DESIGN AND ANALYSIS OF A MORPHING TRAILING EDGE STRUCTURE

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ABSTRACT

The research proposes a kind of topology optimization method to design the main load-bearing structure of adaptive compliant trailing edge. This approach uses a special class of mechanisms called compliant mechanisms powered by a single input actuator. The key design issue in this approach is the synthesis of a suitable compliant mechanism for the task. In order to implement this scheme, a topological optimal design procedure for such compliant mechanisms is presented. During the topology procedure parametric analysis method is introduced. The optimal design method for compliant trailing edge is validated by a nonlinear finite element analysis and a test.

1 INTRODUCTION

The need for a next generation of air vehicles that has high performance and low environmental impact has gained during the past years due to the "green-liner" demands on civil aeronautics 1.

Morphing airframe technologies represent a very promising area of investigation in the field of aircraft design. The use of morphing structures on the new generation wings will enhance the flight performance and at the same time will significantly reduce the power consumption, the noise emission and the overall aircraft environmental impact2,3,4.

Several morphing concepts have been proposed for the conventional high lift devices5,6,7 and most of them modified specific wing parameters(local or global camber, wing span, twist)8,9,10. Some efforts have been focused on the development of kinematical chains, such as the quaternary binary crossed-linked mechanism (QBCLM), others on the development of compliant structures. Most of them have developed some sophistic morphing mechanisms and achieved effective results. However, theses design methods of morphing wing are impeded when they are used in the engineering practice for the following facts:

1. The morphing trailing edge needs enormous power to morph to the desired shape.
2. Some morphing trailing edge schemes have intricate and cumbersome mechanisms which seriously reduce the reliability and increase the weight of these systems.
3. Due to the limited driving range the common smart actuators is difficult to meet the need of large deformation.
4. The location and the form of the actuator significantly influence the last shape of the morphing structures. However, most of the developed design methods leave these factors out of consideration.

In this paper, compliant structures optimization design approach based on parametric analysis for a small unmanned aerial vehicle(UAV) is proposed which has overcome the above drawbacks to a great extent.

2 COMPLIANT STRUCTURES TOPOLOGY OPTIMIZATION BASED OF PARAMETRIC ANALYSIS METHOD

2.1 The mathematical model of the compliant structures topology optimization problem

Compliant structures optimization design approach based parametric analysis divides the optimization process into topology optimization and size optimization. Compliant structures design problem is to determine a structure which will deformed to a target shape under the input force or displacement. To compare the deformed and target curves, the two curves was expressed in terms of two sets of sampling points that are evenly distributed along the curve lengths, as shown in Fig. 1. The least square error (LSE) deviation is defined as the sum of Euclidian distance between each pair o f sampling points on the two curves. This is shown in Eq.(1), where n is the total number o f sampling points; ($u_{def,i}$) and ($u_{tar,i}$) are the displacement of the sampling points along the deformed and target curves respectively.

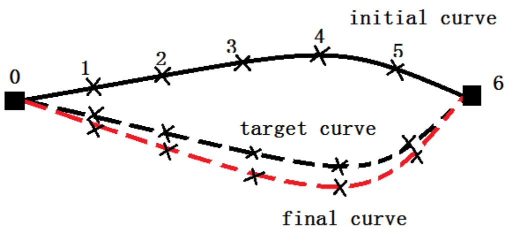


Fig. 1 Target curve, target curve and final curve

Thus, the mathematic model of the compliant structures topology optimization problem can stated as below:

$$\min: \ LSE = \sum_{i=1}^{n} w_i (u_{out,i} - u_{out,i}^{*})^2$$

$$S.T.: \begin{cases} [K]\{d\} = \{F\} \\ Volume \le V_{\max} \\ \sigma_{\max} \le \sigma_s \\ 0 \le \rho_{\min} \le \rho_e \le 1.0 \end{cases}$$

where n is the total number o f sampling points; ($u_{out,i}$) and ($u_{out,i}$) are the displacement of the sampling points along the deformed and target curves respectively; [K] is the stiffness matrix;{d} is the node displacement vector; $V_{\max}$ is the maximal volume; σ_s is the material strength; ρ_e is the element material density.

2.2 Parametric analysis method

Input conditions(e.g. input size, input location) seriously influence the topology result in the topology optimization. In addition, the input conditions are restricted by the real conditions(e.g. the space of structures). However, previous studies of compliant structures have not concerned the input conditions. To solve this issue, an parametric analysis approach based on the essential topology optimization was developed to obtain the optimal topology and determine the actuator condition correspondingly in this paper.

In this method, the topology optimization was conducted to determine the optimal topology of the compliant trailing edge structure which consider the actuation location, the actuation form and the actuation size. Figure 2 illustrates the parametric analysis method which has three varibles.

