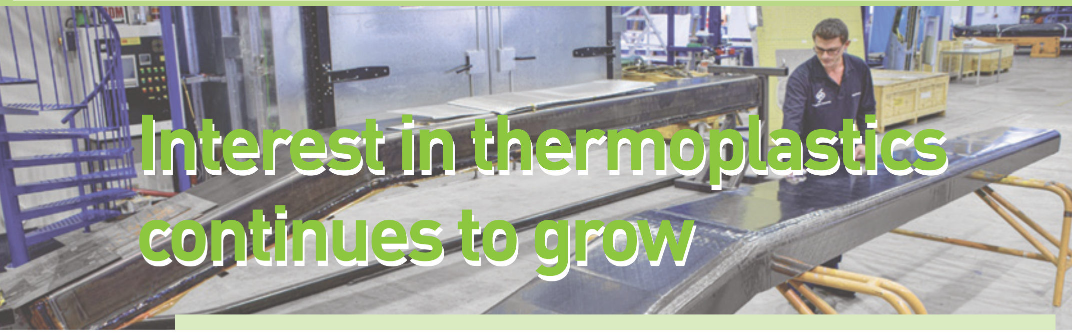

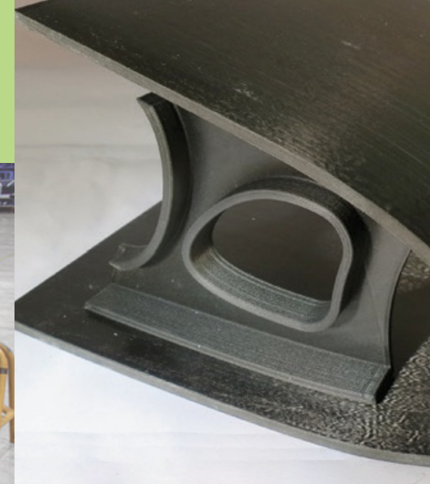

structural part

Structural characterization of a composite FishBAC morphing trailing-edge device

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The University of Bristol is currently developing a composite variable camber morphing device for airplane wings, the FishBAC concept. Its structural behaviour was simulated using a two-camera point tracking system, showing that the FishBAC can improve the airplane's aerodynamic efficiency by around 25%.

Airplanes can be controlled due to the existence of a series of rigid panels that are hinged to the wings. These panels are commonly known as ailerons, elevator and rudders and, when they deflect, they change the wings' pressure distributions. These changes in pressure induce changes in forces, which allows pilots to control airplanes.

However, these panels change the wing shape in a steep, discrete and discontinuous way, which increases the amount of drag. When drag increases, fuel consumption and noise also increase, reducing the efficiency of the aircraft. A more efficient solution is to generate these changes in shape in a smooth and continuous way. An alternative to hinged control surfaces is variable camber morphing devices, which achieve these deformations in a large, smooth and continuous way. One of these concepts, the FishBAC, is currently under development at the University of Bristol. Such a concept has already shown promising results in terms of drag reduction, achieving an improvement in aerodynamic efficiency of around 25% [1].

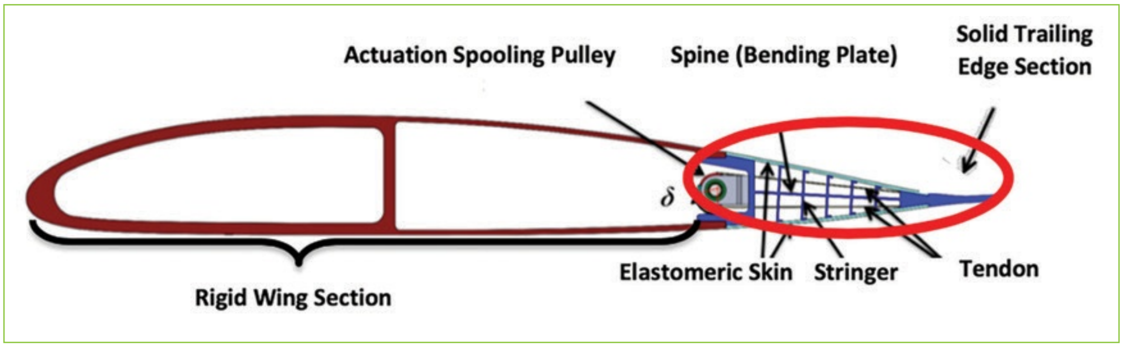

Fig. 1: The FishBAC morphing trailing-edge concept

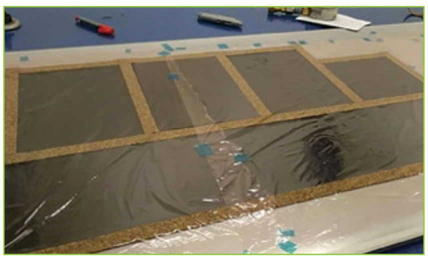

Fig. 2: Manufacturing the carbon fibre spine using a standard vacuum bag and autoclave curing process

Fig. 4: FishBAC wing during the static structure test. Extra light sources are added to increase the visibility of target points

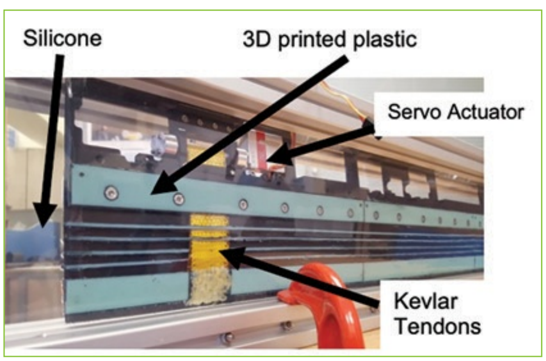

Fig. 3: Composite FishBAC model during the last stage of the manufacturing process (silicone skin bonding)

The Fish Bone Active Camber (FishBAC)

The Fish Bone Active Camber (FishBAC) device is a camber morphing concept capable of generating large, smooth and continuous changes in camber. It consists of a central load-bearing bending plate (spine) that has a series of spanwise stringers attached, an antagonistic tendon-based actuation mechanism and an elastomeric skin (Figure 1) [2].

