Control of flow around a pitching/plunging airfoil for lift enhancement

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Abstract

Dynamic stall caused by unsteady motion of airfoil widely exists in insects, wind turbine, aircraft and other objects. Leading-edge vortex (LEV) determines the aerodynamic evolution of dynamic stall (Corke and Thomas 2015). Thus, it is necessary to control the LEV to improve the lift. Pitching/plunging airfoil is a motion model which is widely used to study dynamic stall. The previous investigations by Widmann and Tropea (2015) indicated that the LEV detachment mechanism could be divided into bluff body detachment and boundary layer eruption detachment. Eldredge and Jones (2019) summarized recent research about LEV formation, growth and shedding, and they pointed out that LEV was likely to play a central role in flow control for achieving agile flight. Thus, a numerical study of flow control for LEV is conducted in this study.

Here, flow control strategies have been tested for boundary layer eruption detachment mechanism and thus to increase the aerodynamic performance of a pitching/plunging airfoil. The basic strategy is placing the actuator such as suction/synthetic jet near the upper surface of the airfoil to inhibit the formation of the secondary vortex or decrease its strength. It is aimed at increasing the strength of the LEV and thus to increase the lift coefficient, or postponing the detaching time of the LEV and thus to achieve a high-lift state with long duration.

Control effects of suction/synthetic jet has been tested on a pitching/plunging SD7003 airfoil by numerical simulation. The computational study employs an SST (Shear stress transport) model within the unsteady RANS (Reynolds averaged Navier-Stokes) framework. The simulation is conducted under reduced frequency $k = 0.25$, Strouhal number $St = 0.08$ and maximum effective angle of attack $\alpha_{eff,max} = 22°$. For the control cases, actuator is conducted at momentum coefficient $C_\mu = 0.004$ and the chordwise placement x_p is ranging from $0.1c$ to $0.9c$. The obtained results for natural case, including lift coefficient and flow structure, agree well with the corresponding published experimental data. The present control cases indicate that actuator has a considerable influence on pitching/plunging airfoil. One example is placing the suction control at 40% chord length of the airfoil from the leading edge, which reduces the strength of secondary vortex, leading to an increase in the strength of the LEV and thus the lift coefficient. However, the control process and effects of the suction differ with the position of the actuator, which is significantly determined by the relative distance between the actuator and the secondary vortex. It is indicated that there is an optimal control strategy for certain case. Similarly, the synthetic jet placed at the upper surface could also influence LEV development and improve aerodynamic performance of a pitching/plunging airfoil, but the flow physics becomes more complex.

Key words: Flow control; pitching/plunging airfoil; leading edge vortex; lift enhancement

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