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Enhanced Performance of Morphing Wing Through Composite Fabrication and Structural Health Monitoring

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Abstract: Structural health monitoring (SHM) in aircraft involves using sensors to assess the condition of critical components in real time, helping detect potential issues and improve overall safety. Common techniques include strain gauges, accelerometers, and non-destructive testing methods like ultrasound. SHM aids in early fault detection, minimising maintenance costs, and enhancing aircraft lifespan. Morphing wings have a large potential to improve the overall aircraft performance, as natural flyers do. By adapting or optimizing dynamically the shape to various flight conditions, there are yet many unexplored opportunities beyond current proof-of-concept demonstrations This project focuses on exploring the concept of bird-inspired morphing wing, a cutting-edge technology that aims to develop adaptive wing structures capable of altering their shape and configuration during flight.

Keywords: Structural health monitoring, Non Destructive Testing, Aerodynamic efficiency and morphing wings.

I. INTRODUCTION

A. Bird Aerodynamics

Birds dynamically adapt to disparate flight behaviours and unpredictable environments by actively manipulating their skeletal joints to change their wing shape. This in-flight adaptability has inspired many unmanned aerial vehicle (UAV) wings, which predominately morph within a single Geometric plane. By contrast, avian joint-driven wing morphing produces a diverse set of non-planar wing shapes.

Fig. 1 Albatross Bird

One of the key concerns in the aviation sector is enhancing the aerodynamics of flying objects under various flight situations. The design of an aircraft wing assigns maximum efficiency to cruise flying conditions, while other flight conditions, such as take-off, landing, and altitude control, result in suboptimal performance.

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The smart deformation in the wing configuration improves the aerodynamic performance of the aircraft; to put it another way, the deformable wing develops a unique configuration for each flight state by adjusting its shape to the present flight conditions. Because of the different flight conditions, it is impossible to discover a single configuration that increases aerodynamic efficiency and manoeuvrability.

B. Elastic Wings

Elastic aerofoils will significantly improve aircraft performance in the future. A basic problem here is that the structure, which is the aeroplane wing, needs to be flexible enough to bend elastically while also being robust enough to resist deformation from aerodynamic forces. The development of intelligent materials has made it possible to actively manage ductility deformation, preventing irreparable wing body distortion.

