NOVEL MORPHING SKIN STRUCTURES BASED ON SMART MATERIALS AND STRUCTURES

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Summary Traditional aircrafts are designed according to their particular missions, and usually optimized in the most concerned flight performance. However, the geometry of wing is not always optimal in the various and continuous flight environment. Morphing aircrafts can realize the optimal objective through changing its aerodynamic layout according to the outside flight environment. One of the key techniques to realize morphing aircraft is the morphing skin. This paper presents some recent progress of morphing skin base on smart materials and structures. Special emphasis are focused upon morphing skin based on shape memory polymer (SMP) and its composites, pneumatic muscle fiber (PMF) and variable stiffness tube. Some primary tests are conducted on these morphing skins and the test results confirm the feasibility of morphing methods. In addition, some theoretical methods are developed to analyze the morphing skins and their components. The presented analysis provides useful guidance to assist design and manufactures of morphing skins.

INTRODUCTION

Through the history of the aircraft, aircrafts have been designed according to the special mission, flight altitude, Mach number and flight weight of the aircrafts, as well as usually optimized in the most concerned flight performance. However, the geometry of wing is not always optimal in the various and continuous flight environment. In view of these, morphing aircrafts are designed to solve this issue, and the recently emerged smart materials and structures open an avenue to the development of morphing aircrafts. One of the key techniques to realize morphing aircraft is the morphing skin [1], which should possess low in-plane stiffness to ensure enough deformation, as well as high out-of-plane stiffness to handle the aerodynamic load [2].

SMP MORPHING WING

As a typical smart material, shape memory polymer (SMP) possesses the flexibility under high temperature condition and the rigidity under low temperature condition, which are able to recover their original shape upon applying an external stimulus. Due to many novel properties and great potential, SMP has been one of the most popular subjects under intensive investigation in recent years. In order to maintain airfoil shape throughout transition and not to suffer from large out-of-plane deformation under aerodynamic pressure loads, a sandwiched structure is designed by Yin et al. [3]. It consists of honeycomb and SMP skins. It is capable of changing in chordwise and increasing chord by 20%. Embedded heating wire springs act as the activation system for the SMP. Experiment results show the morphing wing model with SMP skins can be driven successfully by DC motor.

Deployable wing technology can offer many benefits to specific flight missions, most importantly low-volume storage of the wings when the aircraft is not in-flight. Deployable wing designs enable aircraft to be more effective by providing large numbers in volume-restricted applications [4]. Base on the application of SMP, a deployable morphing wing is proposed by Yu et al [5]. The designed morphing wing consists three parts: SMP filler, metal skeleton and SMP plate. The primary tests are conducted on the designed deployable morphing wing, including the deploying velocity of the SMP filler and morphing wing as the main testing aspects. The test results demonstrate the feasibility and the controllability of designed deployable morphing wing. Furthermore, wing’s deformation under the aerodynamic loads is also analyzed by using the finite element method to validate the structural stability. Finally, same tests are conducted to investigate the recovery performances of SMP composites. During the test, the deployment and the wind-resistant ability of the morphing wing are dramatically improved by adding reinforced phase to the SMP.

In addition, Sun et al. [6] presented a new kind of epoxy SMPCs reinforced with different volume contents of spandex fiber. The research results show that epoxy SMPCs reinforced with spandex fiber brings some advantages to SMP, such as the improvement of Young's modulus and tensile strength, the increase of break elongation ratio and recovery speed, the decrease of recovery time. The new kind of SMPCs would be further expanding their application scopes in space, aerospace, electronics, automatics, and chemical industry.

VARIABLE STIFFNESS MORPHING SKIN

Recently, a new kind of variable stiffness skin that composed of variable stiffness tube and flexible matrix was proposed and studied [7, 8]. While the variable stiffness skin exhibits high out-of-plane stiffness, it can undergo large strain and has low in-plane stiffness. One of the key components is the variable stiffness tube, namely fluidic flexible matrix composites (F^2MC) tube. The variable stiffness tube is composed of outer FMC tube, inner liner tube and fluid.

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Significant changes of effective axial elastic modulus can be achieved through controlling the interior fluid. Based on classical laminated-plate theory and anisotropic elasticity, a three dimensional analytical method is proposed to characterize the axial mechanical behaviour of the F^2MC tube [9]. In comparison with the experiment result, the analysis is deemed to possess satisfying accuracy in the effective axial elastic modulus prediction of the F^2MC tube. In addition, it is also found that the modulus ratio can be significantly changed by adjusting the material and geometry parameters of F^2MC tube. The presented analysis could serve as reference to design and fabricate of F^2MC tube in variable stiffness skin applications.

MORPHING SKIN BASED ON PNEUMATIC MUSCLE FIBER

The nature always enlightens people in structure design, just as the morphing aircraft was invented after people got inspiration from the flight birds [10]. A kind of morphing skin embedded with pneumatic muscle fibers is proposed and fabricated from the bionics perspective [11]. The morphing skin realized the integration objective such as self-actuating ability, deformability and stress-bearing capability. The output force testing results show that the contraction ratio of the pneumatic muscle fiber in morphing skin is larger than the camber requirement of morphing skin with maximum strain level below 2% [12]. The stress-bearing capability testing result shows that the transverse stiffness can be regulated by the regulation of pressure value with different loads. It also could be seen that the objective of avoiding or restraining the swelling can be accomplished through regulating the pressure value and changing the transverse stiffness value.

CONCLUSIONS

In this paper, some recent progress of morphing skin base on smart materials and structures is presented. In order to realize the deformation function, several kinds of morphing skins based on shape memory polymer (SMP) and its composites, pneumatic muscle fiber (PMF) and variable stiffness tube are proposed. The primary tests and theory analysis are carried out on these morphing skins and their components. The experiment results demonstrate the feasibility of the designed morphing skins. The presented analysis provides useful guidance to assist design and manufactures of morphing skins. In addition, a morphing skin concept composed of NPR honeycomb substructure and flexible face-sheets is also proposed recently [13, 14]. This kind of morphing skin possesses low in-plane stiffness that can satisfy the deformation requirement, and high out-of-plane stiffness that can handle the aerodynamic load. It also shows great potential in morphing aircraft applications.

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