Advances in Technology Innovation, vol. 1, no. 1, 2016, pp. 13 - 15

Composite Elements for Biomimetic Aerospace Structures with Progressive Shape Variation Capabilities

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Received 01 February 2016; received in revised form 11 March 2016; accepted 02 April 2016

Abstract

The paper presents some engineering solutions for the development of innovative aerodynamic surfaces with the capability of progressive shape variation. A brief introduction of the most significant issues related to the design of such morphing structures is provided. Thereafter, two types of structural solutions are presented for the design of internal compliant structures and flexible external skins. The proposed solutions exploit the properties and the manufacturing techniques of long fibre reinforced plastic in order to fulfil the severe and contradictory requirements related to the trade-off between morphing performance and load carrying capabilities.

Keywords: morphing structures, composite structures, chiral topologies, corrugated laminates

1. Introduction

Morphing structures have been intensively studied in the last decades in the aerospace field, with the objective of developing innovative, more flexible and efficient methods to change the shape of aerodynamic surfaces. Imitation of nature plays an important role in conceiving such type of structures, since organisms have solved the problems related to flight control and adaptation to different flight phases without the use of rigid moveable surfaces, which are currently used in aircraft. For instance, a flexible wing with the capability of shape variation can increase the curvature, when higher lift is required at low velocity, whereas, at high speed, curvature can be reduced to decrease drag (1). Another concept, called "chiral sail" is proposed in (2) and is based on wing with a central morphing part that increases its camber when angle of attitude is changed (Fig. 1). This can lead to noticeable advantages for the surfaces that generate the forces for the stabilization of a vehicle, like the tail empennages of aircraft. Indeed, these surfaces could be reduced with overall weight saving and drag reduction. However, although morphing is an appealing concept, there are critical engineering issues to be solved for the development of such type of structures, which are hereby summarized in the following point:

a) Compliance of structures must be finely tuned to accomplish shape variations induced by aerodynamic loads (passive morphing) or of actuators (active morphing).

b) Shape can vary but must retain the aerodynamic efficiency, without angular points, surface waviness, and anomalous modification of profiles.

c) Aerodynamic loads acting in morphing directions must be transmitted, so that morphing structures must exhibit flexibility and strength at the same time (passive morphing), or reacted by load bearing actuators (active morphing).

d) Stiffness and strength in non-morphing directions must be maximized to avoid the need of additional structural parts that would increase structural weight, thus reducing or eliminating the advantages of morphing concepts.

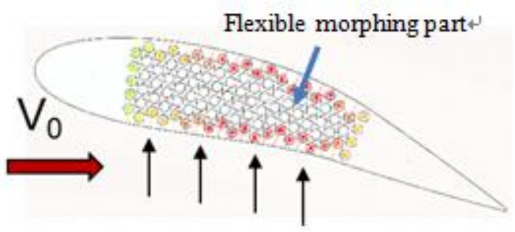

Fig. 1 Variable camber wing with central morphing part

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In the following sections, two concepts will be presented to fulfill the aforementioned severe and contradictory requirements.

2. Composite Chiral Structures

Chiral topologies are special non centre-symmetric geometries that consist of circular elements, called nodes, connected by straight ligaments (Fig. 2-A). Their deformation mechanism leads to a transverse expansion, when a tensile load is applied, and a contraction, under the action of a compressive load (Fig. 2-B). Hence, if the chiral tessellation is considered as a meta-material, it turns out to be characterized by a negative Poisson's ratio (auxetic behavior). Such response avoids the development of localized displacements and weak points, and allows the achievement of controlled shape variations, as it is shown in Fig. 2-C, referred to deformation modes of the chiral sail depicted in Fig. 1. For such reasons, chiral topologies were proposed to develop the internal structure of morphing airfoils [1], but manufacturing of chiral honeycombs represent a critical problem for application to real world structures. The process devised at Politecnico di Milano (4), allows the production of composite chiral elements by means of a procedure based on the bonding of composite units, which are produced in a previous step and then uniformly pressed together during bonding by means of elastomeric inserts (4,5). The resulting composite chiral elements can be produced with very thin ligaments and different types of composite materials, thus enhancing the design flexibility of the concept. Some examples of manufactured chiral elements are provided in Fig. 3.