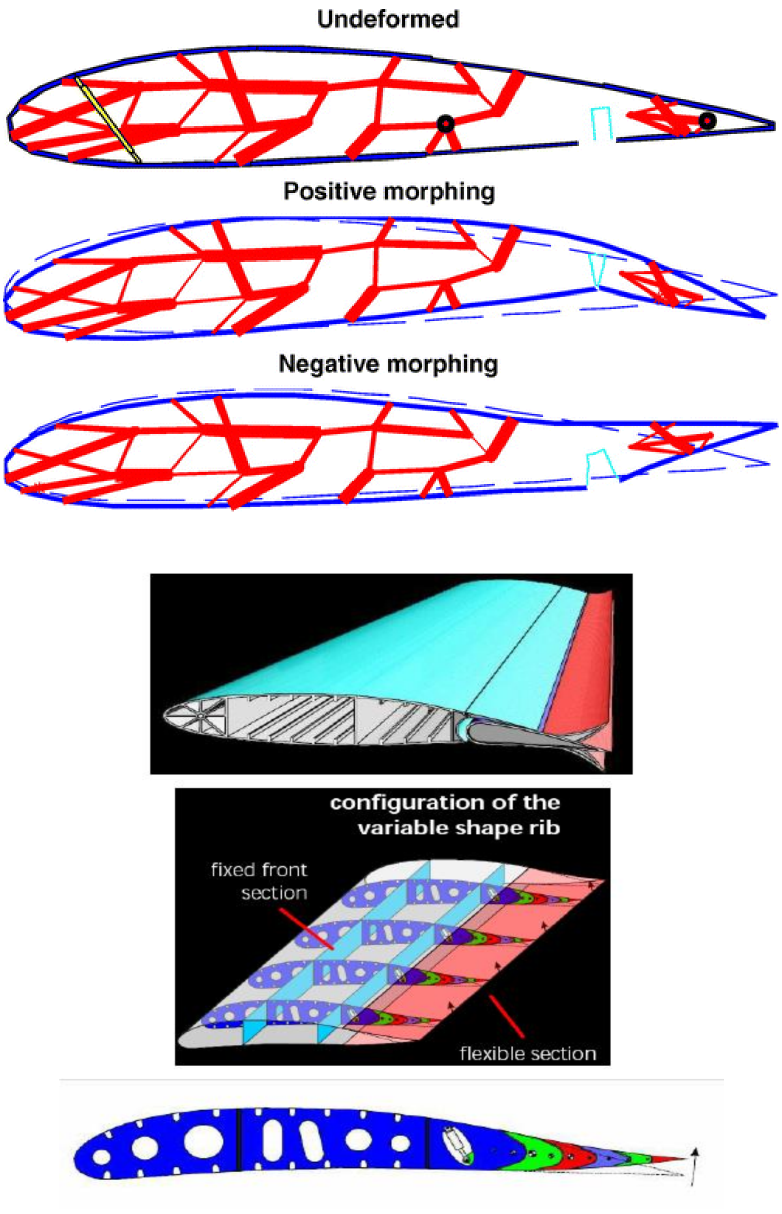

Fig. 2 Elastic Wings

Due to the many benefits of elastic wings, numerous efforts have been made in this area. A large body of work on morphing structures exists and is based either on material or shape morphing mechanisms. Some of these references classified morphing wings based on the geometry change or the actuator concepts, while other references focused on one specific element, such as special materials and relative techniques, special actuators and applications. Many attempts have been made in this field since elastic wings have so many advantages. There is a substantial amount of research on morphing structures that are either based on mechanisms for material or form morphing.

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C. Composites Structures/ Structural Health Monitoring

The aircraft sector has witnessed a surge in the use of composite structures owing to its mechanical attributes, including corrosion resistance and a high strength-to-weight ratio. The growing demand for lightweight structural materials is crucial in the aircraft industry, as structures must withstand general loads and vibrations to remain stable and undamaged. Sandwich composite material, consisting of a laminate composite and a core between skins, is a potential solution, Carbon fibre is chosen for its high mechanical strength, but studies have shown lower damping properties. This study aimed to determine vibration characteristics in the form of damping properties from various carbon composite specimens to create an effective carbon sandwich composite composition. As a result, there are now fewer maintenance tasks and lower operating expenses. However, internal damage that is invisible during maintenance processes might make it difficult to evaluate and monitor aircraft structural degradation. It is challenging to forecast how damage will increase in composite aircraft structures under stress due to the complexity of the damage mechanisms and growth behaviour. Maintenance engineers require a complete damage diagnosis on all four SHM levels, including damage detection, localization, type identification, and severity, for realistic aviation maintenance scenarios. The requirement for multi-sensor data fusion in aerospace applications for composite structures is increasing day by day.

