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Parameters effect of pulsed-blowing over control surface

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ABSTRACT

Control surface, which is often located in the trailing edge of wings, is important in the attitude control of an aircraft. However, the efficiency of the control surface declines severely under the high deflect angle of the control surface because of the flow separation. To improve the efficiency of control surface, this study discusses a novel flow control technique aimed at suppressing the flow separation by pulsed blowing at the leading edge of the control surface. Results indicated that flow separation over the control surface can be suppressed by pulsed blowing, and the maximum average pitching moment coefficient of the control surface can be increased by nearly 90% when average blowing momentum coefficient is 0.03 relative to that of without blowing. Moreover, the lift coefficient of the control surface can be 95% times higher than that of without blowing, and the drag coefficient of the control surface can be reduced by 43% compared with that of without blowing. Finally, this study shows that the average blowing momentum coefficient and non-dimensional frequency of pulsed blowing are two of the key parameters of the pulsed blowing control technique. Both experimental and numerical simulations are used in this study. The experiment is completed in D-4 wind tunnel of Beihang University under conditions of Re 0.8×10^6.

1. Introduction

Control surface, which is often located in the trailing edge of wings, is important in the attitude control of an aircraft. However, the efficiency of the control surface declines severely under the high deflect angle of the control surface because of the flow separation (see Fig. 1). This condition leads to the penalty of attitude control and limited aerodynamic performance of an aircraft. Therefore, suppressing the flow separation is considered in this study.

Flow control [1] is the most available approach to achieve the goal of suppressing flow separation. In the past decades, scientists have exerted considerable effort to develop flow control techniques. Moreover, various flow control techniques have been used to suppress flow separation such as moving surface control technique [2–4], plasma flow control technique [5–8] and co-flow jet control technique [9–12]. Although flow separation on the control surface can be suppressed substantially by moving surface control technique or plasma flow control technique, the application of these techniques in engineering is limited because of complicated devices. For the co-flow jet control technique, a large amount of gas is necessary to suppress the flow separation. Thus, a powerful device is required to supply a high mass flow rate of jet. Recently, Wang et al. [13] developed a micro-blowing flow control technique to suppress the flow separation and improve the aerodynamic efficiency of the control surface.

Wang et al. set a blowing airfoil (see Fig. 2) based on NACA0025 to demonstrate the micro-blowing flow control technique. A blowing slot that is normal to the boundary of flap was set near the leading edge of the flap. A high energy jet parallel to the upper surface of flap is injected to the main flow. The study shows that the flow separation can be suppressed by blowing at the leading edge of the flap. Moreover, the study shows that the maximum increment of lift coefficient of the flap can be 150%, while AOA (angle of attack) of the main wing is 0°, the deflection angle of flap is 20° and the Reynolds number is 0.8×10^6. Wang et al. considered pulsed blowing to reduce the considerable gas requirement. Even though several researchers have also made improvements in development of the pulse jet technique to control the flow separation over the control surface [14,15], such technique is considerably more difficult to adopt in engineering because of lack of profound understanding of the fundamental mechanism and parameter similarity.

This study introduces an innovative flow control technique by pulsed blowing near the leading edge of the control surface to suppress the flow separation over the control surface that is located on the tailing edge of an airfoil. First, the effect of continuous

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Nomenclature

C_μ	average blowing momentum coefficient	
$C_{\mu t}$	instant blowing momentum coefficient	
V_∞	velocity of the freestream	m/s
Re	Reynolds number based on chord length of model	
c_0	chord length of the model	m
m_j	mass flow rate of blowing	kg/s
V_j	jet velocity from the blowing slot	m/s
S_e	reference area of the control surface	m^2
S_j	area of the blowing slot	m^2
f	frequency of pulsed blowing	Hz
Str	non-dimensional frequency of pulsed blowing	
h_j	width of the blowing slot	mm
C_p	pressure coefficient	
C_{L-p}	average lift coefficient of the flap generated by pressure	
C_{m-p}	average pitching moment coefficient of the flap generated by pressure	
C_{D-p}	average drag coefficient of the flap generated by pressure	
C_L	total average lift coefficient of the flap	
C_m	total average pitching moment coefficient of the flap	
C_D	total average drag coefficient of the flap	
C_{Lt}	instant lift coefficient of flap	
c	chord length of flap	m
ρ_∞	density of free stream	kg/m^3
α	attack angle of main wing	°
δ_e	deflect angle of flap	°
δ_j	angle between blowing jet and freestream	rad
y'	the vertical distance from the surface of flap	m

