Experimental investigation on unsteady aerodynamic behaviors of a variable camber airfoil

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Summary An experimental investigation is carried out to study the unsteady aerodynamic behaviors of a variable camber airfoil. The forece measurements and related flow visualization depict that there are two types of unsteady flow phenomena: the hysteresis in the flow and the unsteady flow separation. The unsteady characteristics become more and more obvious as the increase of the frequency of camber deformation. A Hysteresis loop in the aerodynamic coefficients comes up when the frequency of camber deformation increase to some extent. However, under the circumstance of low-frequency oscillation, the unsteady trailing-edge separation will cause the random fluctuations of lift coefficient curve.

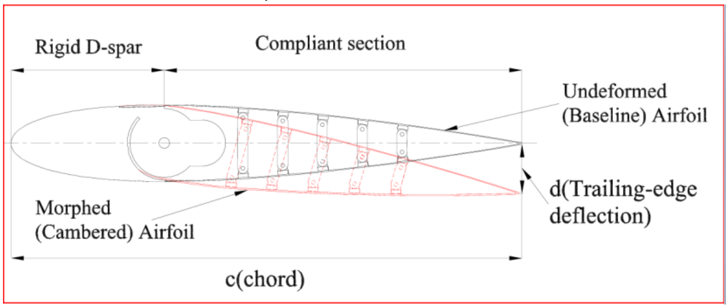
Introduction

Aircraft morphing, especially variable camber airfoil has the potential value both from the viewpoints of fundamental aerodynamics and flight application. In aerodynamics, a variable camber airfoil can improve aircraft flight performance and allow efficient multiple missions[1]; in biology, it can help us understand the mystery of animals' flight. Under the circumstance of low-speed aircraft, the performance of low Reynolds-number airfoils is greatly determined by the relatively feeble separation resistance of the laminar boundary layer. Better understanding and effective control of laminar separation is therefore valuable for improving the flight mechanics of low Reynolds-number aircraft such as Micro Air Vehicles (MAVs) [2]. Recent researches show that variable camber airfoil has obvious advantages in control of separation[3] and flight maneuverability[4]. Besides, compliant deformation of airfoil can also help us understand the nature of the aerodynamic characteristics of the membrane wing such as bats.[5]
In this study, the unsteady aerodynamic behaviors of a variable camber airfoil are investigated experimentally. We firstly designed a kind of variable camber airfoil test model whose camber can be changed smoothly. Aerodynamic load measurements and flow visualization technique such as PIV are combined to reveal the aerodynamic characteristics caused by the camber deformation and corresponding flow structures, from which the complex mechanism is hopefully to be figured out.

Airfoil model and experimental setup

Variable camber airfoil

We designed a kind of variable camber airfoil which can change its camber from zero to desired extent smoothly. A rigid D-spar, the primary load carrying member, extends from the leading edge of the airfoil to 30 percent chord (Fig.1 (Left)). The D-spar does not undergo any deformation in the chordwise direction, and consequently, only the section aft of the D-spar can deform. This section aft of the spar is specially designed to have an internal substructure as shown in Fig.1 (Right). The substructure comprises five rows of hinge-like units ranked serially along chordwise direction. The design of the substructure is to support the flexible skin which provides the aerodynamic shape and is capable of morphing[6]. A servomotor was fixed in the D-spar to offer power to pull the lower surface of aft section into D-spar to a certain extent with the help of a gearing. As a part of lower surface is pulled into D-spar, the discrepancy on the areas between the upper surface and lower surface comes up and then the airfoil becomes asymmetric, in other word, has some camber. The airfoil camber produced due to the actuation loading can be quantified in different ways including vertical tip deflection or equivalent flap angle. In this paper the former is used, so we use the deflection ratio $d^* = d/c$ to define camber, where c is the airfoil chord and d is the trailing-edge deflection as showed in Fig1 (Left).



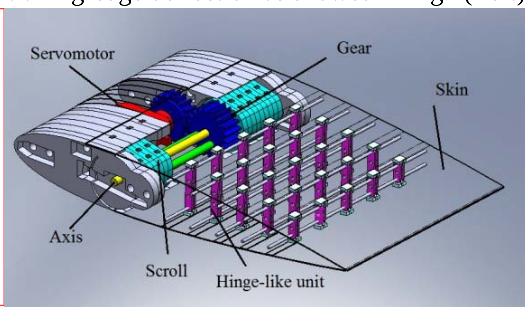


Fig. 1. Construction of variable camber airfoil: (Left) basic design; (Right) internal structure.