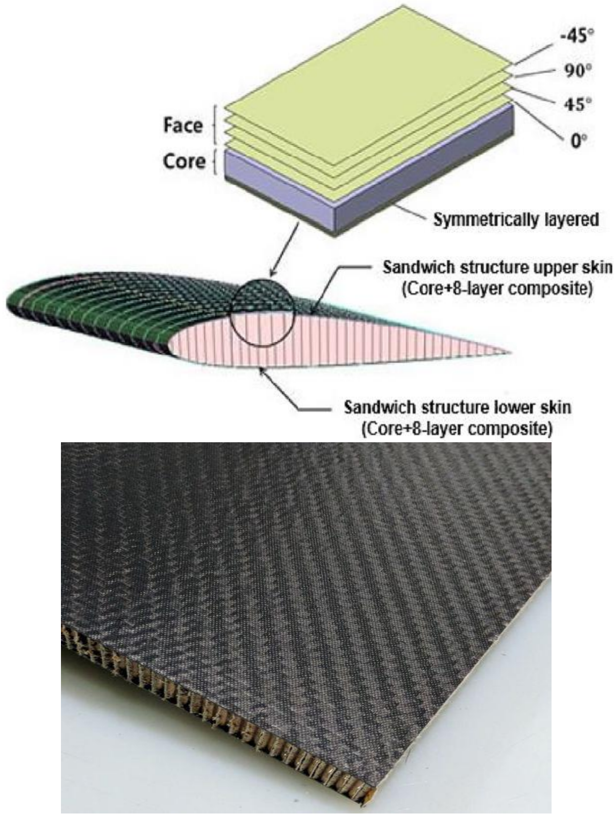

Fig. 3 Sandwich composites

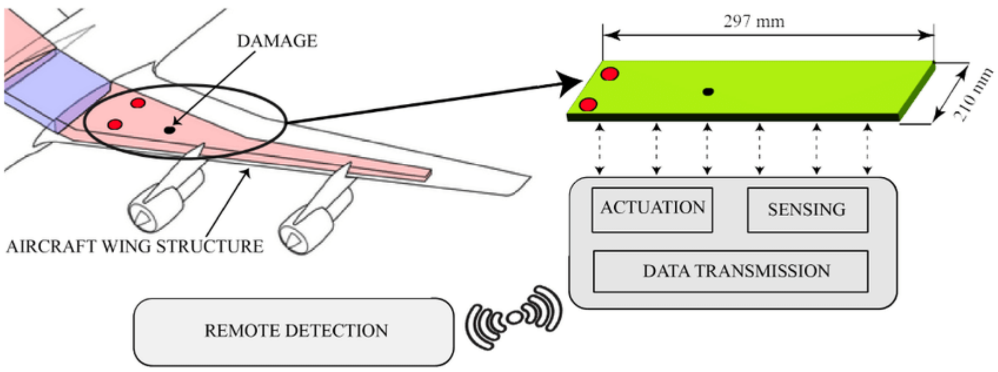

Fig. 4 Structural Health Monitoring

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II. DESIGN AND ANALYSIS OF MORPHING WING

The wing model was designed using XFLR5 software. Three aerofoil shapes were designed: the un-deformed NACA 4412 aerofoil and the two deformed NACA 4412 aerofoils at -15deg and +15deg. The aerodynamic characteristics were investigated by using the analysis software XFLR5 for the above three aerofoil shapes. Aerodynamic analysis was carried out under the following conditions: the flight velocity was 15m/s at an altitude of 9000m, air density, dynamic viscosity and kinematic viscosity were 1.79e-5m/s2, 1.46e-5m2/s, respectively. The lift coefficient, drag coefficient, and lift-to-drag ratio coefficient are compared among the three models. The lift-to-drag coefficient increased as the angle of attack increased for upward deflection, and for downward deflection the lift-to-drag coefficient increased when the angle of attack decreased. Design of the morphing wing:

