Optimisation of Multistable Helical Structures using AFP Manufacturing

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Automated Fibre Placement (AFP) offers significant opportunities to create novel and highly adaptable morphing structures. Morphing structures are capable of undergoing large, controlled and seamless shape changes in order to optimise the structure for different requirements [1, 2]. Potential beneficiaries of such technology include the aeronautical and wind energy industries, that use morphing wings or blades to eliminate hinged aerodynamic surfaces. This leads to an increase in aerodynamic efficiency due to elimination of aerodynamic gaps, as well as a loss in weight due to removal of heavy and complex actuation systems. Further weight reductions are also possible through active load alleviation. As a result, aircraft benefit from a reduction in fuel consumption and carbon emissions, while wind turbines increase energy harvesting capabilities [3, 4]. Deployable structures also provide substantial benefits to spacecraft. Due to payload volume/weight constraints imposed by the launch vehicles, structures that can be stowed for launch and deployed in space are highly sought after [5]. Enhancing the shape changing capabilities of a structure while minimising weight is therefore of prime industrial interest.

Maximising the potential of morphing structures is currently hindered by the opposing requirements of a flexible surface capable of large deformations (enabling morphing), structural rigidity (reducing deformation under in-service loads) and low weight (to achieve efficiency goals) [6-8]. Composite materials can provide solutions to these challenges. Firstly, by exploiting anisotropic material properties and pre-stress of fibre-matrix composites, novel morphing structures with large deformations and tailored strain energy landscapes become possible. Secondly, the high strength-to-weight ratio of composite materials allows for strong yet lightweight structures. When combined, these properties enable lightweight yet stiff structures that can morph through careful control of their flexural stiffness. Finally, by exploiting fibre steering and precise control of AFP, it is possible to develop a new range of viable morphing structures featuring variable stiffness and complex geometries.

A morphing helix is an example of a deployable morphing structure that can be optimised further by AFP manufacturing. The structure consists of two curved composite strips, which are subsequently flattened and connected by rigid spokes. This process introduces pre-stress,

which can be tailored (by means of changing the spoke length, the strip's initial curvature or its stacking sequence) to provide the desired multistable response (see Figure 1).

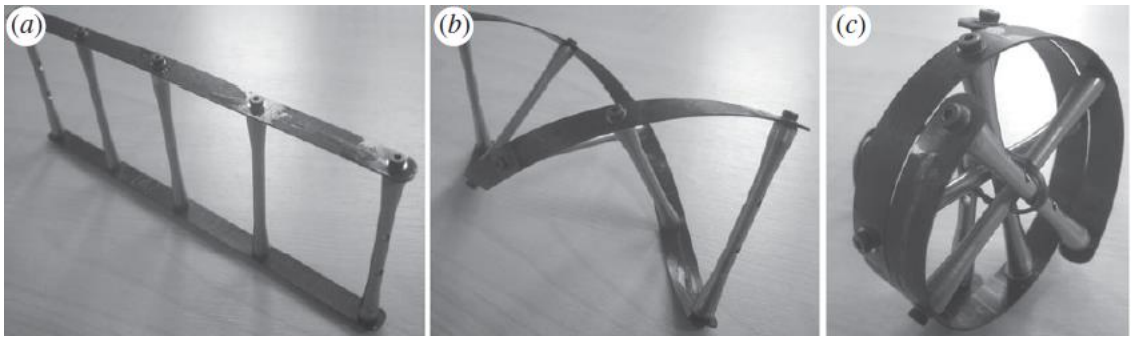

Figure 1 Multistable helical structure in (a) the straight, (b) the twisted, and (c) the coiled configuration. Reproduced with permission from [4].

It has recently been reported [9] that increasing the length of a multistable helix beyond a critical value can result in a *perversion* being introduced. This perversion reverses the direction of twist of the structure, as shown in see Figure 2(a), and creates new opportunities for morphing helices in morphing structures.

This work aims to observe experimentally the existence of a perversion in a multistable helix. AFP was used to manufacture the strips by laying carbon fibre reinforced plastic (CFRP) tape circumferentially onto a cylindrical mandrel. Once manufactured, the strip was cut into two 1 m lengths and assembled into a helix. Ten equally spaced spokes were used to connect the strips. Two multistable helical shapes were immediately obtainable, with a +/- 45° angle of twist. It was not possible to introduce any perversions in this configuration. However, upon removal of a spoke it was possible to introduce a stable perversion and reverse the direction of twist (see Figure 2(b)).

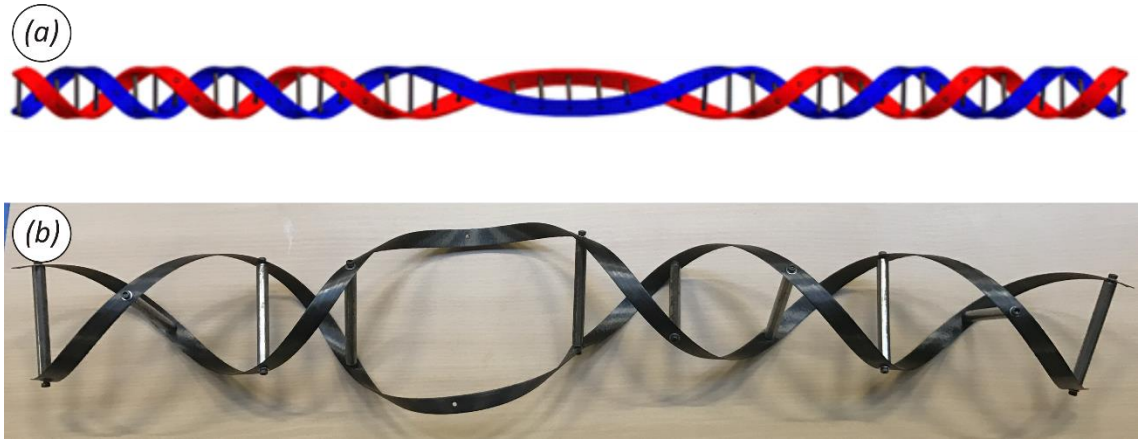

Figure 2(a) Example of a stable perversion in a helix (reproduced without permission from [9]), and (b) manufactured multi-stable helix featuring a stable perversion (note the missing spoke at the centre of the perversion).

The need to remove a spoke to introduce the perversion was unexpected. As such, a Finite Element (FE) model (based on [4]) was developed to capture the development of the

perversion. Results from this FE model are compared against a theoretical model (based on [9]) and experimental findings.

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