Sudden Nonlinear Increases in Lift for Folded Thin Airfoils at Low Reynolds Number

Atsuto Izumi*, Asuka Ichiyama*, Kyoji Inaoka*

To elucidate the aerodynamic characteristics of airfoils with discontinuous geometries, such as corrugated airfoils, at low Reynolds numbers, this study investigated the aerodynamic characteristics of folded thin airfoils, which represent the simplest forms of discontinuous geometries, with the folding position p set within the front parts. p was set in five ways, 7%c, 15%c, 23%c, 30%c, 40%c from the leading edge, based on the chord length c. The folding angle θ was varied from 10 ° to 40 ° by 10 ° increments. In addition, the flat plate with θ of 0 ° was also investigated. For each of the total of 21 airfoils, 41 angles of attack (AOA) were prepared in 1 ° increments. Experiments were conducted with Reynolds number set to 3.0×10^4, measuring lift and drag forces and visualizing the flow around the upper surface of airfoils using smoke-wire technique.

Figure 1 shows aerodynamic characteristics for the flat plate and airfoils with $p = 7$ %c - 40 %c and $\theta = 30$ °. For the flat plate, as the AOA was increased, the lift coefficient C_L reached its peak at the AOA of about 15 °, after which C_L gradually decreased. In contrast, the maximum lift coefficient $C_{L\,max}$ of folded thin airfoils increased as the folding angle θ increased, exceeding that of the flat plate under most airfoil geometries. Notably, for airfoils with $p = 15$ %c - 40 %c, sudden nonlinear increases in lift were observed under conditions of large θ, and the AOA at which they occur depends on θ. Furthermore, under certain conditions, as the AOA increases, the lift slope was found to decrease to approximately 0, followed by a sharp nonlinear rise in lift. Due to these increases, the AOA at which $C_{L\,max}$ occurs was delayed by up to 30 ° depending on the folding angle θ. Figure 2 visualizes the flow around the upper surface of the airfoil with $p = 23$ %c and $\theta = 30$ ° at the AOA of 14 °, a condition where the sudden increase in lift occurs as shown in Figure 1. At the slightly smaller AOA of 12 °, the flow separated at the folding apex and intermittently reattached near the trailing edge, failing to continuously form a separation bubble. At the AOA of 14 °, in contrast, the flow separated at the folding apex and steadily reattached near the central rear part of the airfoil and continuously formed a separation bubble as shown in Figure 2. The nonlinear increase in lift was also observed in the study by Hidaka et al.[1] They considered that the increase occurs when the separation bubble at the leading edge of the airfoil forms beyond the folding apex. In the present experiment, the AOA at which sudden nonlinear increases in lift occurred was dependent on θ. Therefore, the primary cause of these increases is considered to be the shift in the reattachment position of the wake behind the folding apex from the trailing edge to the central rear part of the airfoil, which results in the continuous formation of a separation bubble.

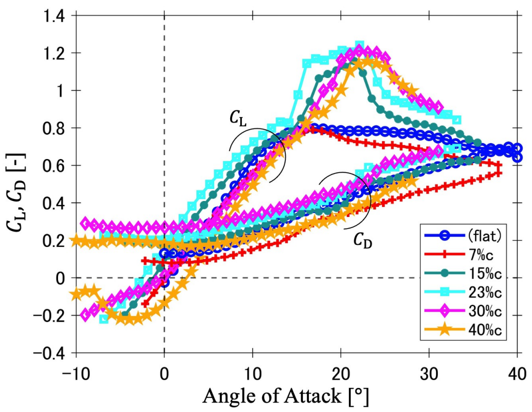

Figure 1: Aerodynamic characteristics for flat plate and folded thin airfoils with $\theta = 30$ °.

Figure 2: The flow around the upper surface of the airfoil with $p = 23$ %c and $\theta = 30$ ° at the AOA of 14 ° showing sudden nonlinear increase in lift.

*Doshisha University, Kyotanabe, Kyoto 610-0394, Japan

[1]Hidaka et al., *Trans. JSASS Aerospace Tech. Japan* **Vol.12, No.ists29**, pp.Pk_21-Pk_27 (2014)