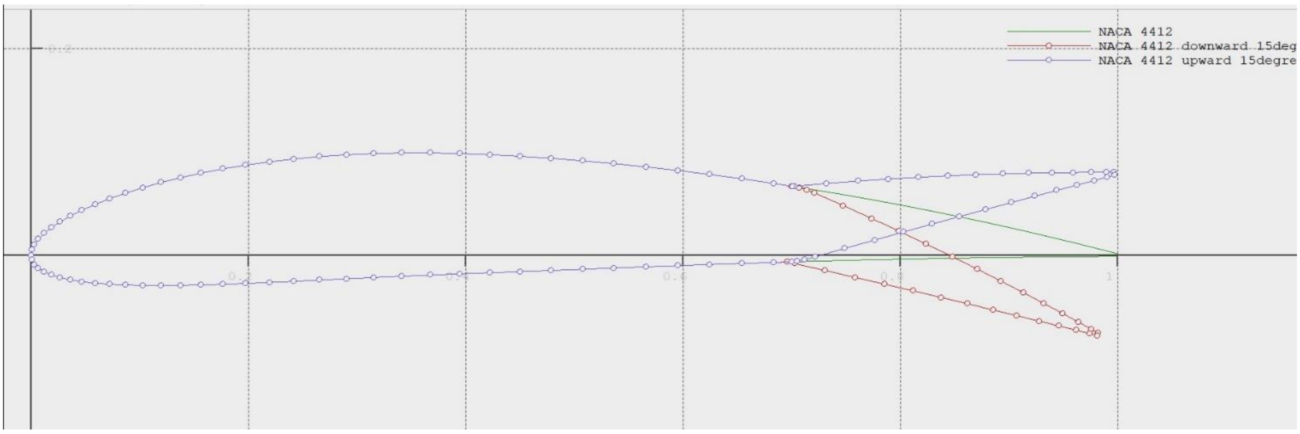

Fig. 5 Airfoils

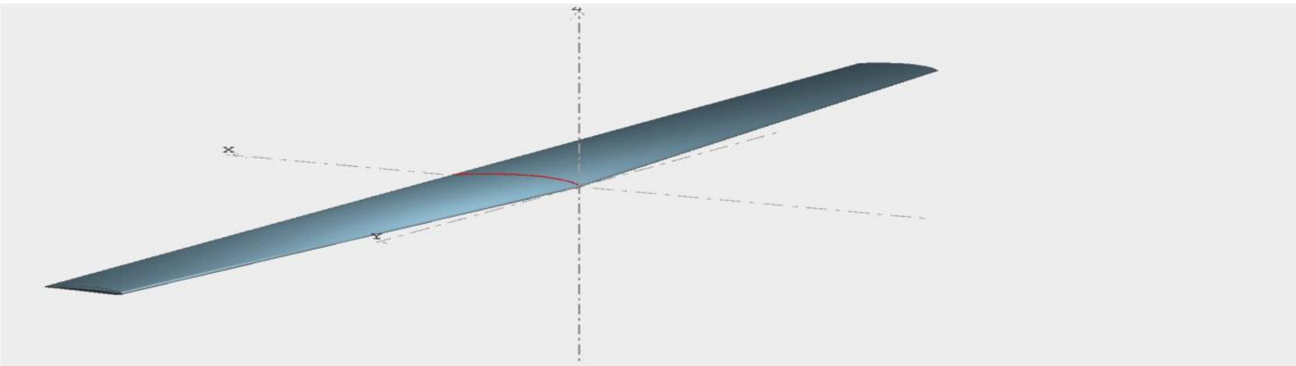

Fig. 6 Undeformed wing

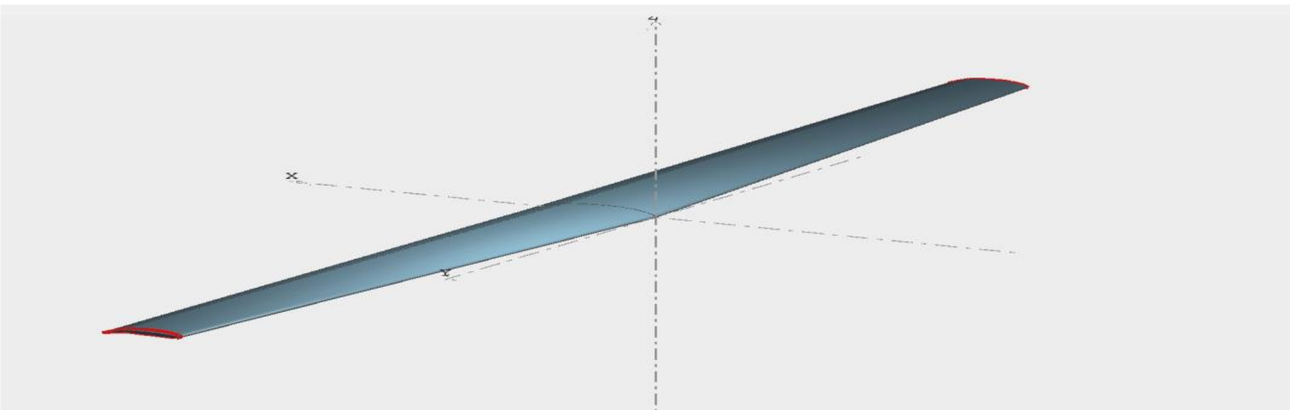

Fig. 7 Downward deflection of wing

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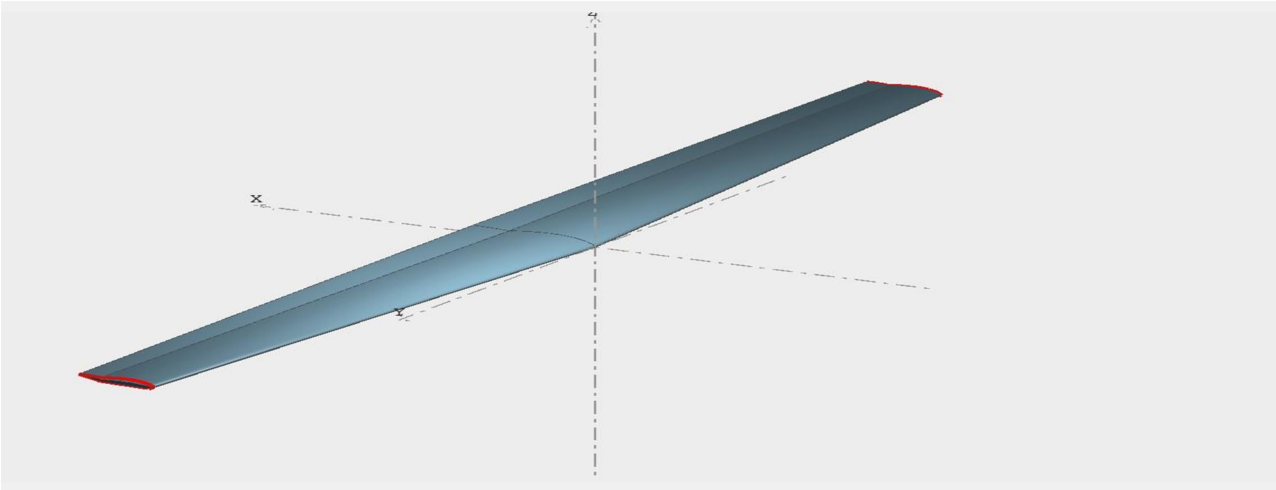