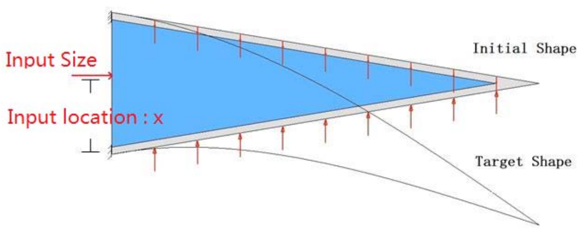


Fig. 2 The parametric analysis method

3 COMPLIANT TRAILING EDGE OPTIMIZATION DESIGN AND ANALYSIS

3.1 Topology optimization

Changing wing shape in response to the flying condition can potentially produce maximum lift and reduce drag, thus increasing the fuel economy. Active wing morphing also allows a single aircraft to perform multiple tasks that requires different wing shapes, leading to potential improvements in maneuverability and performance. A morphing trailing edge of a UAV(unmanned aerial vehicle) under external loads are introduced in the following to demonstrate the capability of the synthesis approach developed in the proceeding text. The compliant wings have a total wingspan of 1.8m (excluding the fuselage), and a wing chord of 0.3m.Fig.3 shows the model of the topology optimization problem. The black solid line is target shape and the external loads has been linearized along the chord.

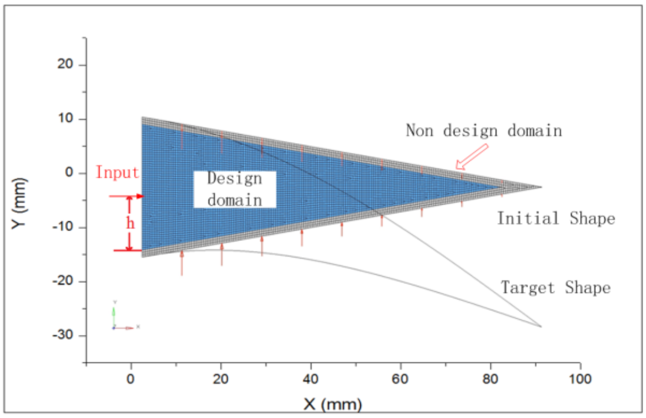


Fig. 3 The model of the topology optimization

The airfoil achieves the optimum aerodynamic performs as LSE is close to zero, therefore, the object function of the topology optimization problem is LSE in this work. A Optistruct topology optimization procedure with re-development method by Hypermath was implemented. And the optimization program is based on SIMP method. As shown in Table.1, the variables in the parametric analysis are the coordinate of input location and input size for different type of drive. Fig. shows the density contour of the optimal topology. In addition, the corresponding optimal actuator condition is -5mm x-direction displacement with h=0.5.

Input model	Input Position	Input Magnitude
Angle	0.2~0.8	$\sim 30^{\circ}$
Force	0.2~0.8	-200N~200N
Displacement	0.2~0.8	-10mm~10mm

Table. 1 The range of the parameters

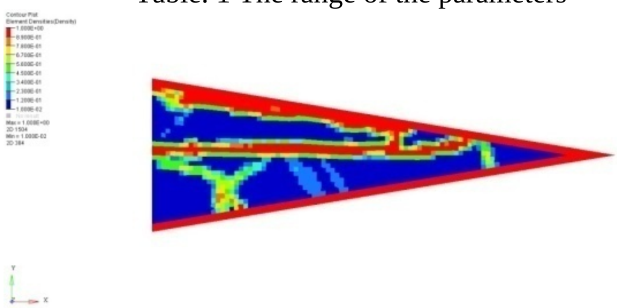


Fig. 4 The density of material contour

3.2 Size optimization

The goal of size optimization for compliant trailing edge is to generate a detailed description of the structure's size for a given topology. This can be performed considering the exact operational boundary conditions experienced by the mechanism and accounting for pratical performance requirements such as stress and mechanical or geometric advantage constraints.

To optimize size, a designer must first begin with a topology which can satisfy basic motion requirements. These topologies are successful identified using topology synthesis techniques developed in previous texts. The topology of the compliant structures are simplified as frame structures. And the variables of size optimization are the height of all beam elements. Fig. shows the model of the size optimization.

