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RESEARCH ARTICLE

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Deformation analysis of shape memory polymer for morphing wing skin under airflow

Abstract The method for analyzing the out-of-plane deformation of a flexible skin under airflow is developed in this paper. The aerodynamic analysis is performed using the CFD software, and the structural analysis is performed using finite element method. The chief aim of the present study is to investigate the out-of-plane deformation of the shape memory polymer (SMP) skin at different temperatures. Numerical results show that the maximum out-of-plane displacement of the SMP skin increases with increasing temperature. When the SMP skin is heated to 53°C, the maximum out-of-plane displacement is about 7 mm. It decreases by 72%, when the SMP skin is applied with a uniform pre-strain of 0.1.

Keywords aircraft, morphing, skin, shape memory polymer (SMP), deformation, pre-strain

1 Introduction

Morphing can provide a mission adaptable aircraft suitable for many tasks, instead of being limited to a single one. For aircraft morphing, the key technology is flexible skin. Morphing aircraft wings require flexible skins that can undergo large strains and have low in-plane stiffness. The skin must handle the out-of-plane aerodynamic loads whereas simultaneously carrying some shear loading, which is the primary function of wing skins. A suitable skin material for the morphing wing must be elastic, flexible, have high recovery, resistant to different weather conditions, resistant to abrasions and chemicals, and especially be hard enough to handle the aerodynamic loads of the aircraft in different flight conditions [1]. Therefore, an aerodynamic skin made of traditional materials such as metal and polymer film cannot provide any functionality.

Shape memory polymers (SMPs) are an attractive and promising candidate for the skin material of a morphing aircraft. SMPs can change their shape in a predefined way from shape A to shape B when exposed to an appropriate stimulus. When shape B is given by the initial processing step, shape A is determined by applying a process called programming. Their multiple state abilities allow them to easily change shape and once cooled, to resist appreciable loads. Enabling the shape memory materials to change between the rigid and the elastic states is the responsibility of the skin activation system. To activate the SMP, using embedding heating wires into the skin was developed by CRG [2]. At 40 W, the wires were able to heat the SMP above its transition temperature; however, the heat distribution was observed to be not adequately uniform. Lockheed Martin Aeronautics Company has demonstrated the feasibility of morphing SMP skin concepts [3].

In Ref. [4], embedded heating wire springs act as the activation system for the SMP. An electric current is passed through the heating wire springs to heat the SMP over its transition temperature. This approach overcomes some challenges that the SMP embedded straight wires must face. The best advantage is that the inherent separation does not occur between the heating elements and the SMP upon elongation due to the elasticity of wire springs.

An SMP skin can be elongated or sheared when SMP is in the state of the low modulus. There is a question whether the out-of-plane stiffness of the SMP skin is high enough to handle aerodynamic loads. This paper develops the procedure of analyzing the deformation of flexible skins under airflow. The out-of-plane deformation of SMP skins at different temperatures is simulated. The effect of the out-of-plane deformation on aerodynamic pressure distributions is also discussed.

2 Deformation analysis of flexible skin

The material acting as a morphing wing skin must be flexible enough to change its shape as required; however, it

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should be strong enough to withstand the aerodynamic forces that the material will be subjected to during flight. In fact, it is a fluid-solid interaction problem. Figure 1 shows the process of obtaining the structural loads for the deformation of the flexible skin and the fluid dynamic pressure over the aerofoil along with the aerodynamic lift and drag. The aerodynamic analysis is performed using the CFD software. The structural analysis of the flexible skin is done using the ANSYS software. From the aerodynamic surface pressure, the aerodynamic loads acting at the nodes of each skin element can be determined. The effect of this deformation also changes the aerodynamic loads. The changed aerodynamic static pressure is calculated using the CFD software. ANSYS analysis is performed again using this changed aerodynamic pressure. The procedure is repeated until an equilibrium position of the flexible skin is achieved.

