High-speed PIV measurements of the influence of artificial surface structures on the near-wall flow field of 3D wing models based on an owl geometry

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Keywords: Three-dimensional airfoil aerodynamics, Velvet surface structures, High-speed PIV

The barn owl is a well-known example for a biological system that possesses a high level of adaptation to its habitat. It has developed special adaptations on its wing to fly silently. The wing is characterized by an almost elliptical planform and a comparatively large wing size. Three special adaptations of the owl wing, the leading-edge serrations, the trailing-edge fringes, and the velvet-like surface structure were identified [1]. It is expected that the special surface structures of the owl wing directly affect its aerodynamic performance. As discussed in [2], a laminar separation bubble is likely to occur at the aforementioned wing geometry. Also, it was found that the velvet surface structures directly influence the size of the separation bubble. To further investigate the influence of the surface structures, high speed particle-image velocimetry (PIV) measurements were performed. This measurement technique allows the detailed time-resolved analysis of the turbulent flow structures.

Experimental setup

The experiments were performed in the low speed wind tunnel of the Institute of Aerodynamics. Reynolds numbers based on the chord length of \( Re_c = 4 \times 10^4 \), \( 6 \times 10^4 \), and \( 1.2 \times 10^5 \), that correspond to freestream velocities of \( u_w = 3.5 \), 5.3, and 10.5 m/s, respectively, were measured. The measurements were conducted at angles of attack of \( \alpha = 0^\circ \), \( 3^\circ \), and \( 6^\circ \) at four spanwise positions, namely \( 2y/b = 0.12 \), 0.2, 0.25, and 0.3. The sampling frequencies were 2000 Hz for the measurements performed at \( Re_c = 4 \times 10^4 \) and \( Re_c = 6 \times 10^4 \) and 4000 Hz for \( Re_c = 1.2 \times 10^5 \), respectively. Two synthetic velvet-like surface structures were selected to mimic the surface of the natural owl wing. The first velvet was chosen to emulate the natural surface with respect to the length and density. The second velvet possesses longer hairs and thereby is softer than the natural surface.

Results and Discussion

It was found that the artificial surfaces strongly influence the flow field of the wing model. The extent of the separation bubble normal to the wing surface was significantly reduced for both velvet structures. In some cases the separation bubble was fully eliminated. Figure 1 shows the averaged velocity fields at \( 2y/b = 0.20 \) for \( Re_c = 40,000 \), \( \alpha = 0^\circ \) which clearly visualize effect of the surface structures on the separation bubble. Fig. 2 shows that the clean configuration C (c) possesses a significantly smaller decay rate in the power spectral density distribution, which indicates that the turbulent structures have a higher kinetic energy at higher frequencies compared to the artificial surfaces. Thus, the surfaces also influence the distribution of the kinetic energy in the different length scales.

References