Fig. 8 Upward Deflection of the Wing

Here are some of the analysis results:

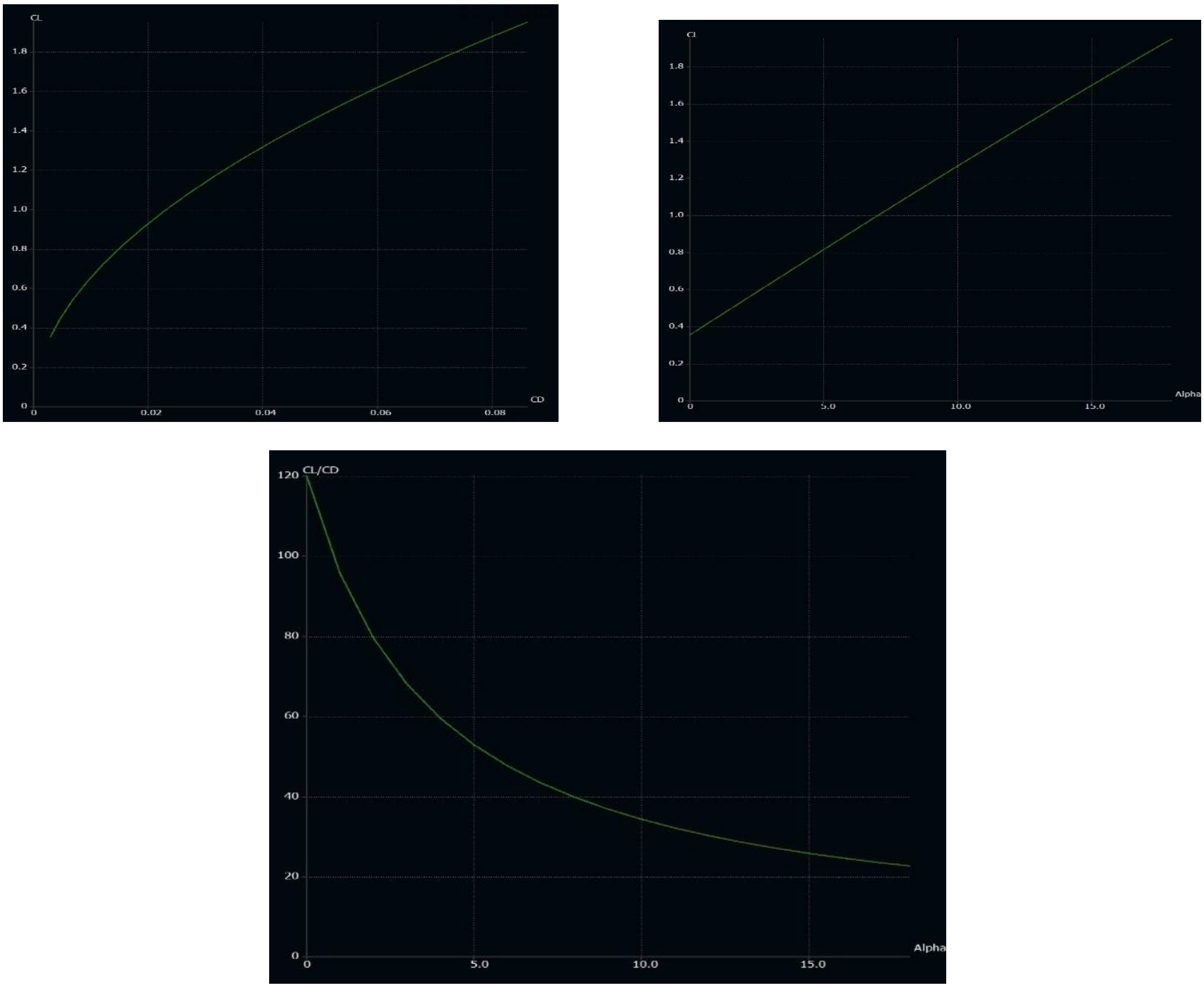

Fig. 9 Cl vs Cd, Cl vs Alpha and Cl / Cd vs