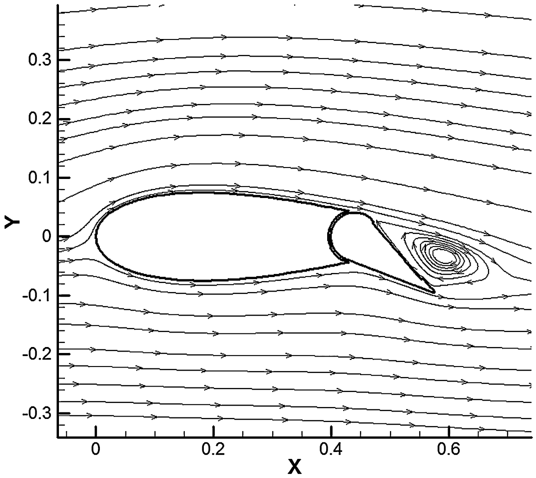

Fig. 1. Flow separation over the control surface ($\alpha = 0°$, $V_\infty = 20$ m/s, $\delta_e = 35°$).

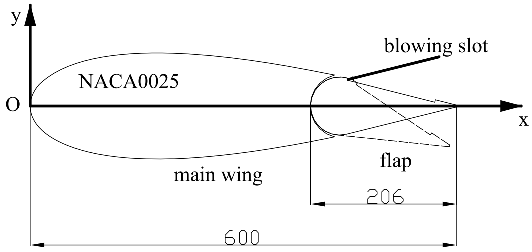

Fig. 2. Sketch of the blowing slot.

blowing on the suppression of the flow separation over the flap is mentioned briefly. Thereafter, the effect of pulsed blowing on the aerodynamic performance of the flap is investigated thoroughly. Furthermore, the mechanism of lift enhancement by pulsed blowing is discussed. All the results of this study are completed based on the following conditions: the AOA of the main wing is 0° and the deflect angle of the flap is 20°.

2. Experimental facilities and data processing

2.1. Wind tunnel and measurement device

The experiment is conducted in the D-4 low-speed wind tunnel of Beihang University (see Fig. 3), which has a 1.5 m × 1.5 m square test section and 2.5 m length. The velocity of the D-4 low-speed wind tunnel can be changed from 0 to 80 m/s with a turbulence level of 0.08%.

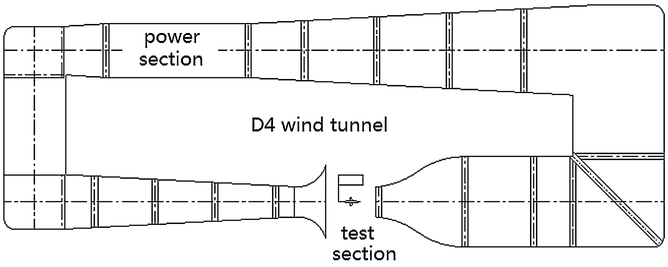

Fig. 3. Sketch of the D4 wind tunnel.

The DTC initium electronic scanner valve (see Fig. 4) is used to measure the pressure distribution of the model with an accuracy of 0.05% and the highest sampling frequency is 650 Hz.

A flow map DPIV system is used to acquire the velocity and vorticity fields over the flap. This system comprises four parts: a double-pulsed Nd:YAG laser, a four-megapixel CCD camera, a synchronization, and frame-grabber cards. The adaptive correlation, which uses iterations to offset the second window for cross-correlation analysis, is applied to calculate the velocity fields. The correlations are calculated using fast Fourier transform (FFT). The size of the interrogation windows is 32 × 32 pixels, and the overlapping interrogation windows in both directions are 25%. The corresponding spatial resolution is 3.1 mm. To reduce cyclic noise, the window function, which acts similar to an input filter to FFT, is selected as a Gaussian window. The filter used in the frequency domain prior to the inverse FFT is a low-pass Gaussian filter. The vorticity is solved using a normal second-order central difference, and the streamlines are parallel to the velocity vectors.

2.2. Model and blowing system

The airfoil model used in this study is based on NACA0025 (see Fig. 5). The model has 1 aspect ratio and 0.6 m the spanwise length. This model can be divided into two parts: the main wing and a control surface (flap) that is as long as 0.206 m. The flap can be deflected from −40° to 40° with a 5° interval. A spanwise blowing slot with a 0.5 mm height is located near the leading edge of the flap which is selected based on the flow separation point on the upper surface of the flap. Compressed air flows downstream along the tangential direction of the upper surface of the flap from the slot. The proposed model is equipped with 44 pressure taps at the longitudinal symmetric section along the upper and bottom