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EXPERIMENTAL RESEARCH ON UNSTEADY VORTEX SEPARATION AND CONTROL ABOUT A DELTA-WING-BODY COMBINATION

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ABSTRACT

In this paper the experimental results and analysis concerned with unsteady aerodynamic characteristics and vortex flow over a delta-wing-body combination at high angle of attack are presented. The experiment was conducted in CARDC Φ3.2m subsonic wind tunnel. By the application of PIV the flow field structure above wing was obtained. The unsteady aerodynamic characteristics of delta-wing-body combination undergoing large amplitude pitching and rolling oscillation were obtained respectively. In addition, application of spanwise blowing(SWB) over wing to control vortex separation was also investigated. PIV technique was applied to investigate the flow mechanism of unsteady aerodynamics and spanwise blowing flow control.

Keywords: wind tunnel test; PIV; high angle of attack; unsteady aerodynamics; spanwise blowing

INTRODUCTION

Recently, the designers of advanced fighter plane have exhibited an unprecedented level of interest in maneuverability, supersonic cruise, short take-off and landing performances, especially in super-maneuverability or post-stall maneuverability, which demands significant improvements in aerodynamic characteristics at high angles of attack. The high performance aircraft is expected to operate routinely at angles of attack under the condition vortex breakdown over the wings and fuselage is known to occur. In association with this, usually asymmetry in flow separation over the forebody and induction of yawing moment appear. Breakdown of the vortices over wings can cause a pitching up problem which, in extreme case, can lead to deep stall, and also tend to occur asymmetrically over wings to induce rolling moment. Because of this, many attempts have been made to control the evolvement and breakdown of vortex.

Considering the effects of spanwise blowing in delaying and alleviating the leading edge vortex breakdown and flow separation over wing at high angle of attack, we can assume that applying spanwise blowing on the wing could improve the hysteresis of aerodynamic characteristics. In order to increase the

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understanding of the flow physics of unsteady vortex, PIV technology is utilized to measured the vortex flows and the effects of spanwise blowing on vortex characteristics while aircraft model undergoing large amplitude oscillation.

APPARATUS AND EXPERIMENTAL TECHNIQUE

1.1 Wind tunnel and test model

The unsteady aerodynamic characteristics and flow field structure was investigated in Φ3.2m subsonic wind tunnel at CARDC. It is a single return-flow wind tunnel and has an open jet test section. The maximum velocity is 115m/s in the testing section.

The model is a delta-wing-body combination. The wing has a 60° sweep with sharp beveled leading and trailing edge at only the lower surface. The spanwise blowing nozzles were located at the wing-body joint, over the wing, parallel to the leading edge of the wing(fig.1).

1.2 Apparatus

The sketch in fig.1 shows the oscillation system which consists of a worm gear retarder. By changing the cam with different contour different amplitude and motion law of model can be obtained. The maximum amplitude is 50°. A photoelectric encoder mounted on the cam shaft provides the instantaneous angle of attack and triggers the data acquisition system to acquire the test data.

The system was designed as a crossed parallel ram with an eccentricity to obtain sinusoidal oscillation with amplitudes of 10°,15°,20°and50°. The various oscillation frequencies of 0～2Hz can be obtained by the motor control.

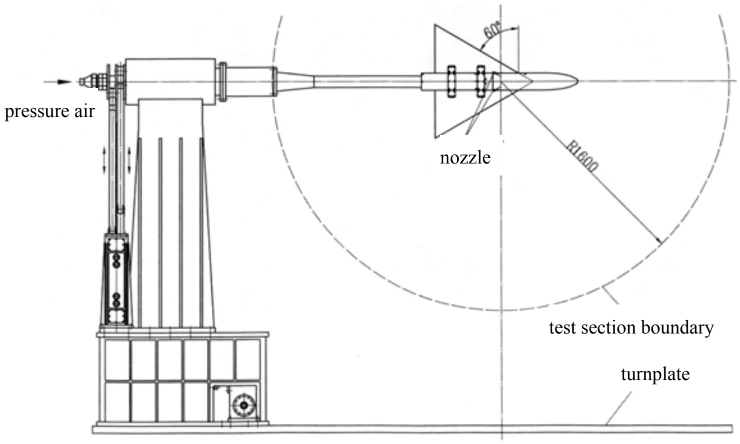

Fig.1. High amplitude oscillation apparatus

The PIV system consists of CCD camera, laser sheet generator, seeding system and data acquisition system. The pulsed laser light sheet is created by a high power dual oscillator Nd-YAG laser with pulse energy of 120mJ. Particle seeding is the main technical barrier for non-invasion measurement technology. The particle is generated by smoke generator some distance away from model. A high particle seeding rate is required so that enough particles can reach vortex core. Particles should be small enough to follow well with flow. Both conditions were met with the seeding system used. One meter diameter smoke area was introduced in the flow in the wind tunnel settling chamber by a large size multi nozzle injector.

1.3 Data Acquisition and Reduction

The vortex structure image at different longitudinal section over the wing is taken by CCD camera during pitching oscillation. Dynamic force data presented in this paper are digital filtered and averaged over several cycles. Only part of test results are given here and no corrections are applied.

