Wing Rock Induced by Forebody Asymmetric Vortices in Coning Motion and its Control Method

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Abstract

An experimental investigation of wing rock induced by forebody vortex in coning motion over wing/body model with sweep angle of 30° and its control method has been conducted in wind tunnel at angle of attack of 50° and Reynolds number of 1.56×10⁵ based on the diameter of the cylinder body with free-to-roll equipment. Firstly, wing rock pattern is determined by nose tip perturbation in coning motion, which is same as the static case. Secondly, coning rate has no effect on the frequency and amplitude of wing rock. Finally, wing rock can be suppressed by control technique of rotating nose perturbation also.

Keywords: Wing rock, forebody asymmetric vortices, coning motion, perturbation control, high angle of attack aerodynamics.

Nomenclature

α angle of attack
γ circumferential location of artificial nose perturbation
ϕ roll angle around body axis
ϕe roll angle around velocity vector

1. Introduction

High performance of super maneuverability has become one of the most important requirements in modern fighter aircraft designing to succeed in air-to-air combat. It means that fighter aircraft must be operated at high
angles of attack or even beyond the post stall. For example, Herbst maneuver includes sustained flight up to 70 degrees angle of attack, velocity vector roll in deep post-stall conditions, and post-stall turn from high entry to exit speeds with ultra-low turning/transitional conditions [1]. Angles of attack and sideslip will not change when aircraft rolls around velocity vector, which is called coning motion.

Lots of researches show that most of aircrafts will undergo asymmetric vortex flow and wing rock phenomenon at high angles of attack, such as wing/body models [2-5]. Wing rock at static angles of attack has been investigated intensively. It has been shown in Deng’s research that asymmetric vortex at high angle of attack can be determined and controlled by artificial nose perturbation [6-8]; wing rock is induced by the asymmetric forebody vortex and can be determined by artificial nose perturbation also [5]; there exist three patterns of wing rock when the circumferential location of nose perturbation is changed from 0° to 360° at static angle of attack, limit cycle oscillation at 0° or 180°, irregular oscillation at 90° or 270°, and tiny oscillation around non-zero roll angle at other circumferential locations [5]; wing rock can be suppressed by the method of rotating nose perturbation [9]. All of the results above are obtained in the case of static angle of attack, but how is the character of rolling oscillation in coning motion?

The purpose of this paper is to find out the character of rolling oscillation in coning motion. The following critical issues will be discussed: (1) effect of nose tip perturbation on rolling oscillation in coning motion; (2) effect of coning rate on rolling oscillation in coning motion; (3) application of perturbation control method on rolling oscillation in coning motion.

2. Experimental Equipment and Procedure

2.1. Wind tunnel and models

The experiments were carried out in the D-4 wind tunnel of Beijing University of Aeronautics and Astronautics, which is a low turbulence and low speed wind tunnel with test section of 1.5m×1.5m and turbulence intensity of 0.085%. The tests are carried out at Re=1.56×10^5 (V=25m/s) based on the diameter (90mm) of the cylinder body, where the boundary layer on the forebody exhibits laminar separation without reattachment.

The test model, shown in Fig. 1, is wing/body configuration with sweep angle of 30° and the apex of wing is located at section of x/D=4. It is noticeable that the nose with length of 27.5mm can be rotated by the motor which is installed inside of forebody. Artificial tip micro-perturbation with diameter of 0.2mm is fixed at rotatable nose, shown in Fig. 2.
2.2. Measuring equipment

The time history of free-to-roll test is recorded by an encoder with resolution of 0.022° which is installed inside of free-to-roll sting. High precision mechanical bearings are used to minimize the friction in free-to-roll test. Free-to-roll sting is installed on the coning mechanism which is driven by servo motor, shown in Fig. 3.

3. Results and Discussions

3.1. Effect of nose tip perturbation on rolling oscillation in coning motion

It is concluded from previous work that there exist three patterns of wing rock when the circumferential location of nose perturbation is changed from 0° to 360° at static angle of attack. Whether the effect of nose perturbation on wing rock will be changed in coning motion? Free-to-roll tests with circumferential location of nose perturbation of 0°, 45° and 90° are conducted at $\alpha=50°$ and the coning rate of 10°/s. From the results shown in Fig. 4, it is observed that all of the patterns of wing rock are same as the case of static angle of attack, which are limit cycle oscillation at $\gamma=0°$ (circumferential location of 0°), irregular oscillation at $\gamma=90°$, and tiny oscillation around non-zero roll angle at $\gamma=45°$. It means that wing rock in coning motion is also induced by asymmetric vortices which can be determined by tip-perturbation.
3.2. Effect of coning rate on rolling oscillation in coning motion

In coning motion, the model will roll around velocity vector, so what is the effect of coning rate on wing rock? The test was conducted with coning rate of 10°/s, 100°/s, and 360°/s at α=50° and circumferential location of 0°. It has been shown that wing rock patterns in three coning rate cases are all limit cycle oscillation in Fig. 5.
Frequency and amplitude, as the representative parameters of limit cycle oscillation, are extracted from the time history in Fig. 5 with method of frequency analysis and summarized in Fig. 6. Amplitudes and frequencies in different coning rate cases are almost same to each other and same with the case of static angle of attack from Fig. 6.

It is known that wing rock is induced by asymmetric vortex of forebody. Vortex asymmetry is the characteristic feature at high angles of attack. Angle of attack will not be changed in coning motion, so coning rate has no effect on wing rock induced by forebody vortex.
However, coning motion will change the local air-path angle of model, which is relative to the coning rate and the distance between local position and rotating center of model. But it is still unknown what the effect of local air-path angle on the flow behavior of slender body-wing model is.

3.3. Application of perturbation control method on suppression of rolling oscillation in coning motion

It is known that coning motion has no effect on the wing rock induced by asymmetric vortex. The control method of rotating nose tip perturbation may be still available for wing rock in coning motion. Free-to-Roll tests with nose rotating frequency of 6Hz are conducted at \( \alpha = 50^\circ \) and the coning rate of 100°/s. Amplitude of oscillation decreases from 34.65° before controlling to 6.91° after controlling from Fig. 7. It proves that rotating nose perturbation can also suppress wing rock in coning motion.

4. Conclusion

With free-to-roll technique, wing rock motion induced by forebody asymmetric vortex in coning motion over wing/body model with sweep angle of 30° and its control method are investigated in this paper. The following conclusions can be obtained from discussion of the experimental results: (1) wing rock pattern is determined by nose tip perturbation in coning motion, which is same as the static case; (2) coning rate has no effect on the frequency and amplitude of wing rock; (3) wing rock can be suppressed by perturbation control technique also.

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