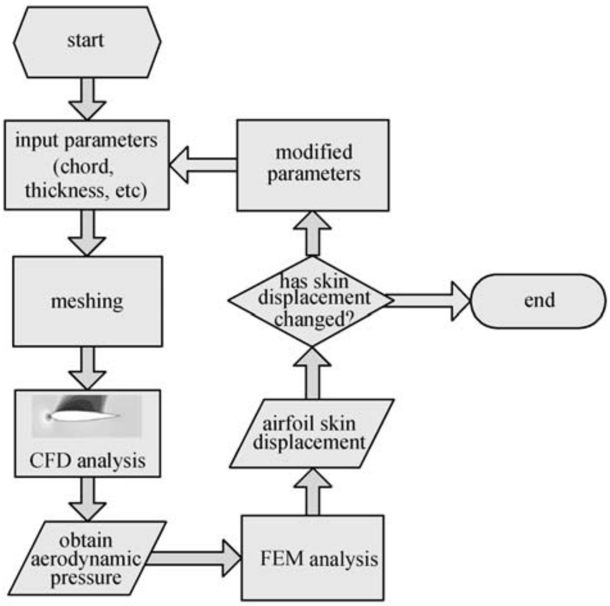

Fig. 1 Flowchart of CFD/structural analysis process

3 SMP skin

The present study examines the deformation of SMP skins for a variable camber airfoil. The baseline airfoil is assumed to have an NACA 0020 profile and a chord of 150 mm as shown in Fig. 2. Figure 3 shows the pressure distribution of NACA0020 with a free stream velocity of

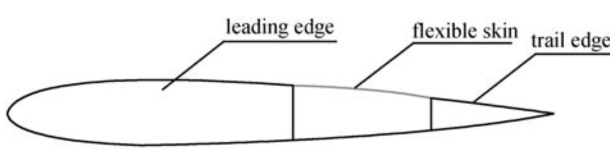

Fig. 2 Variable camber morphing airfoil with rigid leading and trail edges

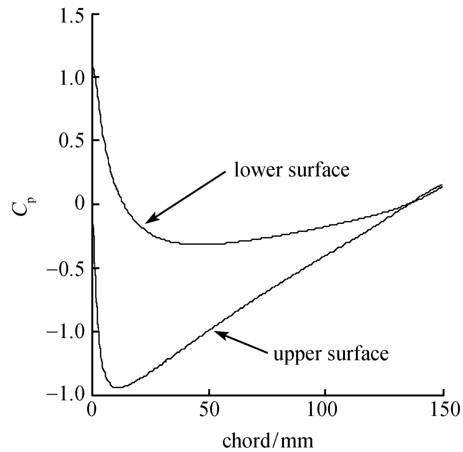

Fig. 3 Pressure distribution of NACA0020 (M = 0.2, α = 5°)

0.2 M, pressure of 1 bar, and air density of 1.225 kg/m^3 at an attack angle of 5°. It can be seen that the pressure coefficient on the upper surface is negative. In other words, the flexible skin will be heaved under aerodynamic pressures.

SMP is used to act as the flexible skin. As shown in Fig. 4, the elastic modulus of SMP is reduced with increasing temperature. It can be seen that the elastic modulus of SMP will drop one or two orders of magnitude when SMP is heated over its transition temperature. The out-of-plane deformation of the SMP skin at different temperatures is shown in Fig. 5. It can be seen that the out-of-plane deformation increases with increasing temperature. When the temperature is as high as 53°C, the maximum displacement of the SMP skin is about 7 mm. The aerodynamic pressure distribution of the NACA 0020 with the SMP skin at different temperatures is shown in Fig. 6. The out-of-plane deformation of the SMP skin impresses on the aerodynamic pressure distribution. As shown in Table 1, the lift decreases by about 34.8% and the

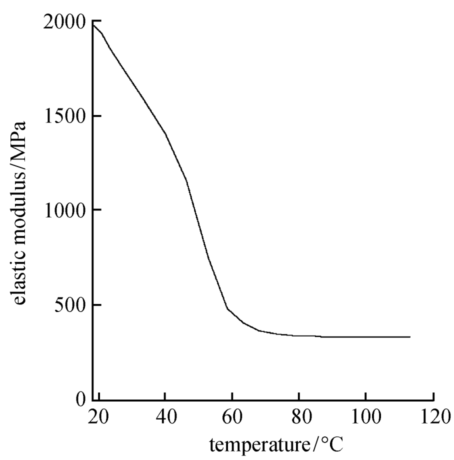

Fig. 4 Elastic modulus of SMP at different temperatures

drag increases by about 35.4% when the SMP skin is heated to 53°C.