Alpha for Undeformed Wing

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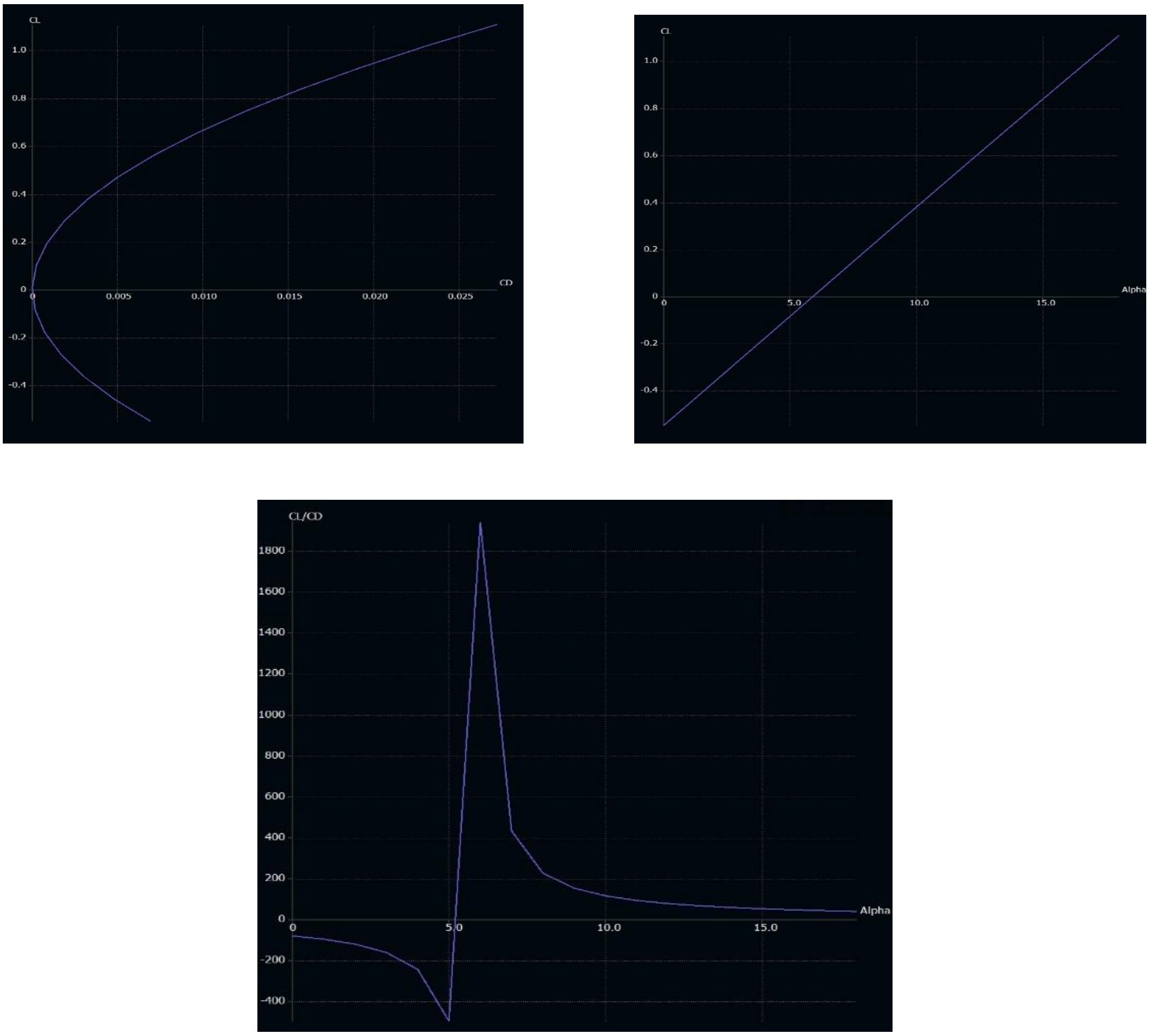
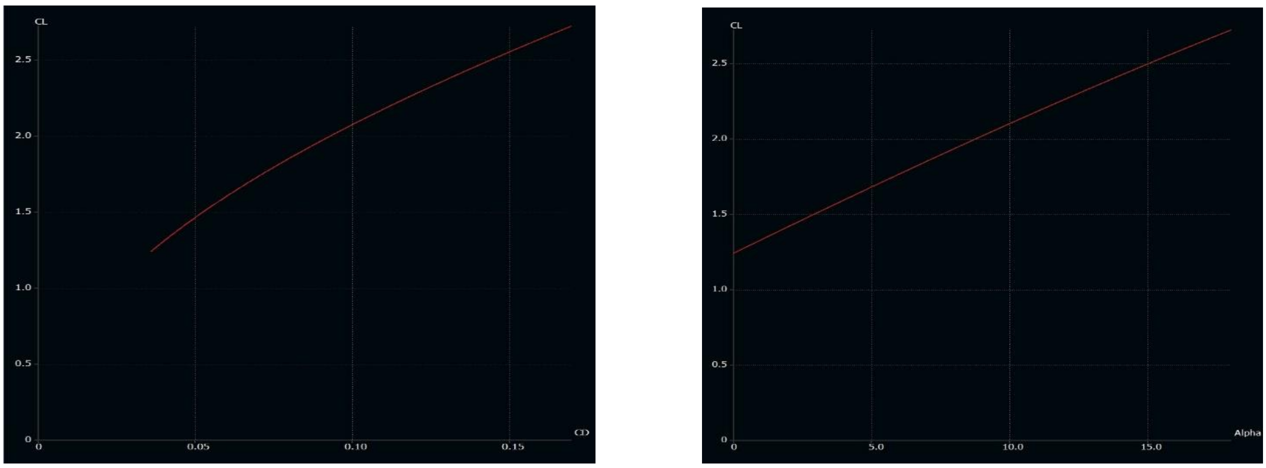


