Realization and Aeroelastic Characteristics of a Variable Planform Morphing Wing

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Abstract The present paper is aimed at developing a variable planform morphing wing and investigating its aeroelastic characteristics. An innovative morphable mechanism of single degree of freedom is proposed based on a revolvable truss which enables the wing to vary span and sweep angle simultaneously. A metallic wing model is designed and built to demonstrate the feasibility and potential performance of this morphing wing. Attention is then paid to the aeroelastic behaviour of the morphing wing, in particular, flutter characteristics which keeps changing while the wing is morphing. Finite Element (FE) model is used to explore structural dynamics of the wing during its morphing process. Open-loop flutter speeds are predicted in time domain using state space approach. The results of this investigation provide preliminary understanding into morphing effects on aeroelastic stability and facilitate the closed-loop Aeroservoelasticity (ASE) analysis at next stage.

INTRODUCTION

The morphing concept for unmanned aerial vehicles is a topic of current research interest in aerospace engineering. The morphing wing is a birdlike wing that has the ability to adapt to accommodate multiple flight regimes or to obtain better flight performance. A number of studies exploring morphing concepts have been performed over the past decades [1]. Methods of wing morphing include folding wing, varying wing camber, twisting wing, varying wing sweep, changing wing chord and/or wing span [2].

The present paper is intended to propose and develop a morphing wing which is able to greatly vary sweep angle and span simultaneously. This kind of planform varying is designed to change the wing configuration of an aerial vehicle for various flight conditions. Actually, the concept of variable sweep wing has been successfully realized in various modern military aircraft such as the F-14, F-111, and B-1. These aircrafts change their wing sweep angle to decrease drag as the speed increases. Wing span change is to reduce the induced drag or to improve the manoeuvrability. As a result of increasing the wing span, the aspect ratio and wing area increase and the spanwise lift distribution decrease for the same lift. Thus, the induced drag of the morphing wing decreases, and consequently, the range of the aerial vehicle is increased. However, the wing root bending moment can be increased considerably due to the increase of the span. Therefore, aeroelastic characteristics, in particular ASE stability should be investigated in the design stage of the variable planform morphing wing.

Structural Concept

The concerned morphable structure is composed of a set of truss with particular placed revolution constraints, as shown in Fig.1. Joint B is pivoted on the base, and joint A keeps free of motion. Thus, this truss is a single degree of freedom mechanism and its shape can be determined once the location of joint A is obtained. A desired angle θ and length BB_3 can be obtained by pulling joint A to the location A' using an actuator.

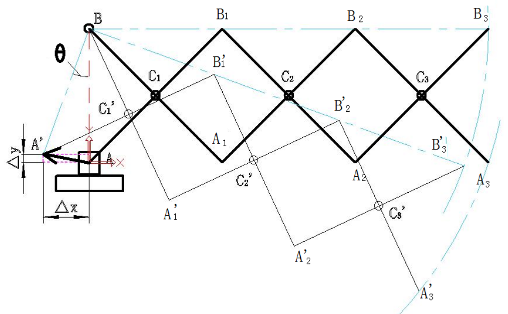

Fig.1 kinematics of revolvable truss concept

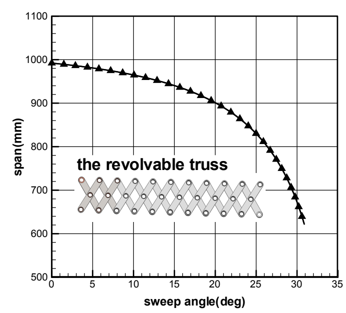

Fig.2 kinematics analysis results

Based on this concept, a revolvable truss is sized to mount inside a straight wing with 1m of span and 0.3m of chord and enable the wing to sweep back to 30deg in the mean time contract to 0.6m. The kinematic analysis of this truss is performed and the results are shown in Fig.2. Due to the actuation trace of joint A, sweep of the truss is the dominant motion at the beginning while contraction is very slow. The contraction speed of the wing is increased as the sweep angle increase, and becomes a major motion when sweep angle is larger than 25deg.

Morphing Wing Model

A proof-of-concept model is built to accommodate the revolvable truss sized above. As shown in Fig3, the wing model is equipped with 3 segmental wings, and each of which has 2 telescopic spars and a sliding rib. The sliding ribs are

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designed to associate telescopic spars with revolvable truss and transfer the motion from the later to the former. A servo motor is used to drive joint A of the truss to the desired location to vary wing planform. The exploration has been conducted on morphing skin as well. The skin is segmented corresponding to each wing section and nested to adjacency, as shown in Fig.4. The thickness of the skin is equal to 1mm.