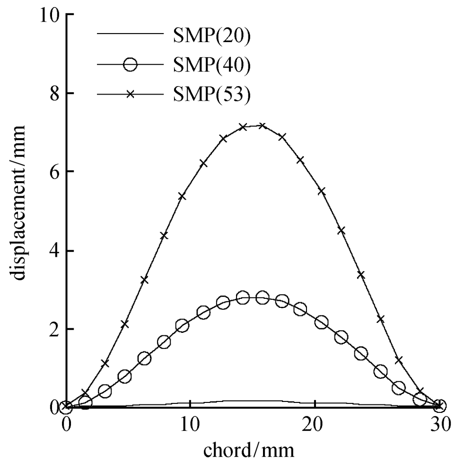

Fig. 5 Deformation of SMP skin at different temperatures

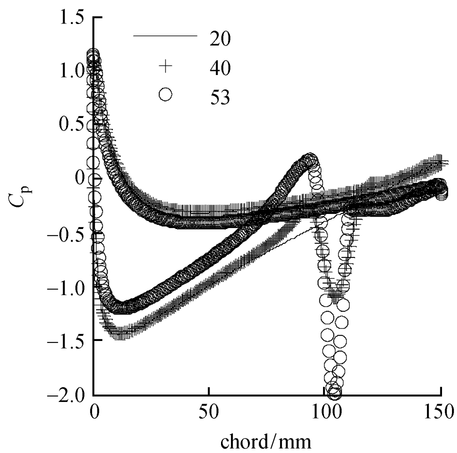

Fig. 6 Aerodynamic pressure coefficient of NACA 0020 with SMP skin at different temperatures

Table 1 Aerodynamic characteristics of SMP skin at different temperatures

temperature/ °C	lift/ N	drag/ N	lift to drag ratio
20	238.195	25.658	9.283
40	239.515	26.526	9.029
53	155.278	34.746	4.469

One possible way of reducing or eliminating the out-of-plane deformation of the flexible skin is the pre-strain method [5]. Figure 7 shows the variation in the out-of-plane displacement of the SMP skin at 53°C as the pre-strain increases. The out-of-plane displacement decreases due to the increase in pre-strain. It can be seen that the maximum displacement decreases by about 72% when the pre-strain is equal to 0.1.

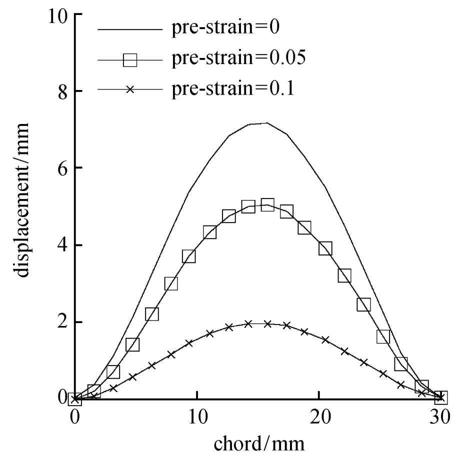

Fig. 7 Deformation of the SMP skin (53°) under different pre-strains

4 Conclusions

The out-of-plane deformation of a flexible skin at different temperatures and its effect on aerodynamic pressure distributions are discussed in this paper. The conclusion is drawn that the maximum out-of-plane displacement of the SMP skin increases with increasing temperature and the maximum out-of-plane displacement is reduced rapidly by using the pre-strain method. Therefore, SMPs will become a more practical skin material for morphing aircraft.

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