Fig. 10 Cl vs Cd, Cl vs Alpha and Cl / Cd vs Alpha for Upward Deflection of the Wing



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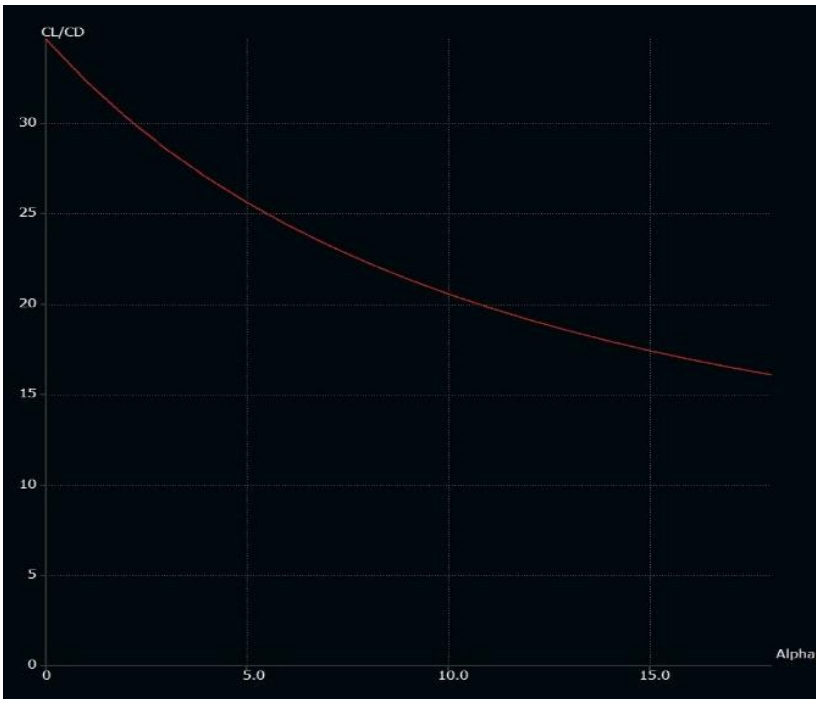

Fig. 11 Cl vs Cd, Cl vs Alpha and Cl / Cd vs Alpha for Downward Deflection of the Wing

The table of values showing the CL/CD ratio for the angle of attack at which the wing performs best is displayed by the analysis results displayed in the aforementioned diagrams.