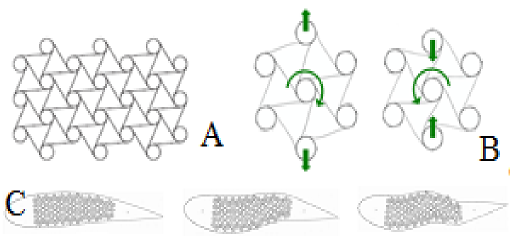

Fig. 2 Chiral topologies (A) deformation mechanism (B) and deformation mode of a chiral airfoil (C)

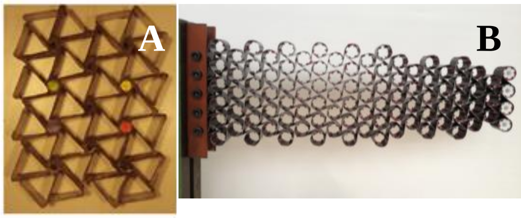

Fig. 3 Composite chiral honeycomb (A)and composite chiral rib for the chiral sail concept (B)

3. Composite Corrugated Laminates

The development of morphing surfaces always requires the development of a flexible skin to collect aerodynamic forces. The requirements presented in the introduction are valid also for the skin, which has to undergo large recoverable strains, carrying and transmitting aerodynamic pressures to the internal structure. Moreover, in traditional aeronautical constructions, skin also provides a valuable contribution to structural stiffness, so that optimal solutions should present adequate structural response in non-morphing directions. Composite corrugated laminates have been proposed (6) to develop skins thanks to their inherent anisotropy that allow high compliance and strains at failure in corrugation directions, and noticeable stiffness and strength in non-morphing directions (Fig. 4-A).

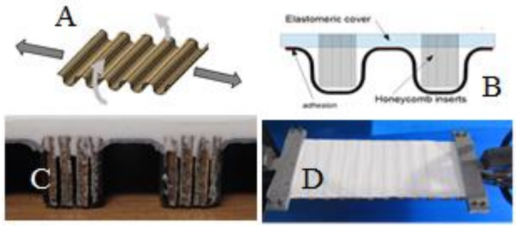

Fig. 4 Corrugated laminate (A) composite chiral rib for the chiral sail (B)

Unfortunately, the usage of composite corrugated laminates as morphing skin has a major drawback represented by the surface irregularities that increase aerodynamic drag and reduce the generated lift (7). For such a reason, a solution was developed at Politecnico di Milano (8) to integrate in the corrugated laminate an elastomeric layer, supported by honeycomb inserts (Figs. 4-B and 4-C). The developed skin system was tested up to elongation of 20% (Fig.

4-D), proving that the elastomeric layer provides a smooth efficient aerodynamic surface without interfering with the mechanical response of corrugated laminates. The composite corrugated laminates can be designed with appropriate lay-up and guarantee very high bending stiffness in non-morphing directions and even a not negligible shear stiffness, which can exceed 50% of the shear stiffness obtained by a conventional panel of the same weight and lay-up (8).

4. Concluding Remarks

The development of innovative solutions for internal structure and skin of morphing aerodynamic surface has been accomplished by jointly exploiting special structural geometries and the properties of composite materials. The presented solutions fulfil the peculiar requirements of morphing structures and have been applied to develop a demonstrator of the chiral sail concept, which is shown in Fig. 5, in order to assess technological feasibility, functional aspects and structural response.

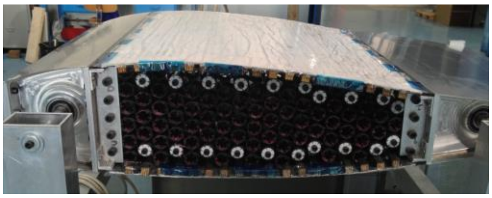

Fig. 5 Chiral sail demonstrator

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