Large-Eddy Simulation of the flow over a Thin Airfoil at Low Reynolds Number

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Abstract The performance of airfoil NACA0002 at Reynolds number of 2.3×10^4 is investigated with large-eddy simulation(LES). The angle of attack is 3, 6, or 9 degree. The behavior of a larminar separation bubble which appeares over a thin airfoil and its effects on aerodynamic characteristics are mainly discussed.

1 Introduction

The experimental results by E. V. Laitone at Re = 2.07×10^4 show the possibility that the larger camber, smaller thickness, or sharper leading edge airfoil has, the better performance it has at low Re than ordinary airfoil.[1] However, the reason has not been clarified yet and it is assumed that a laminar separation bubble exists.

In this study, we focus on the flow characteristics of a thin airfoil, and discuss the behavior of a laminar-separation bubble resulting in its superior aerodynamic characteristics.

2 Numerical settings and methods

Mach number is 0.2 and Reynolds number is 2.3×10^4. NACA0002 is adopted as the representative of a thin and symmetric one, for simplifying the problem. Angle of attack(α) is 3, 6 or 9 degree.

Three-dimensional unsteady compressible Navier-Stokes equations are solved. The convection and viscous terms are evaluated by sixth-order compact scheme and tenth-order tridiagonal filter at $\alpha_{\mathrm{coef.}} = 0.495$, respectively. ADI-SGS is used for time integration, while three-time inner iterations maintain second-order in time.

The grid is C-type, and the number of grid points is approximately 12 million.

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3 Results

It is found in Fig.1 that the flow separates from the leading edge at each α including as low as 3 degrees due to the sharp leading edge of NACA0002 airfoil. The sharp leading edge keeps separation point the leading edge at all the α.

In the separated shear layer, two-dimensional vortices is shed and the flow transits to generate three-dimensional structured or complex vortices. Transition causes the separated flow to reattach at $\alpha = 3$ and 6 degrees and, as the result a laminar-separation bubble is formed as shown in Fig.2.

A recirculation zone is observed on the upper surface at each α in Fig.2, and the separated shear layer at $\alpha = 3$, 6 degree reattaches to upper surface to form a laminar-separation bubble. At $\alpha = 9$ degree, the leading edge stall occurs. Moreover, as α increases, the size of a laminar separation bubble increases. This bubble is classified into ”long bubble.”

From the corresponding airfoil part in Fig.2 and Fig.3 (a), it is noticeable that a laminar-separation bubble enhances the negative pressure. Despite the existence of a laminar separation bubble, the lift curve, shown in Fig.3 (b), is linear.

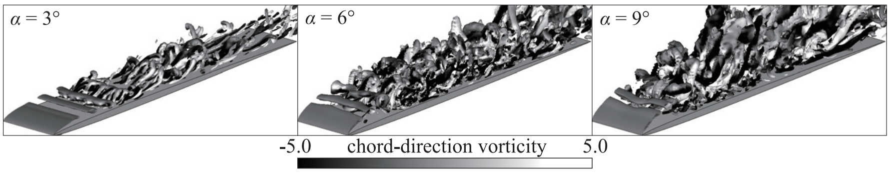


Fig. 1 Instantaneous vortical structure colored by chord-direction vorticity at each angle of attack

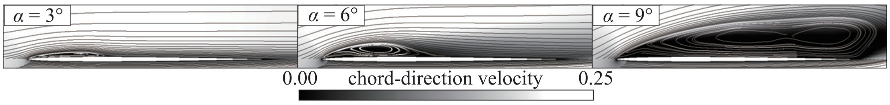
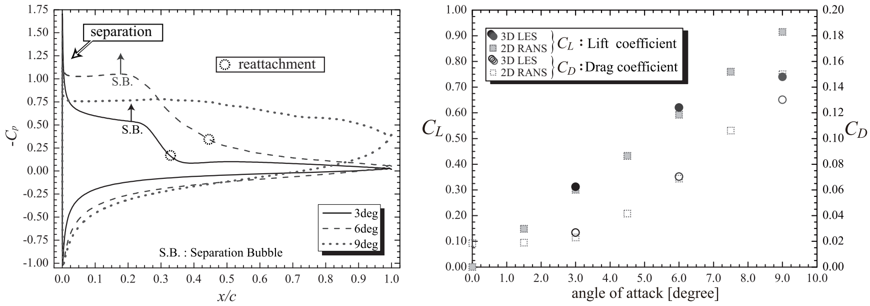


Fig. 2 Span and time averaged chord-direction velocity and stream lines at each angle of attack



(a) C_p distribution (b) $C_L, C_D - \alpha$ curves

Fig. 3 (a) C_p distribution and (b) $C_L, C_D - \alpha$ curves of span and time averaged flow

References

1. Laitone, E. V. : Aerodynamic Lift at Reynolds Numbers Below 7×10^4. Barkely, California(1996)