Wing	**Angle of Attack**	**Cl/Cd Ratio**
Unmorphed wing	0deg and 1deg	120 and 95.54
Morphing wing (downward deflection)	0deg and 1deg	34.616 and 32.29
Morphing wing (upward deflection)	5deg and 6deg	-494.97 and 1941.33

III. FABRICATION AND ACTUATION OF THE MORPHING WING MODEL

The wing was manufactured manually; in this case, the hand-layup method was used for the production. Initially, we selected the wood for the model's preparation. Later, we used a CNC machine to slice the wood portion of the NACA aerofoil. After selecting the epoxy resin and hardener mixture for the fabrication, we later place the glass sheet on the mould’s surface. We apply the first layer using the resin mixture, followed by the fibreglass, and continue in this manner for two more layers using the fibreglass and resin. With the aid of a mould, the skin is produced in two parts so that the onsets can be positioned and co-bonded. In the centre of the wing body, the actuation mechanism is positioned to align with both skin halves.

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The CFRP rods are then inserted through the top skin and cemented to the onsets. A push-pull rod that is attached to the bottom skin in the back part is actuated by two electromechanical servos that are housed in the forward portion.

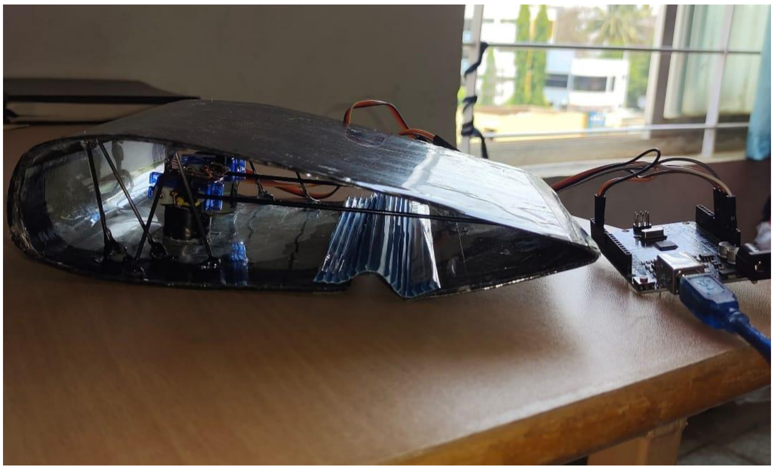

Fig. 12 Fabricated model using composite materials

IV. STRUCTURAL HEALTH MONITORING OF MORPHING WING

Utilizing piezoelectric sensors mounted atop the wing model and linked to a breadboard by jumper wires from each of the three sensors connected in series, structural health monitoring is accomplished. Afterward, we attached the oscilloscope probe to the breadboard. After the connections are complete, the oscilloscope is used to obtain readings by gently disturbing the model in both morphed and un-morphed states. The readings are transferred from the BMP file to the Excel sheet and the graphical data is stored in the BMP file format. The oscilloscope data visualization is displayed in the image below.

Fig. 13 Oscilloscope Data Visualization

V. CONCLUSION

Within this work, a new structural concept and parameterization for morphing wings based on periodic CFRP lattice structures is presented. The wing structure transfers the aerodynamic loads and provides the required load-carrying capabilities of the wing. The performed optimization, based on a verified aero-elastic analysis tool (XFLR5), enabled the exploitation of the large design space, resulting in a lightweight morphing wing.

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The optimized wing can withstand the acting loads without the occurrence of buckling and flutter, and it produces large deflections. The material of the structure is thereby arranged in a structurally efficient manner, removing any excess material and reducing the mass of the wing. Furthermore, the arrangement of the rods promotes shape morphing, which is used for active flight control obtained with an integrated actuation mechanism.

A demonstrator was fabricated to evaluate the actuation integration and morphing performance. To assess the lightweight and morphing potential of the wing, an optimization of the wing is carried out. For the investigated wing, the parameters describing the rod arrangement, the skin layup, and the actuation are optimized. A lightweight morphing wing with high load-carrying capabilities and sufficient rolling moment coefficient compared to existing morphing wings was achieved.

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