Experimental Exploration of Macro-fiber Composite Morphing Wing

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Abstract. In this paper, a experimental model of morphing swept-wing with carbon fiber is designed and driven by Macro-Fiber Composites (MFC). Dynamic analysis of the wing structure is carried out. The maximum twist angle of the carbon fiber structure driven by the MFC in the experiment is 10.72°. External excitation can be applied to the wing structure for its dynamic analysis and the modal performance of the structure is analyzed.

1. Introduction

The dream of every aeronautical engineer is to design the best possible wing which is able to smoothly run in all operating flight conditions. Morphing wing, as a type of shape-adaptive structures, are enabled to improve performance with flight condition and smooth geometric changes. Therefore, morphing wing becomes a hotspot in research nowadays. Morphing swept angle for airfoils is a classical morphing type and good at reducing the shock wave resistance and improving the flight dynamics. Moreover, the development of smart materials and structure offers a great potential in the field of shape control in different fields of application, especially in the aviation field.

Some studies have explored the use of such actuators to change or control the shape of aerodynamic bodies. Bilgen et al. investigated the use of MFCs to change the wing camber for roll and pitch control of a remotely piloted micro-air-vehicle (MAV) [1]. At Virginia tech in 2004, Neal and others designed a kind of adaptive UAV model, of which the wing can turn 20°, drone sweepback can vary from 0° to 40°, wing exhibition can change 17.3% and long tail wing can compress closer to 11%. The effectiveness of the MAV model under different deformation was verified by wind tunnel test [2]. In 2011, the national research council of Canada's school of aeronautical research designed a wing structure with variable curvature, in which MFC was used as the driver, and torsional angle of the wing was 24.2° from the theoretical calculation. In one of the experiment analyses, the wing torsion angle of micro-air-vehicles could arrive to 27.3° with 40N axial force and 2000V driving voltage [3].

In this paper, a preliminary exploration of a new design of morphing swept-wing is studied, which is driven by MFC, and the dynamic response of the smart structure is analyzed by using the experimental methods.

2. Experiment Results

2.1. Driving Performance Testing of MFC Actuator

Firstly, consider a single cantilever carbon fiber composite plate with MFC actuator added at the free end as shown in Figure 1. The geometries of the plate are 150*40*0.2 mm and the dimensions of MFC actuators are 85*28*0.3 mm [4]. The other material properties of the components are as follows:
cross-ply carbon fiber composite: \( E = 117 \text{GPa}, \mu = 0.44, \ \rho = 1800 \text{kg/m}^3 \)

MFC: \( E_x = 30.3 \text{GPa}, \ E_y = 15.9 \text{GPa}, \ E_z = 15.9 \text{GPa}, \ G_{xz} = 10.7 \text{GPa}, \ G_{yz} = 10.7 \text{GPa}, \ G_{zx} = 5.7 \text{GPa}, \ d_{33} = 4.18 \times 10^{-10} \text{m/V}, \ d_{32} = d_{31} = 1.98 \times 10^{-10} \text{m/V}, \ \rho = 5440 \text{kg/m}^3 \)

Here, \( E \) is Young’s modulus, \( G \) is the shear modulus, \( \mu \) is Poisson’s ratio, \( \rho \) is the density and \( d_{ij} \) is the effective piezoelectric constant.

The torsion angle of the composite plate varies with the increasing voltages are shown in Table 1. And the proportional relationship of these two variables is shown in Figure 2, where the maximum deflection angle is 3.32°.

**Figure 1.** The MFC actuator

**Table 1.** Deflection angle and displacement at different voltages

| Voltage (V) | Displacement (mm) | Deflection Angle (°) |
|-------------|-------------------|---------------------|
| 300         | 2.08              | 0.66                |
| 600         | 4.53              | 1.44                |
| 900         | 6.65              | 2.12                |
| 1200        | 8.27              | 2.63                |
| 1500        | 10.41             | 3.32                |

**Figure 2.** Structural deflection angle under different driving voltage

2.2. The Modal Analysis of Carbon Fiber Wing Ribs

Then, a new kind of the experimental model of morphing swept wing are design and the dynamical characteristics are analyzed in this part. In order to optimize the structure of swept wings and minimize the weight, we design a full carbon fiber composite wing rib structure as shown in Figure 3.
it contains four cantilever fin plates with certain radians and connected by the slots board, the geometrical parameters are: The total length is 410mm, the maximum height is 110mm, and the thickness is 0.2mm. The MFC actuators are fixed at the root of the fixed end in the two middle fin plates to drive the deformation as what has been finished in the section 2.1

![Image 3](image3.png) ![Image 4](image4.png)

**Figure 3.** The three dimensional wing rib model  
**Figure 4.** Physical model of wing rib

JZK-5T are applied at the root of the experimental model to simulate the aerodynamic disturbance, and The B&K 4517 acceleration sensor is mounted at the rear of the wing rib. Firstly, the first and second natural frequencies of the structure are obtained as 9Hz and 28Hz, respectively, through sweep test of LMS test lab [5]. Then, the dynamical behavior of the morphing wing in the resonant case is studied. Set the frequencies of excitation forces be 9Hz and 28Hz, respectively and increase the amplitude of the forces though change the voltage of signal generator which can change the amplitude forces of the excitation. At the same time, the extra voltage 1500V is added to the wing rib. And the maximum swept angle is 10.72°.

![Image 5](image5.png)

**Figure 5.** Some mode shapes corresponding to the natural frequencies of the model
The figure 5 shows the vibration modes of the first and second natural frequencies. And the varies of the amplitudes of the wing with voltage are shown in Figure 6. It is concluded that the displacements of middle two wing ribs with MFC are relatively synchronous at the first frequency, which have large amplitude at the root of the ribs. In the second frequency, the vibration of the outer flank ribs is more violent and they are out of sync.

3. Conclusions
In this paper, a new type of driving material MFC is proposed, and a deformable machine rib model is designed. The feasibility of this method is demonstrated through preliminary experimental exploration. The performance of composite plate with MFC actuators are measured firstly. Deflection angle is proportional to the driving voltage and the maximum deflection angle is 10.72°. Secondly, a kind of intelligent fin structure with MFC as driver is designed, and the modal performance of the structure is analyzed. The vibration of the two wing ribs is more synchronous under the first resonant frequency and they are different under the second resonant frequency. This study lays a foundation for the feasibility of applying the morphing swept-back airfoil with MFC.

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