ACTIVE CONTROL EXPERIMENTAL INVESTIGATION ABOUT AERODYNAMIC CHARACTERISTICS AT HIGH INCIDENCE

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Abstract

In this paper, three experimental schemes of active control for asymmetric force, controllable rotating nose-tip, controllable blowing jet at nose and controllable strake, in a low speed wind tunnel are discussed. The investigated models are 60mm diameter cylinder with a tangent ogive nose, 60mm diameter cylinder with a cone and an aircraft model with strakes respectively. The active control devices are designed. The control laws are investigated.

The experimental results show that the asymmetric forces at high angle of attack are reduced significantly for all experimental schemes. The developed active control programs can automatically limit the side force on the models to its minimum magnitude. The schemes of controllable blowing jet and controllable strake can be adopted to enhanced the lateral maneuverability.

\[ \begin{align*}
C_\alpha & \quad \text{Angle of attack (deg)} \\
\theta & \quad \text{Deflection of strake (deg)} \\
C_t & \quad \text{Blowing jet coefficient} \\
S_f & \quad \text{Reference area (cross section area of cylinder or wing area)} \\
C_b & \quad \text{Freestream dynamic pressure} \\
b & \quad \text{Reference length (diameter of cylinder or average aerodynamic chord of wing)}
\end{align*} \]

Subscript

L Left \\
R Right

Introduction

In high incidence flight, asymmetrical aircraft and missile may be subjected to asymmetric forces because of vortex wake asymmetry. The asymmetric vortex on the wake can bring about serious control problems for aircraft and missile flying at high incidence due to their large magnitudes coupled with sudden change in direction. In this field, the aerodynamicist have done a great deal of research work[1--8]. To alleviate the asymmetric forces various methods, such as roughness strips, fixed strakes and change nose shape etc., are presented. These methods raise the onset angle and alleviate the asymmetric forces but their efficiency is only at the certain range of incidence.

It is well know that the active control technology is a good way to control the asymmetric force at high incidence. Some concept of active control for asymmetric force, such as hinged strake, spinning nose devices and active blowing jet etc [9--13], have

Nomenclature

\[ \begin{align*}
C_L & \quad \text{Lift coefficient}=\text{Lift}/qs \\
C_y & \quad \text{Side force coefficient}=\text{Side force}/qs \\
C_m & \quad \text{Yawing moment coefficient}=\text{Yawing moment}/qs \text{b} \\
C_r & \quad \text{Rolling moment coefficient}=\text{Rolling moment}/qs \text{b} \\
C_x & \quad \text{Resistance coefficient}=\text{Resistance}/qs
\end{align*} \]

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been presented.

In this paper, three experimental schemes of active control for asymmetric force in a low speed wind tunnel are discussed. The active control devices are designed. The control laws are investigated.

The experimental results show that the asymmetric forces at high incidence are reduced significantly for investigated schemes. The developed active control program can automatically limit the side force on the model to its minimum magnitude. The schemes of controllable blowing jet and controllable strake can be adopted to enhanced the lateral maneuverability.

Model and Equipments

The experimental investigations for active control of asymmetric side forces at high incidence were carried out in a 1.5 m open jet single circuit low speed wind tunnel at N.P.U.

In the investigated scheme of controllable rotating nose-tip, the model investigated, shown in Fig. 1a, is a 60 mm diameter cylinder with tangent ogive nose. The slenderness ratio of the nose is 3.5. The total length of the model is 510 mm. There is a rotating part at the tip of the model. The length of the rotating part is 60 mm. The rotating nose tip is driven by a variable speed D.C. motor mounted in the model.

In the investigated scheme of controllable blowing jet, the model investigated, shown in Fig. 1b, is a 60 mm diameter with a cone. The slenderness ratio of the nose is 3.5. The total length of the model is 530 mm. There are several blowing holes at the nose. The diameter of the hole is 1 mm. The blowing jet holes are connected to a high pressure air tank by plastic hose. The blowing jet rate is controlled by a flow-regulation valve, which is driven by a servo-motor.

In the investigated schemes of controllable strakes, an aircraft model, shown in Fig. 1c, is investigated. The fuselage of the model is a 80 mm diameter cylinder with a tangent ogive nose (slenderness ratio = 3.5). The wing of the model is a planar wing with sharp edge. The aspect ratio of the wing is 2.2 and the sweepback angle at leading edge is 50°. The sweepback of the strake is 75°. The strake can rotate around the axis which is perpendicular to the fuselage axis. The deflection of the left and right strake are driven by two servo-motor mounted in the fuselage respectively.

The experimental speed of the wind tunnel is about 30 m/s. The Reynolds number base on freestream velocity and diameter of the model or the average aerodynamic chord of the wing is about $1.5 \times 10^5$ or $6 \times 10^5$. The model were sting-supported at their base.

The aerodynamic forces were measured by six-component mechanical-strain gauge balance. The vorticity distribution in the wake was measured by a photo-electric digital vorticity meter consisting of two major parts: a vane, shown in Fig. 2, and a digital frequency meter.

