STUDY ON DYNAMIC HYSTERESIS AND LINEAR MODELING OF THE SLIDING-SKIN VARIABLE-SWEEP MORPHING WING AERODYNAMICS

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Summary Unsteady aerodynamic characteristics of a sliding-skin variable-sweep aircraft during morphing were investigated through wind tunnel experiments. Dynamic hysteresis were observed on force vs. angle-of-attack curves as well as on moment vs. angle-of-attack curves. Based on new concepts of dynamic derivatives and novel analyses of the dynamic hysteresis, a linear model was constructed to modeling the time-dependent force and moment. Results show consistency between models and experiments.

INTRODUCTION

Being a new concept in recent years, flight vehicle intelligent morphing means adaptive changes of vehicle configuration according to flight conditions and missions such as a bird does. Because of the prominent bionics characteristics [1-2] and broad aerospace applications [3-4], intelligent morphing flight vehicle has gained more than thirty organizations' interest and more than ten governments' investment, and has become a hot research topic.

Among the key technologies of intelligent morphing flight vehicle, aerodynamics research are now focusing on two aspects: 1) morphing configuration design optimization and multi-mode aerodynamic characteristics studies; 2) in-morphing aerodynamic characteristics studies. In the first aspect, numerous research work has been done in the past ten years. However, in the second aspect, little research work has been seen in public literature. Nevertheless, it is very important to thoroughly study in-morphing aerodynamic characteristics.

This paper presents a experimental investigation on dynamic hysteresis and linear modeling of a morphing aircraft with sliding-skin variable-sweep wings. Methods are outlined at first, followed by results analyses. Finally, concluding remarks are provided.

METHODS

The experiment is conducted in a low speed wind tunnel. Fig. 1 shows the aircraft which morphs in a sliding-skin variable-sweep manner. This manner is different from traditional manner in that the chord line of the wing airfoil is always parallel to the axis of the fuselage. In the morphing process, wing area and shape changes, wing skin shears.

The sweep angle is a trigonometric function of time as follows:

$$\lambda = \frac{(\lambda_2 + \lambda_1)}{2} + \frac{(\lambda_2 - \lambda_1)}{2}\sin\left(\frac{2\pi}{T}t - \frac{\pi}{2}\right) \tag{1}$$

where λ is the sweep angle at time t, λ_1 is the minimum sweep angle, λ_2 is the maximum sweep angle, and T is the period. In order to investigate the effect of morphing rate on in-morphing aerodynamic characteristics, three values of T are specified: 16s for long period, 8s for middle-length period, and 4s for short period. In the real environment of wind tunnel, the three values of T are 17.58s，8.79s，4.40s, respectively.

Morphing aircraft aerodynamic characteristics testing is different from that of fixed-configuration aircraft's. One testing method is a sample of aerodynamic characteristics in a single morphing process [5], another testing method is a sample of aerodynamic characteristics in several morphing periods [6] based on the method of forced-oscillation. This paper use the second method. After obtaining the data, low bypass signal filter with the cut-off frequency of 5Hz is needed for the sake of dismissing noises from environment, equipment and vibration. Then, six components of the filtered signal is iterated accord to the balance formula. Final, weight is eliminated from the total signal so as to obtain the pure aero signal.

RESULTS

Dynamics hysteresis

Figs. 2 and 3 shows the unsteady aerodynamic characteristics during morphing. Three novel characteristics are discovered: (1) There exists notable hysteresis in the process of sliding-skin morphing. The hysteresis loop of lift coefficient is clockwise, and the hysteresis loop of pitching moment coefficient is anticlockwise, i.e. when the sweep angle increases unsteady lift coefficient is larger than quasi-steady lift coefficient,unsteady pitching moment coefficient

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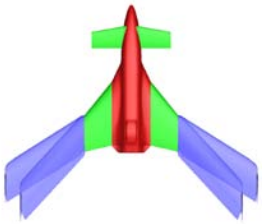

