Characterization and Design of Tubercle Leading-Edge Wings

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Abstract: Leading-edge wing planform variations modeled after protuberances seen on humpback whale flippers are believed to result in improved lift and drag characteristics in the near-stall regime. The unconventional geometry makes flow predictions highly sensitive to turbulence models which are otherwise well validated for conventional wings. Computational studies of planforms with and without variations are performed, showing increased streamwise vorticity production by the varying leading edge as a mechanism responsible for stall delay at constant angle of attack. Motivated by observed whale maneuvers, rapid pitch-up dynamic stall characteristics are analyzed.

Keywords: CFD, Turbulence Modeling, Unsteady Flows, High Lift Devices.

1 Scope

Modified leading-edge aerodynamic devices have recently been found in a wide range of commercial applications. Empirical evidence shows improved performance in industrial fans, wind turbine blades, marine rudders, helicopter rotors, and other applications. Benefits of leading-edge protuberances have been observed in limited experiments[1] when compared to similar planforms without leading-edge variations, but corresponding computational analysis[2] has proven problematic, especially near the stall regime. Results were shown to vary greatly depending on the turbulence model and numerical methods used compared to experiment.

In this work, using well-established unsteady RANS CFD methods we study the characteristics of this class of wing, sensitivity of the flow to Reynolds number, and constant angle of attack performance compared to unsteady rapid maneuvering.

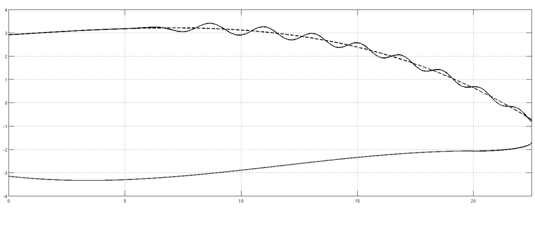

Figure 1: Baseline wing (solid) and modified leading edge (dashed).

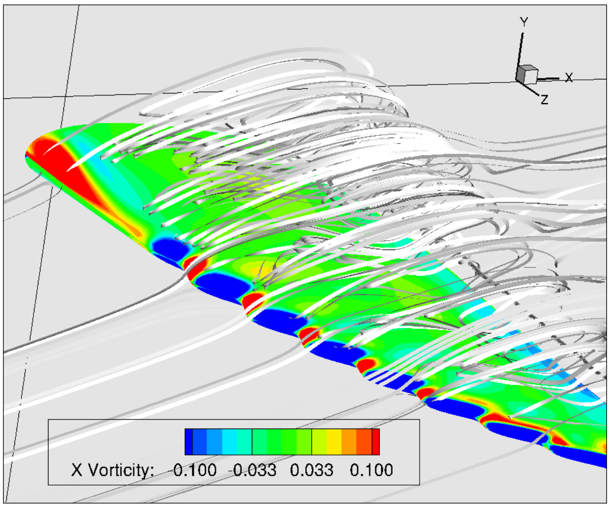

Figure 2: Streamwise vorticity contours near the wing surface and streamtraces at $\alpha = 16°$.

Above a moderate angle of attack ($\alpha > 5°$) the modified planform generates considerable streamwise vorticity near the boundary layer compared to the baseline wing. Lift and drag values quickly change from the baseline values at increased angle of attack, and appear to be Reynolds number dependent. Figure 2 shows a pattern of alternating vorticity generation from the leading edge in front of the separation bubble at high angle of attack. The flow field is strongly unsteady and three dimensional, with periodic vortex shedding from the protuberances affecting the separation bubble.

Once the interactions of these complex flow features are fully explored and characterized for a range of Reynolds numbers, we will investigate the effect of shape modification of the protuberance size and density.

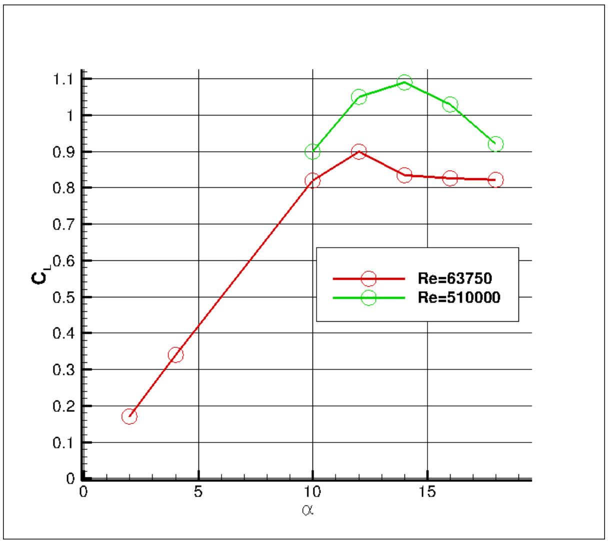

Figure 3: C_L vs. α for tubercle wing.

References

[1] Weber, P. W., Howle, L. E., Murray, M. M., and Miklosovic, D. S., "Computational Evaluation of the Performance of Lifting Surfaces with Leading-Edge Protuberances," *Journal of Aircraft*, Vol. 48, No. 2, 2011, pp. 591–600.

[2] Miklosovic, D. S., Murray, M. M., Howle, L. E., and Fish, F. E., "Leading-edge tubercles delay stall on humpback whale flippers," *Physics of Fluids*, Vol. 16, No. 5, 2004, pp. 39–42.