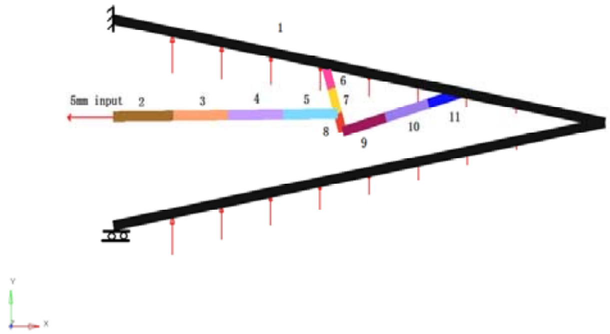


Fig. 5 The model of the size optimization

The detail size optimization was implemented in order to achieve the desired deflected shape. The result of the deformed shape and the optimal height of all beam section are illustrated in Fig. and table 1. As shown in fig.6 the red curve is the actual final shape and the black curve is the target shape. This shows that the final shape of the compliant trailing edge is coincide with the target shape almost very well.

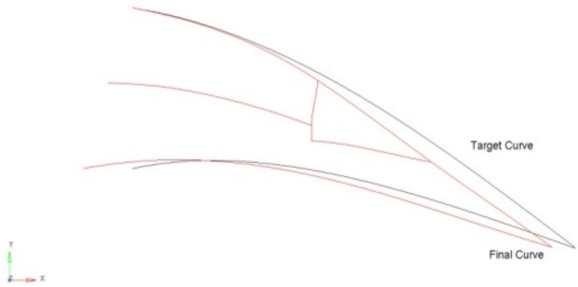


Fig. 6 The contrast of the target curve and the final curve

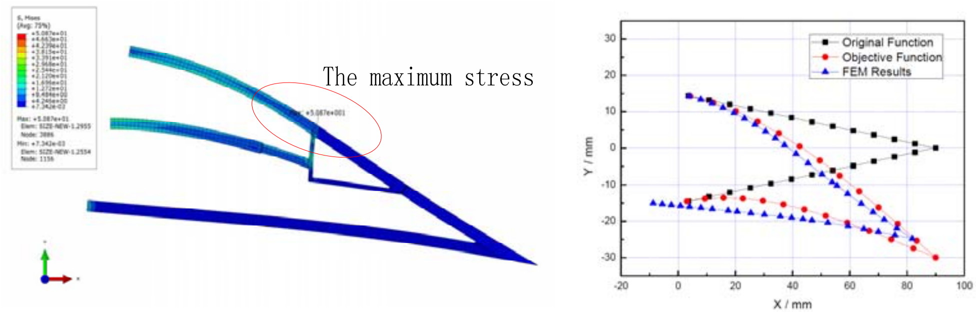
PROP-TYPE	PROP-ID	ITEM-CODE	PROP-VALUE(mm)
PBAR	1	DIM2	2.00E+00
PBAR	2	DIM2	1.00E+00
PBAR	3	DIM2	1.00E+00
PBAR	4	DIM2	1.00E+00
PBAR	5	DIM2	1.00E+00
PBAR	6	DIM2	2.00E+00
PBAR	7	DIM2	2.00E+00
PBAR	8	DIM2	2.00E+00
PBAR	9	DIM2	2.00E+00

PBAR	10	DIM2	2.00E+00
PBAR	11	DIM2	2.00E+00

Table. 2 The optimal height of all beam sections

4 ANSLYSIS AND TEST

To verify the effectiveness of the topology optimization method based on parametric analysis developed in this paper. With the large deformation a nonlinear finite element analysis was conducted in order to examine the maximum stress. As the result of the Abaqus shows that the maximum Von Mises stress is 50.87MPa below the ABS yield strength 71.8MPa. Furthermore, the final deformed shape and the target shape of the compliant trailing edge is match very well.



(a) (b)

Fig.7 The results of the nonlinear element analysis of the compliant trailing edge. (a) Compliant trailing edge stress.(b)The deformed curve and the target curve

Finally, in parallel with the trailing edge design study, a prototype physical model, the actuator and the test-bed were constructed to validate the morphing capacity of the intended shape change. Fig. shows photographs of the physical model of the morphing compliant trailing edge structure. Fig.8(a) is the initial shape of the compliant trailing edge and Fig.8(b) is the final shape of the compliant trailing edge. It is clear that the compliant trailing edge can deflect 20 degree anticlockwise from the initial shape with a +5mm displacement input. Thus the test validated the morphing capacity of the intended shape change with the specific displacement input. And the topology optimization method based on parametric analysis developed in this paper is useful for the shape control problems.

(a) (b)

Fig. 8 Morphing trailing edge physical model shown in 0 degrees(a) and +20degrees(b) positions

5 CONCLUSION

A topology optimization method based on parametric analysis is developed in this research as an alternative way to define the topology design variables in the compliant trailing edge structural optimization problems. Input conditions(e.g. input size, input location) are incorporated into a systematic synthesis approach which is developed to find the optimal compliant mechanism for desired shape morphing. What's more, a analysis and testing of an compliant trailing edge are presented in this article. The results demonstrate that the capability of the topology optimization method based on parametric analysis is effective for compliant trailing edge based on compliant structures.

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