Because the spine is located near the neutral axis, its overall contribution to the aerofoil stiffness is relatively low, allowing for large chordwise changes in camber. Furthermore, the presence of spanwise stringers gives the structure an anisotropic nature, making it much stiffer in the spanwise direction than in the chordwise one, helping to isolate the desired degree of freedom.

Manufacturing a composite FishBAC wind tunnel model

The focus on this first composite FishBAC is the spine, as this is the primary structural member responsible for camber change. For the time being, the other structural components will still be 3D printed, but this work can be considered the first step towards a fully-composite FishBAC.

The first step of the manufacturing process is to create the carbon fibre spine. The lay-up is performed on a flat aluminium tooling plate and cured in an 8552/IM7's standard autoclave vacuum bag cure cycle – maximum temperature of 180°C and autoclave pressure of 7 bar (Figure 2). Additionally, three other plates of the same material are cured in the same vacuum bag to allow for the measurement of material properties. The plastic parts of the wing are 3D-printed using a Stratasys® Objet™ printer, which uses direct jetting of a liquid photopolymer and cures it under UV light.
The stringers and the solid trailing edge end of the FishBAC are also 3D-printed using the same Objet printer.
The stringers are aligned using a series of laser-cut alignment jigs and are finally bonded to the carbon fibre plate using a cyanoacrylate adhesive [3].

Furthermore, the actuation loads are transferred from the actuators to the FishBAC's trailing-edge end using an antagonist tendon configuration. The tendons are made using dry Kevlar-fibre tape coated with Kapton tape, which protects the fibres and keeps them together.
The tendons spool around a machined aluminium drive pulley and are stitched onto the trailing edge of the carbon fibre spine (through small holes drilled into the spine) with Kevlar tow.
After stitching, the tendon is also bonded to the spine using epoxy resin, which provides a combined mechanical and adhesive attachment between

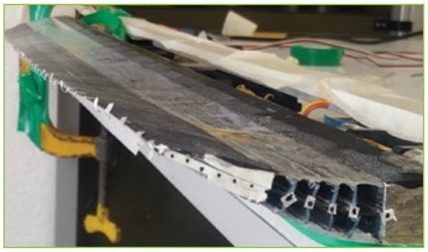

Fig. 5: Target point close-up along the chordwise direction

Fig. 6: Imetrum camera tracking chordwise points

tendon and spine.
Finally, a 0.5mm thick 40° Shore silicone sheet (Silex Superclear from Silex Silicones Ltd.) —that acts as the wing skin (Figure 3) — is bonded to the FishBAC's mounting cartridge, stringers and solid trailing-edge end using a fast-cure silicone adhesive (NuSil MED3-4013).

Structural testing

To both calibrate the actuation mechanism and characterise the structural behaviour of the FishBAC, a two-camera point tracking system, Imetrum's Universal Video Extensometer (UVX) Flexi that incorporates their Video Gauge™ software, is used to measure the transverse displacement of the FishBAC during actuation — but not under aerodynamic loads — along the trailing edge and on one of the chordwise ends.

Using a two-camera setup allows for capturing deflections in two different planes, which is crucial to determine both chordwise and spanwise stiffnesses. Figures 4, 5 and 6 show the Imetrum two-camera system and wing setup for the static actuation test.

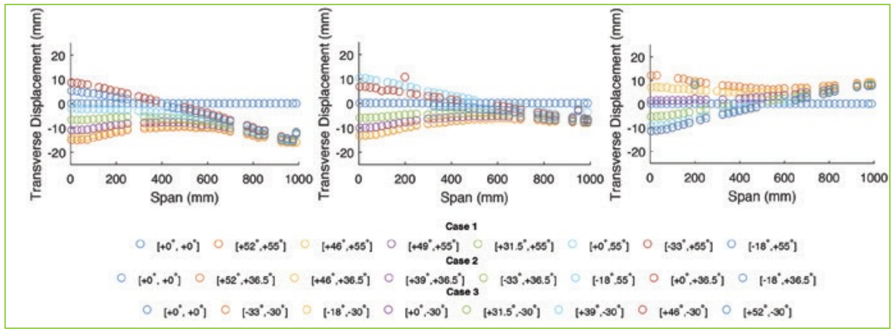

Fig. 7: Deflections — along the spanwise edge — for several actuation combinations

Andrés Rivero, PhD student at the Bristol Composites Institute (ACCIS), considers the Imetrum UVX Flexi system a powerful tool to perform these experiments: *"The Imetrum Video Gauge™ software allows us to capture deformed shapes — in two different planes — without having to apply a speckle pattern to the wing's surface. Because the FishBAC's skin is transparent and elastic, speckling becomes a difficult task. The UVX Flexi system is ideal when displacements need to be obtained, as it is easy to setup, requires no stereo calibration, and data post-processing can be performed with any calculation and graphing software."*

The results of this experiment allow the researchers to estimate the different geometries that the compliant trailing edge can achieve, under different load cases.
For example, it can be observed that, for different actuation inputs, displacements can vary as much as 13 mm, along a 1-metre span (Figure 7).

In conclusion, these preliminary results give the researchers the ability to validate mathematical models that simulate the structural behaviour of the FishBAC.
Future work includes displacement measurements of the composite FishBAC during wind tunnel testing. □

Acknowledgments
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More information:
www.bristol.ac.uk/composites/
www.imetrum.com/

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