2 RESULTS AND DISCUSSION

2.1 Dynamic force results

Fig.2 presents the effect of SWB on hysteresis loop of lift and pitch moment characteristics with different jet momentum coefficient during pitching motion. It can be seen that at small angle of attack the effect of SWB is weak. At high angle of attack, the area of lift coefficient loop reduces significantly while SWB on, and the stall angle and maximum lift coefficient increase. With the increasing of jet momentum coefficient, the area of lift coefficient loop reduces. The effect of SWB on pitch moment is similar to that on lift.

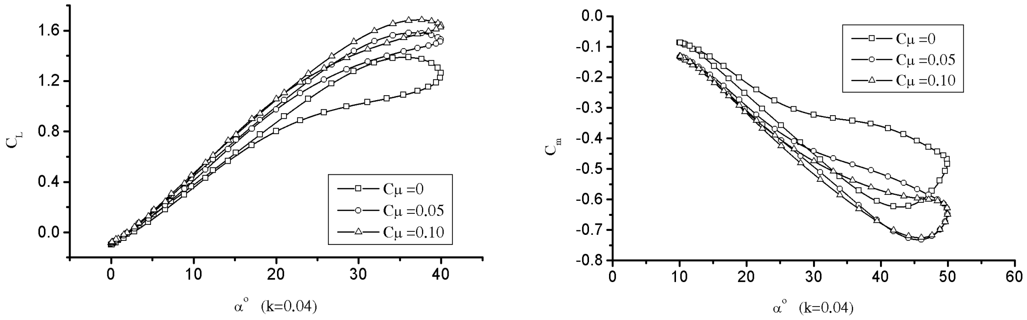

Fig.2. Effect of SWB on lift and pitching moment

2.2 The effect of SWB on flow characteristics in pitching oscillation motion

Fig.3 presents the distribution of streamline and velocity vector over the trailing edge while model pitching up to 35°. The structure of the vortex core is very clear. It indicates the particle seeding is appropriate. Fig.4 presents the distribution of streamline and velocity vector over the trailing edge while model pitching down to 35°. Comparing with fig.3, it can be seen that the distance from wing surface and spanwise location of the vortex core is different during pitching up and down motion. The vortex core is 15mm lower during pitching up than pitching down.

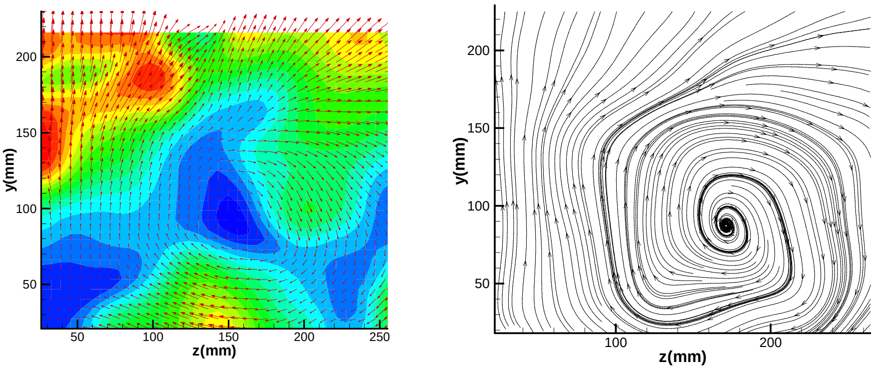

Fig.3. Streamline and velocity vector over the trailing edge while pitching up to 35°

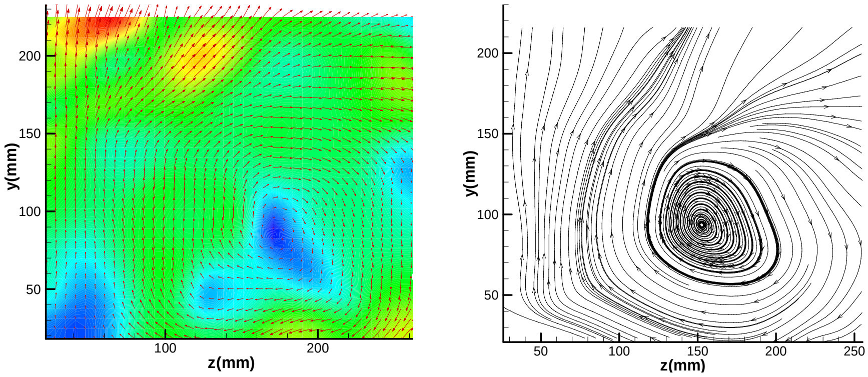

Fig.4. Streamline and velocity vector over the trailing edge while pitching down to 35°

Fig.5 presents the distribution of streamline and velocity vector over the trailing edge while pitching up to 35° with SWB on. Comparing it with fig.3, we can see that the height of the vortex core decreases about 10mm. In fig.6 the height of the core decreases about 35mm. With SWB on, the location of vortex core is closer during pitching up and down motion. It is consistent with the decrease of lift hysteresis loop area.

