conducted.

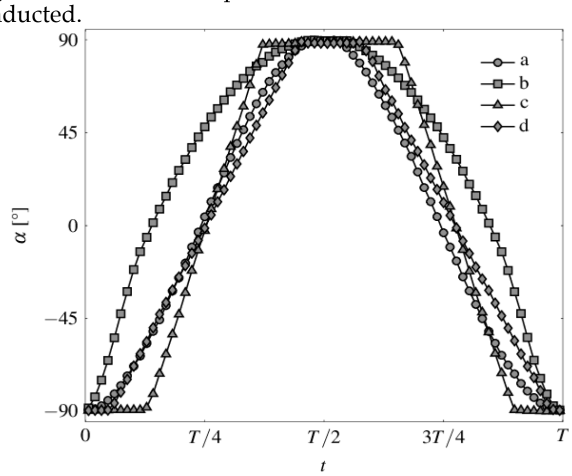

Fig. 1 Kinematic profiles considered . (a) Sinusoidal (b) Parabolic (c) Trapezoidal with RT=0.5 (d) Trapezoidal with RT=0.2

The associated vortex dynamics of a simplified two-dimensional model for various pitching configurations like sinusoidal, parabolic, and trapezoidal with different rest times (Figure 1) are studied experimentally by means of Time-Resolved Particle Image Velocimetry (TR-PIV). Measurements are conducted along the mid-span of a flat plate in a rectangular tank filled with stationary glycerol-water mixture as the working fluid. The sCMOS camera has an acquisition frequency of 26Hz and the wing is maintained at pitching frequency of 1Hz. Information about the vortex formation and growth is sought between the wing amplitude of 180 degrees.

The spatial and temporal growth of the vortices are tracked using the Γ2-criterion as presented by Graftieaux (Graftieaux et al., 2001).The detected vortices are traced through time series of flow fields and comparisons of their trajectories for different cases are drawn.

Owing to the symmetry of the plate, identical shear layers are observed on either edges of the wing. As α is decreased from 90 degrees to -90 degrees, a clear clockwise-rotating vortex is formed at the top surface which evolves coherently and sticks to the plate unitl α reaches zero. The erupting layer that is formed underneath the vortex pushes it further away from the plate with time. The vortex travels a distance of about 0.5 chord lengths away from the plate before breaking down into smaller structures. The most distinct trajectory of the vortex seems to be that of the parabolic profile, where the top vortex travels further upwards in comparison to other profiles during the pitch down motion. It is also observed that the rest time in the trapezoidal profiles influences the trajectory of the vortices. The profile with smaller rest time(=0.2*T, T being the time period) at maximum α pushes the vortex further upwards than the one with a rest time equal to 0.5*T.

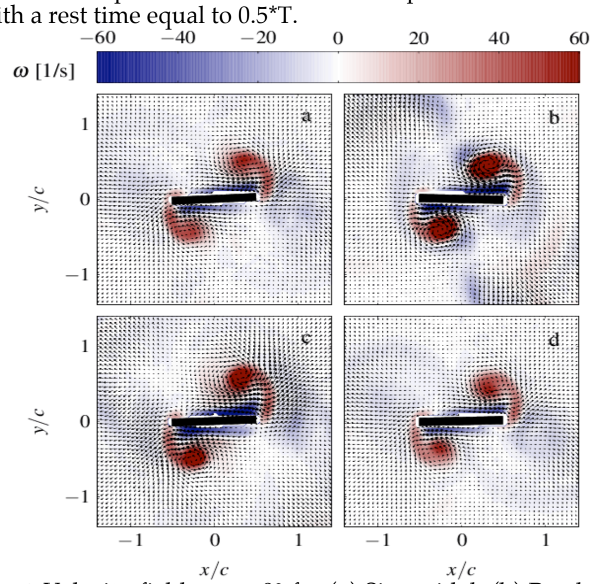

Fig. 2 Velocity fields at α=0° for (a) Sinusoidal (b) Parabolic (c) Trapezoidal with RT=0.5 (d) Trapezoidal with RT=0.2

The bottom anti-clockwise rotating vortex shows an upward trend as the angle of attack is increased, travelling to about the same distance as the the top vortex.

Although the overall topology of the vortex formation and evolution remain similar, variations in the growth and eruption can be observed with changes in the rate of change of angle of attack.

References

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