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Exploring the effects of spanwise wing deformation on lift coefficient and trailing vortices properties at low Reynolds number

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Abstract We have conducted an experimental investigation on the effect of spanwise wing deformation on the lift coefficient and the properties of the wingtip vortices generated by several NACA0012 symmetric wing models.
Keywords: wingtip vortex, aerodynamics, flow visualization, wing model deformation.

The state-of-the-art research on steady-state aerodynamics under subsonic flow conditions presents a wide variety of studies that contemplate the characterization and analysis of flight conditions with rigid wing models. However, the advent of increasingly lighter airfoil materials causes considerable spanwise deformations, which has become a relevant concern for the operation at low Reynolds number regimes of Micro Air Vehicles (MAVs) and Unmanned Aerial Vehicles (UAVs). The flow dynamics at this regime are notably intricate, primarily driven by a laminar separation bubble (LSB) developed on the suction side of the wing profiles. Consequently, even subtle changes in experimental conditions or wing geometry can significantly impact wing forces and wake flow structures, which are critical in determining the optimal active control of the fluid flow.

We have measured both the hydrodynamic forces and the velocity fields generated in the wake of three different NACA 0012 rigid wing models for several angles of attack lower than the stall value in a towing water tank located in the Laboratory of Aero-Hydrodynamics of the University of Málaga, Spain. We conducted all experiments at the same chord-based Reynolds number, $Re = 20 \times 10^3$, and each of the three wing models considered presents a varying level of spanwise deformation: non-deformed (ND), intermediate deformation with a tip deflection of $\delta = 2\%$ (ID) and large deformation with a tip deflection of $\delta = 4.5\%$ (LD). We show in Figure 1 a graphic visualization of the deflection curves along the spanwise direction for these models.

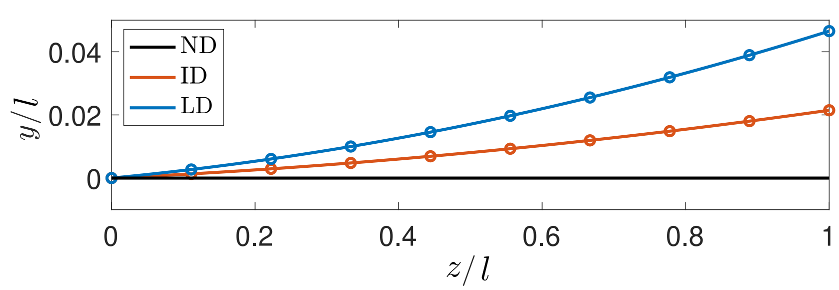

Figure 1: Non-dimensional spanwise deflection levels, extracted from experimental measurements(1): non-deformed (ND, $\delta = 0\%$), intermediate deformation (ID, $\delta = 2\%$), and large deformation (LD, $\delta = 4.5\%$).

Force measurements reveal three discernible zones within the range of angles of attack investigated, each presenting different lift slopes. These zones persist even for the deformed wings, indicating consistent aerodynamic behavior across different wing configurations. One initial observation is that at lower angles of attack, for instance, $\alpha = 4^\circ$, the non-deformed wing configuration exhibits higher lift than the maximum spanwise deformed wing. Conversely, at higher angles of attack, such as $\alpha = 8^\circ$, the spanwise deformed wing configuration presents a higher lift. These changes in the lift forces for different spanwise deformations can be observed in Figure 2 (a).

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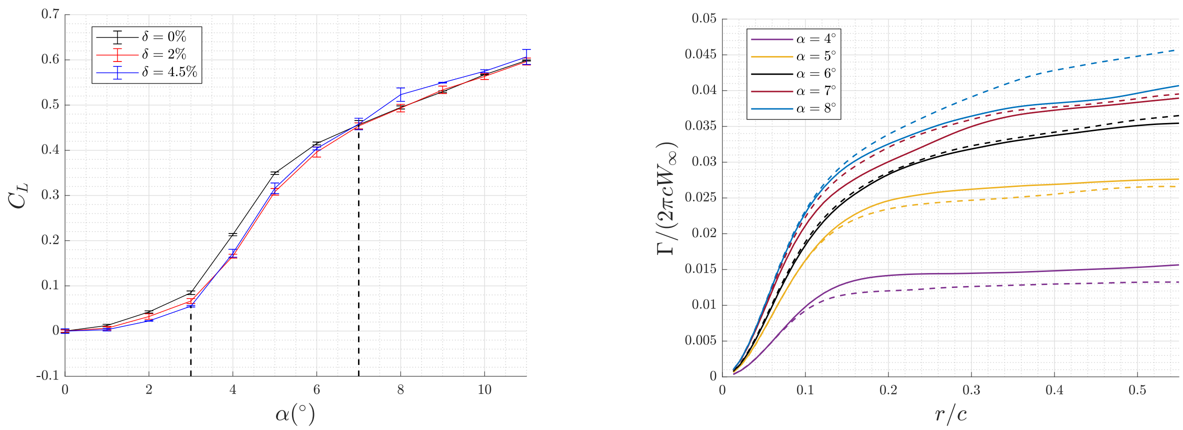
Additionally, the deformation decreases the circulation over the wing for $\alpha < 6$ concerning the circulation of non-deformed values and increases it for greater α, as observed in Figure 2 (b). This tendency change is also directly related to the circulation measured in a plane perpendicular to the wing model movement, as proposed in (3). We have shown that their empirical relationship between the circulation over the wing due to lift vortex (obtained from C_L) and the circulation measured in a plane perpendicular to the wing model movement (computed from 2D-PIV experimental measurements) is valid for our study.



(a) (b)

Figure 2: (a) Lift coefficient versus the angle of attack for three different levels of deformation, and (b) circulation with respect to the radial coordinate for 5 different angles of attack, where solid lines represent non-deformed wings and dashed lines represent deformed wings with $\delta = 4.5\%$. Figures extracted from (2).

References

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