Experimental setup

The aerodynamic load measurements, obtained via a five-component force balance, were carried out in a low-speed wind tunnel at University of Science and Technology of China. The variable camber airfoil, with a chord of 200 mm and a span of 116 mm was used as the test model. The Reynolds number was fixed at 1.1×10^5 so the wind velocity was 8.0 m/s and measured with a hot-wire anemometry. We use PIV technique to measure the flow field around the airfoil. To better reveal the effect of camber on flow separation, we set the initial angle of attack (AOA) at the maximum lift AOA = 16.5° .

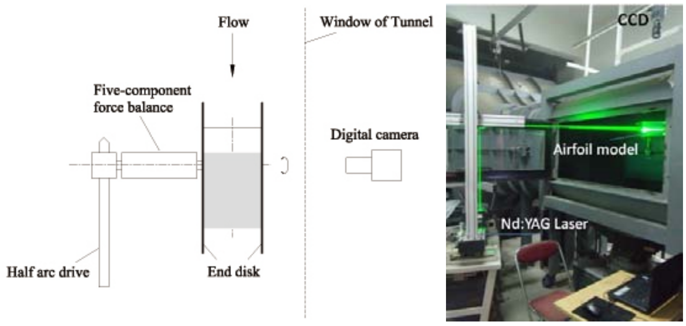


Fig. 2. Sketch of the experimental setup: (Left) aerodynamic load measurements; (Right) PIV set-up at test section.

Unsteady aerodynamic behaviors

The variations of the camber with time were set to be either trigonometric function or triangular wave function during the present experiments. As shown in the following left picture, the variation of deflection ratio d^* versus time upon our airfoil is quite close to fitted triangle function curve and we use such type of motion path to study the unsteady aerodynamic characteristics caused by camber deformation. In the following right picture, from the curve of C_l upon static camber, we can find that the airfoil undergoes a drastic stall around $d^* = 0.05$ (see the "Cl_static" line in the picture of Fig. 3). However, the curve upon quasi-steady camber deformation doesn't show drastic drop and no significant hysteresis loop was found. For the lift coefficient curves of unsteady camber deformation, the unsteady motions restrain the trailing-edge stall and all of these curves don't show abrupt drop. The unsteady characteristics become more and more obvious as the S_t number ($S_t = fA/U$, f camber deformation frequency, A oscillation amplitude, U freestream velocity) increases: when S_t is around 0.000325 the lift coefficient curves are similar to those of quasi-steady; when S_t is increased to 0.0065, a distinct hysteresis loop comes up. According to the result of PIV (omitted in this short paper), fast camber deformation can give the flow little chance to rehabilitate itself so there is a significant hysteresis between upstroke and downstroke. When the camber deformation frequency decreases to some extent, the lift coefficient curve will show random fluctuations caused by the unsteady trailing-edge separation.

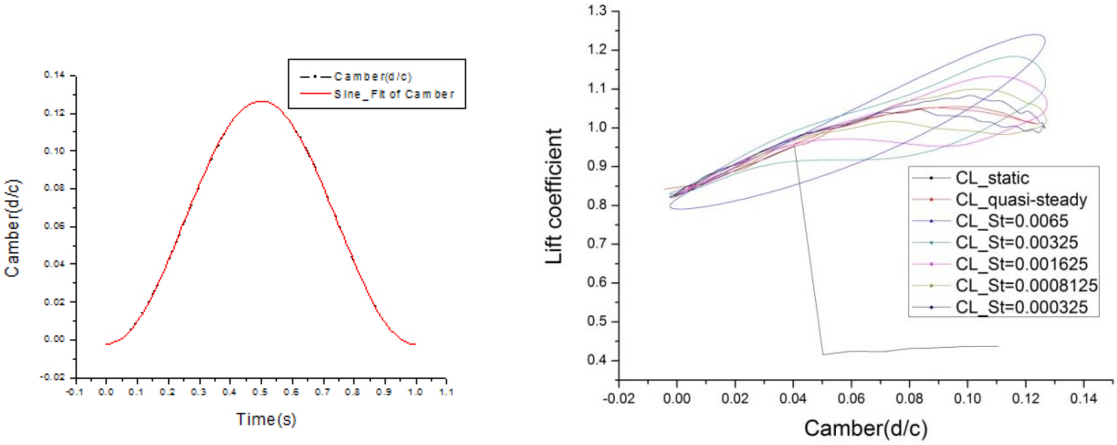


Fig. 3. (Left) Triangle function curve of camber deformation; (Right)Life coefficients vs Deflection ratio.

References

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