![Figure 1. Sketch of the models](image-url)
Active Control Device

The microcomputer is a main component of the active control device. The side forces (side force, yawing moment or rolling moment) elements of the balance were used as a side force sensor. The angle of attack sensor was connected to the angle-of-attack mechanism of the wind tunnel. The signals from these sensors were transformed to digital quantities by analog-to-digital converters and conveyed to the microcomputer. The digital output of the microcomputer was then reconverted to an analog signal to control the servo-motor. The control parameters (such as the rotating rate of the nose tip etc.) are adjusted properly and the asymmetric forces on the model can be reduced to minimum value (or increase to maximum value).

Two active control programs are adopted:
1. Function feedback control (F.F.C)
2. Adaptive control (A.C)

Their principles are briefly discussed as follows:
1. Function feedback control
The control parameter corresponding to minimum side force are measured beforehand at various angle of attack and the results are store in the microcomputer. When the signal of the angle of attack sensor is fed into microcomputer, it will send a previous specified signal to the servo-motor. Thus, the control parameter can be maintained the appropriate value, producing the minimum side force at each angle of attack. The block diagram of function feedback control is shown in Fig. 3a.

2. Adaptive control
When the control parameter varies continuously in their working range, both the side force on the model and the state of the servo-motor are recorded by the microcomputer. Thus, the state of the servo-motor corresponding to the minimum side force found by microcomputer automatically. Thus, the state of the servo-motor is kept invariant and the minimum side force is obtained on the model. When angle of attack is changed, the process is repeated. Hence the minimum force on the model at each angle of the attack be obtained automatically.

The block diagrams of the active control device is shown in Fig. 3b.

\[ \text{Fig. 3. Block diagram} \]
\[ \begin{align*}
(\text{a}) \text{ function feedback control} \\
(\text{b}) \text{ adaptive control}
\end{align*} \]

Results and Conclusions

To obtain the control law for active control of asymmetric forces at high incidence by wind tunnel test, the side forces were measured at each incidence various nose tip rotating speed, blowing jet rate and deflection of strake respectively. The results are shown in Fig. 4, 5 and 6. From these data the relation between the control parameter corresponding to minimum side force and angle of attack, i.e. the control law, can be found as shown in Fig. 7-9. The results show that the side forces can be reduced significantly for all investigated active control schemes, shown in Fig. 10-16. The vorti-
city field on the lee side of the model are measured for schemes of the rotating nose-tip and blowing jet. The results are shown in Fig. 17 and 18. It can be seen that the asymmetry of the wake vortex distribution are decreased significantly.

In same principle, when the control parameters corresponding to maximum side forces at various angle of attack and the results are stored in the microcomputer, the maximum side force on the model can be obtained and the lateral maneuverability can be enhanced. The experimental results are shown in Fig. 19 and 20. The results are very interesting, because the efficiency of the traditional control surface, such as aileron, is very low at high angle of attack.

The influence of the rotating nose tip and blowing jet to longitudinal characteristics is insensitive and the influence of the controlable strake is significant shown in Fig. 21, 22, 23 and 24. Based on above data, some conclusions can be obtained:
1. The asymmetric side forces can be reduced significantly for all investigated active control schemes.
2. The active control programs developed can be automatically limit the asymmetric side force on the model to their minimum magnitude.
3. The lateral maneuverability can be enhanced by controlable blowing jet and controlable strake schemes.
4. The influence of the rotating nose tip and blowing jet to longitudinal characteristics is insensitive and the influence of the strake is significant.

![Fig. 4. Side force coefficient for different rotating rates](image)

![Fig. 5. Side force coefficient for different blowing jet rates](image)

![Fig. 6. Side force coefficient for different deflection of strake](image)

![Fig. 7. Rotating rate corresponding to minimum side force](image)
Fig. 8. Blowing jet rate corresponding to minimum side force

Fig. 9. Deflection of the strake corresponding to minimum side force

Fig. 10. Side force coefficient with and without control (in scheme of the rotating nose)

Fig. 11. Yawing moment coefficient with and without control (in scheme of the rotating nose)

Fig. 12. Side force coefficient with and without control (in scheme of blowing jet)

Fig. 13. Yawing moment coefficient with and without control (in scheme of blowing jet)
Fig. 14. Side force coefficient with and without control (in scheme of controllable strake)

Fig. 15. Yawing moment coefficient with and without control (in scheme of controllable strake)

Fig. 16. Rolling moment coefficient with and without control (in scheme of controllable strake)

Fig. 17. Wake vortices distribution $x=2.8$, $\chi=59.2^\circ$ (a) $n=0$ (b) $n=62$

Fig. 18. Wake vortices distribution $x=1.5$, $\chi=35.1^\circ$ (a) $C_j=0$ (b) $C_j=0.0424$

Fig. 19. Blowing jet rate corresponding to maximum side ($C_j<0.1$)
Fig. 20. Deflection of the strake corresponding to maximum side ($\delta \leq 20^\circ$)

Fig. 21. The influence of the rotating nose to lift coefficient

Fig. 22. The influence of the blowing jet to lift coefficient

Fig. 23. The influence of the blowing jet to resistance coefficient

Fig. 24. The influence of the deflection of strake to lift coefficient

Reference