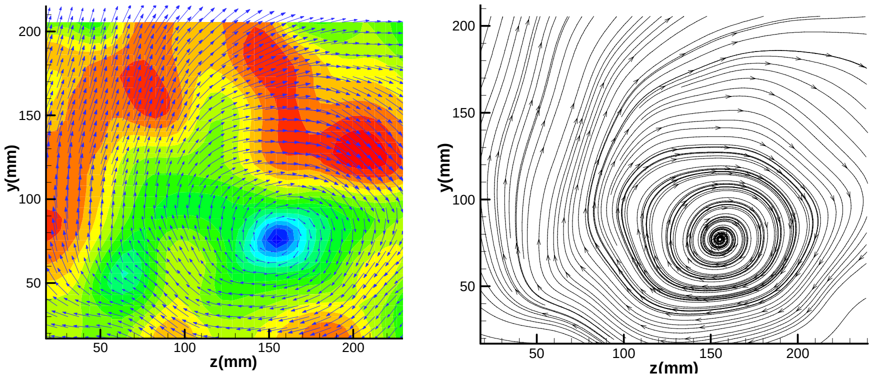

Fig.5. Streamline and velocity vector over the trailing edge while pitching up to 35° with spanwise blowing

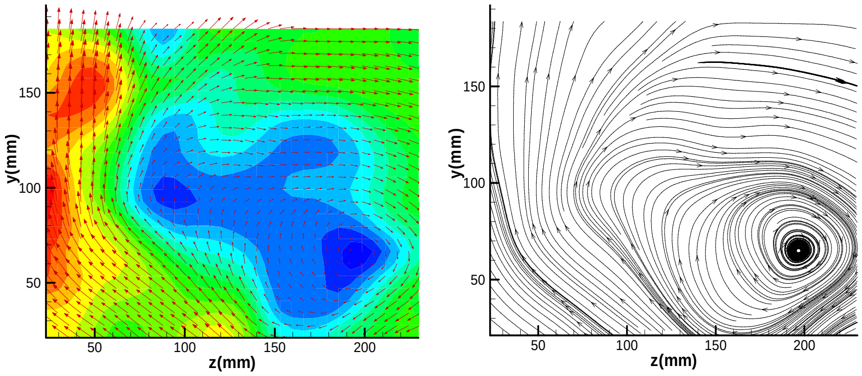

Fig.6. Streamline and velocity vector over the trailing edge while pitching down to 35° with spanwise blowing

2.3 Effect of SWB on transverse aerodynamic characteristics

Fig.7 shows the effect of SWB on rolling moment and yawing moment characteristics in rolling oscillation. Generally, at low angle of attack($\alpha<10^{\circ}$), the effect of SWB on transverse aerodynamic characteristics is very weak because the flow is attached. When the angle of attack increases to more than 20°, the maximum rolling moment coefficient reduces significantly either in pitching up or down motion with SWB on. The slope of curve and the area of the hysteresis loop decreases greatly. This situation is more significant with the increase of blowing momentum coefficient within the range tested here. The rolling aerodynamic characteristics changes from unstable to stable. The asymmetry of the flow over the right wing and the left wing during the rolling oscillation of the delta-wing-body combination can be improved by application of SWB.

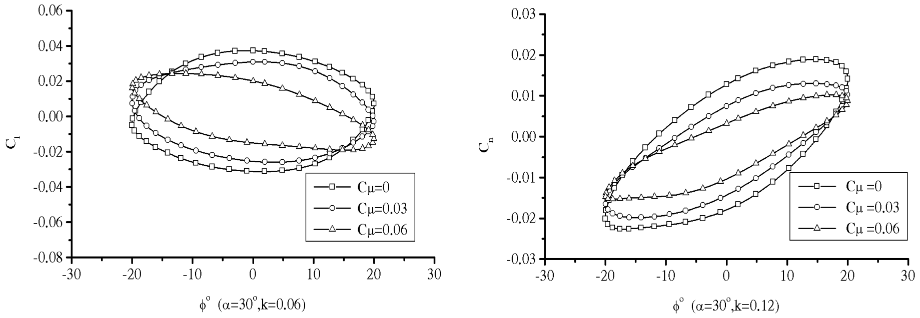

Fig.7. Effect of SWB on transverse aerodynamic characteristics in rolling oscillation

SUMMARY AND CONCLUSIONS

From upper analysis, we can draw following conclusions,

1. SWB can improve longitudinal aerodynamic characteristics significantly during delta wing model's dynamic pitching motion. It can make the aerodynamic coefficient increase greatly during the pitching up and down motion, delay wing stall and reduce area of hysteresis loop significantly.
2. The effect of SWB on transverse dynamic aerodynamic characteristics in rolling oscillation is distinct. At most angles of attack, blowing make the maximum aerodynamic coefficient decrease greatly, the area of hysteresis loop reduces significantly and the transverse stability increases.

3. The effect of SWB is more significant with the increase of momentum coefficients of blowing.

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