Fig. 1 Sliding skin varying-sweep

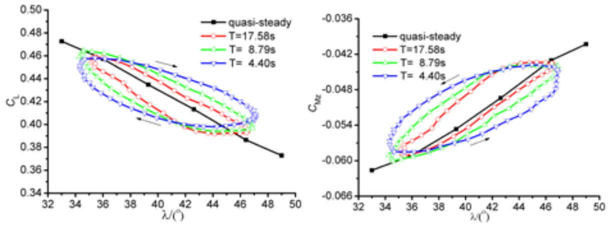

Fig. 2 Unsteady lift and pitching moment coefficients variations with sweep

is smaller than quasi-steady pitching moment coefficient; when the sweep angle decreases, the rule of variation is inverse. (2) As the morphing rate increases, the hysteresis loops become larger, i.e. the quicker the aircraft morphs, the greater the hysteresis. Quantitatively, at 40.5^o sweep angle, the difference between maximum and minimum unsteady lift coefficient (T=4.40s) reaches 9.8% of quasi-steady lift coefficient, the difference between maximum and minimum unsteady pitching moment coefficient (T=4.40s) reaches 19% of quasi-steady pitching moment coefficient. (3) There exists a hysteresis loop phase drift. As the morphing rate increases, the phase drift of hysteresis loops of lift and pitching moment coefficients are more and more notable.

The possible two reasons of hysteresis are: (1)"additional velocity effect" caused by the motion of the wings and subsequent change of the relative velocity between solids and fluids. (2) "flow structure hysteresis effect" caused by fluid viscosity and subsequent hysteresis of dynamic flow structure relative to static flow structure.

Linear modeling

First, two new variables called "dynamic derivatives of aerodynamic characteristics to morphing rate", $C_L^{\dot\lambda}$ and $C_{Mz}^{\dot\lambda}$, are defined. Then, linear model of unsteady lift and pitching moment coefficients are constructed:

$$C_L(\lambda,t) = C_{L0}(\lambda) + C_L^{\dot\lambda}\dot\lambda(t) \tag{2}$$

$$C_{Mz}(\lambda,t) = C_{Mz0}(\lambda) + C_{Mz}^{\dot\lambda}\dot\lambda(t) \tag{3}$$

Where $C_L(\lambda,t)$ and $C_{Mz}(\lambda,t)$ are unsteady lift and pitching moment coefficients, respectively, $C_{L0}(\lambda)$ and $C_{Mz0}(\lambda)$ are quasi-steady lift and pitching moment coefficients, respectively, $\dot\lambda(t)$ is morphing rate of sweep, and $C_L^{\dot\lambda}$ and $C_{Mz}^{\dot\lambda}$ are dynamic derivatives of lift and pitching moment coefficients to morphing rate of sweep angle, respectively. Fig. 4 shows comparison of modeling results and wind tunnel results about dynamic lift and pitching moment coefficients. Consistency could be observed.

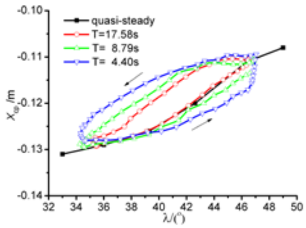

Fig. 3 Unsteady pressure center variations with sweep

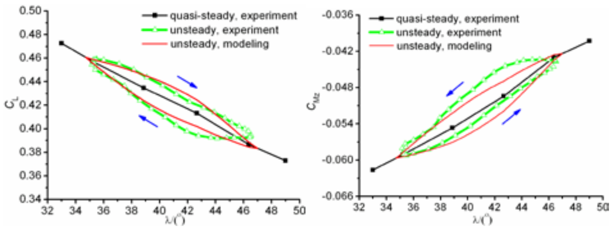

Fig. 4 Comparison of the models and the experiments

CONCLUSIONS

Notable dynamic hysteresis is discovered in unsteady aerodynamic characteristics of a sliding-skin variable-sweep aircraft during morphing. The possible two reasons are "additional velocity effect" and "flow structure hysteresis effect". Linear models based on these two reasons show consistency with experiments.

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