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In-plane corrugated cosine honeycomb for 1D morphing skin and its application on variable camber wing

Liu Weidong [a], Zhu Hua [a,*], Zhou Shengqiang [a], Bai Yalei [a], Wang Yuan [b], Zhao Chunsheng [a]

[a] *State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*
[b] *Institute of Science, PLA University of Science and Technology, Nanjing 211101, China*

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Abstract A novel 0-Poisson's ratio cosine honeycomb support structure of flexible skin is proposed. Mechanical model of the structure is analyzed with the energy method, finite element method (FEM) and experiments have been performed to validate the theoretical model. The in-plane characteristics of the cosine honeycomb are compared with accordion honeycomb through analytical models and experiments. Finally, the application of the cosine honeycomb on a variable camber wing is studied. Studies show that mechanical model agrees well with results of FEM and experiments. The transverse non-dimensional elastic modulus of the cosine honeycomb increases (decreases) when the wavelength or the wall width increases (decreases), or when the amplitude decreases (increases). Compared with accordion honeycomb, the transverse non-dimensional elastic modulus of the cosine honeycomb is smaller, which means the driving force is smaller and the power consumption is less during deformation. In addition, the cosine honeycomb can satisfy the deforming requirements of the variable camber wing.

1. Introduction

Morphing aircraft is drawing considerable attention all over the world for its capability of self-adaption during various flight conditions.[1,2] The researches on morphing aircraft mainly concentrate on morphing wing for it allows a single aircraft to perform multiple missions effectively and efficiently.[3–7] As described by Thill et al.,[8] a morphing skin can be envisaged as an aerodynamic fairing to cover an underlying morphing structure and transfer aerodynamic loads of the morphing wing, so flexible skin becomes one of the key technologies of morphing aircraft.[9] Thill et al.[8] pointed out three main areas of research in the review of morphing skin technology: compliant structures, shape memory polymers (SMP), and elastomeric skins. Hetrick et al.[10] proposed compliant structures based on a tailored internal structure and a traditional skin material to allow small amount of trailing edge camber change. These resin-matrix-composite skins are unsuitable because they are not lightweight and unable to achieve large strains

* Corresponding author. Tel.: +86 25 84896131.
E-mail addresses: 314116796@qq.com (W. Liu), hzhu103@nuaa.edu.cn (H. Zhu).

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when needed. Perkins et al.[11] and Bye and McClure[12] studied the flexible skin based on the material of SMP. SMP skin can get large deformation when heated and cooling and can return to its initial state by re-heating and re-cooling. However, the skin is also not light and manufacturing of the skin is complicated; and besides, it is difficult to implement heating of the SMP to reach transition temperature in the wind tunnel test and it is a high-risk option. Flanagan et al.[13] have been successfully implemented the elastomeric skin on the MFX-1 UAV. The elastomer skin is reinforced by ribbons stretched taught immediately underneath the skin, which proved suitable for wind tunnel testing. However, suitable improvements over the skin, such as a better developed substructure, can be more efficient for morphing. Yokozeki et al.[14] proposed a corrugated flexible skin structure. Refs.[15–17] further studied the equivalent models of several corrugated panels. The structure forms of out-of-plane corrugations and was manufactured from carbon fiber plain woven fabrics. Low transverse non-dimensional elastic modulus (the ratio of transverse equivalent stiffness modulus to the elastic modulus of raw material, E_x/E) can be obtained by choosing appropriate parameters of the structure. However, the thickness in the normal direction of the structure has to be large enough so as to get a low transverse non-dimensional elastic modulus and thus the structure is not light enough for application. Moreover, the fabrication of the structure is complicated. Olympio and Gandhi[18,19] studied 0-Poisson's ratio honeycombed structures, the hybrid and accordion honeycomb. The two honeycombs, whose transverse non-dimensional elastic moduli have nothing to do with the thicknesses in the normal direction, are lighter than structures mentioned above. There into accordion honeycomb is lighter than hybrid honeycomb. In addition, these two flexible honeycombs can be easily manufactured by water jet cutting. Gandhi and Anusonti-Inthra[20] brought into focus some design considerations for flexible skins. It is significant that the skins must have low in-plane stiffness to minimize actuation energy. Traditional flexible honeycombs such as hybrid and accordion honeycomb mentioned above can be further improved to raise the efficiency of the deformation. So structure with lower transverse non-dimensional elastic modulus should be developed to constitute a more efficiency flexible skin.

Taking the advantages of the corrugated structure and the honeycombs mentioned above, a new kind of in-plane corrugated cellular structure, cosine honeycomb is proposed to satisfy the requirements of the flexible skin. Similar to accordion honeycomb, the in-plane corrugated honeycomb is lighter and has better manufacturability than other traditional flexible structures. Most significant of all, it has a lower transverse non-dimensional elastic modulus than the existing flexible honeycombs and is more conducive to morphing. First, mechanical properties are studied and verified by finite element method (FEM) and experiments. Then comparison analyses and verification experiments on cosine and accordion honeycombs have been done to see the differences of the transverse non-dimensional elastic moduli and the energies required by morphing between the two structures. Finally the application of the cosine honeycomb on the flexible skin is discussed.

2. Mechanical properties

The cosine honeycomb mentioned above consists of two supports (one is on the left side of the whole structure and the other is on the right), cosine beams and longitudinal beams, as shown in Fig. 1 (in which F is the tension load, and U the displacement load). The structure is designed for flexible skin and should change its shape when needed. Here the in-plane characteristics of the structure are studied through mechanics method, FEM and experiments.

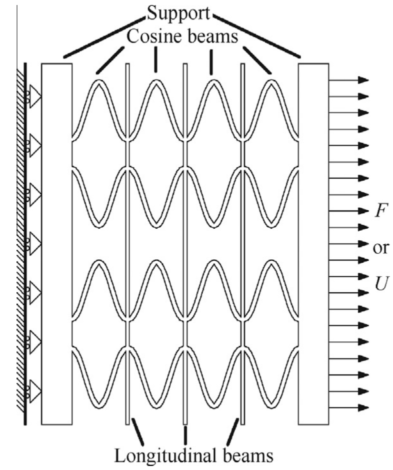

Fig. 1 Structure of cosine honeycomb.

2.1. Transverse properties

This type of cosine honeycomb is basically to deform in one dimension, so tension-compression characteristics of the honeycomb structure are the main objectives to study. Hence the left support of the structure is clamped; the other support is loaded with pulling or pushing pressure or displacement load, as shown in Fig. 1. Then the transverse non-dimensional elastic modulus of the structure could be measured by the corresponding deformation or counter-force.

The deformation of the longitudinal beams is far smaller than the cosine beams and the longitudinal beams have little influence on the transverse non-dimensional elastic modulus of the structure in the load case when the structure is loaded in the transverse direction. The basic cosine cell is picked out to study. Suppose the amplitude of the cosine beam is h, half-wavelength is l, width is t, and normal thickness is b, as shown in Fig. 2.

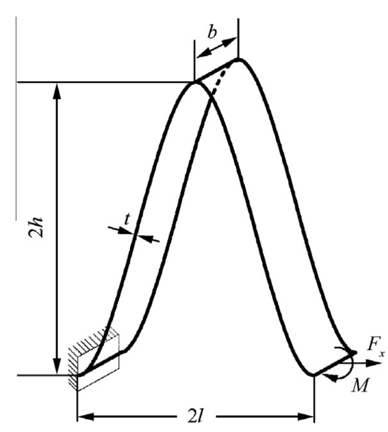

Fig. 2 Single cosine beam.