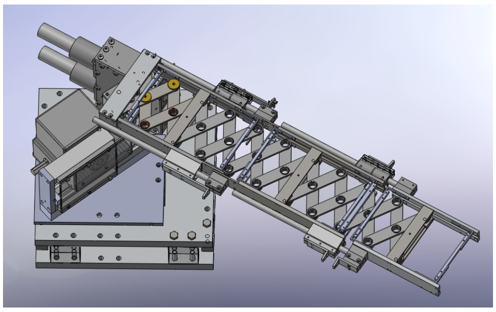

Fig. 3 Internal structure of the morphing wing

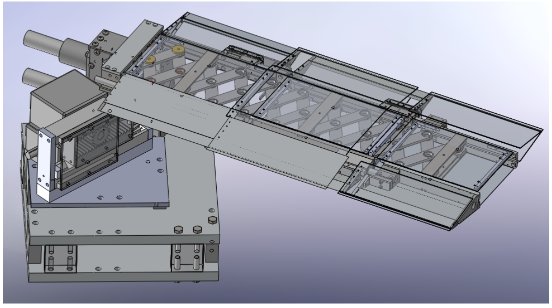

Fig.4 Demonstrative experiment setting up

Open-loop flutter analysis

The FE structural model and the aeroelastic model of the morphing wing are shown in Fig. 5 and Fig.6, respectively. Structural dynamic analysis is carried out. The frequencies of the first 6 modes as a function of sweep angle are shown in Fig. 7. The natural frequencies of the wing are slightly changed as the sweep angle increases. And when the sweep angle is beyond 25 deg, the natural frequencies begin to increase quickly. This is because the contraction of the wing takes the dominant position in the resultant morphing motion as observed in Fig.2.

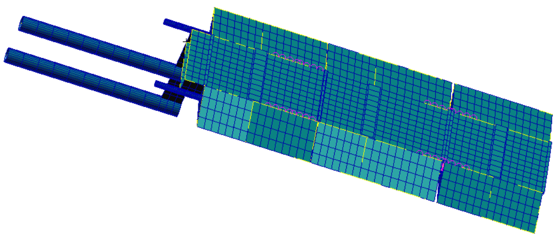

Fig.5 Structural FE model of the morphing wing

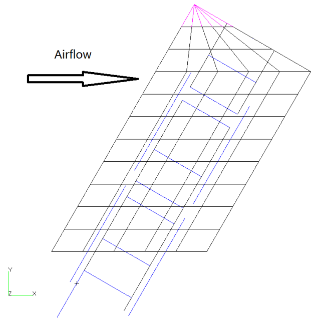

Fig.6 Aeroelastic FE model of the morphing wing

Open-loop flutter speeds are predicted in time domain. The unsteady aerodynamics in state space model is obtained by Minimum-state approximation. The results from PK method in frequency domain are also provided in Fig. 8. Similarly, flutter speed is increased as the sweep angle increases. In addition, the open-loop flutter speeds agree well with the flutter speeds predicted in frequency domain at every wing planform configuration. By redesigning the actuation trace of joint A, the wing can start morphing from contraction rather than sweeping and the flutter speed can be hence increased significantly at very beginning of morphing.

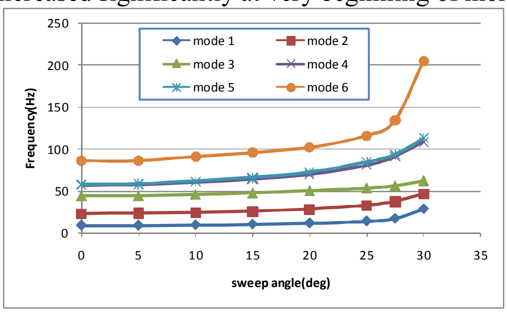

Fig.7 Structural dynamic analysis results

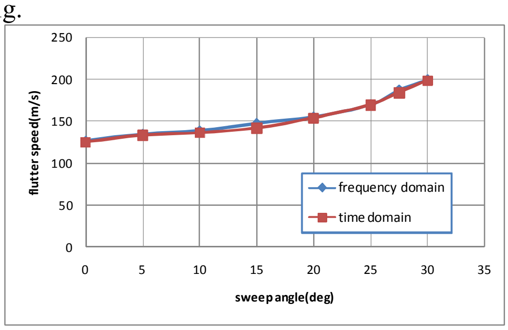

Fig.8 Flutter speed predictions

CONCLUSIONS

A variable planform morphing wing based on revolvable truss concept is originally proposed in this paper. Kinematic analysis of the morphable structure is performed. A metallic wing model is designed and built to demonstrate the viability of this concept. FE method is employed to perform the structural dynamic analysis. Open-loop flutter speeds are predicted in state space time domain by Minimum-state approximation. The results show that effects on the flutter characteristics of the wing are more pronounced when the span is greatly varied. The benefits of the larger stability margin could be achieved on the concerned morphing wing if actuation trace is properly designed.

References

[1] Armando R. Rodriguez, Morphing Aircraft Technology Survey, AIAA 2007-1258.
[2] Akhilesh K. Jha , Jayanth N. Kudva, Morphing Aircraft Concepts, Classifications, and Challenges, SPIE Vol. 5388, doi: 10.1117/12.544212.