DESIGN AND DEVELOPMENT OF MORPHING AEROFOILS FOR FIXED-WING UAVS

Computational Sensing and Smart Machine Laboratory

A.K.M. De Silva   K.K.D.V. Chamika   T.H.S.D. Madhuranga

Supervisors – Prof. Nirosh D. Jayaweera   Dr. Asitha L. Kulasekera   Dr. Nalaka Samaraweera

Introduction

- Unmanned Aerial Vehicles (UAVs) have revolutionized aviation, but conventional fixed-wing UAVs face challenges in aerodynamic performance and manoeuvrability.
- Inspired by nature, the concept of "morphing" allows UAV wings to adapt their shape during flight for optimal performance.
- To address this, we propose a novel approach using morphing wings and soft actuation.
- Soft actuators, with their flexibility and compliance, enable real-time wing deformation, overcoming the limitations of rigid control surfaces.
- This project **aims** to design a practical and cost-effective solution for small fixed-wing UAVs **to improve the aerodynamic performance in different flight operations** using the morphing concept.

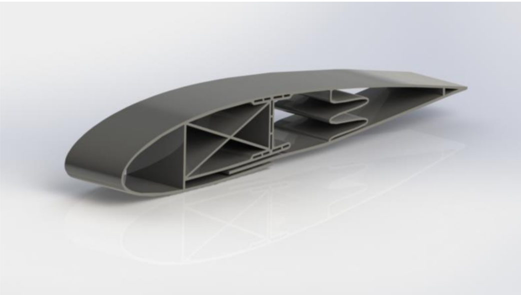
Objectives

1) Design a morphing aerofoil and its actuation mechanism for use in fixed-wing UAVs.
2) Fabricate the morphing aerofoil and evaluate the structural characteristics of the aerofoil.
3) Experimentally evaluate the aerodynamic performance of the morphing aerofoil.

Methodology

Aerofoil Design

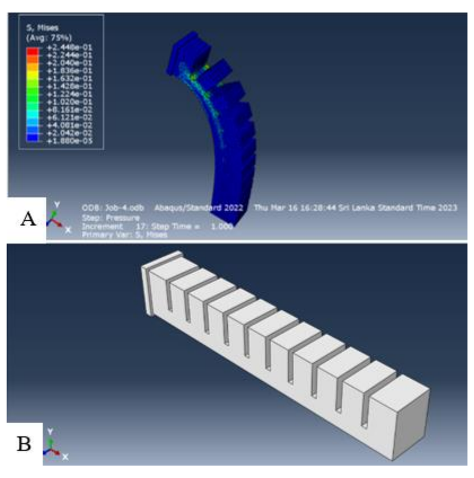
Original Concept (NACA 2412) [2]



Developed Concept (NACA 2415)

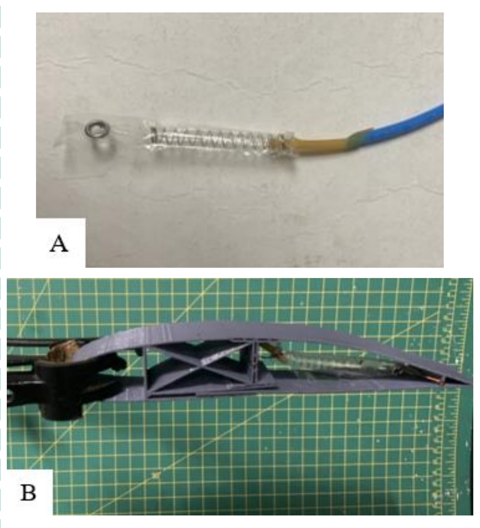
Actuator Conceptual Design

Concept 01



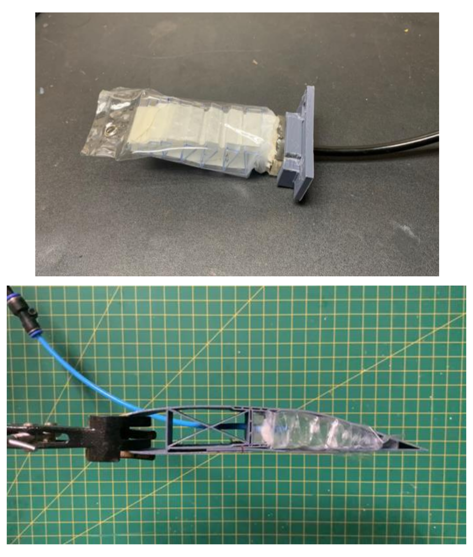
A) pneu-net actuator simulation done by Abaqus software B) 3D model of the actuator

Concept 02



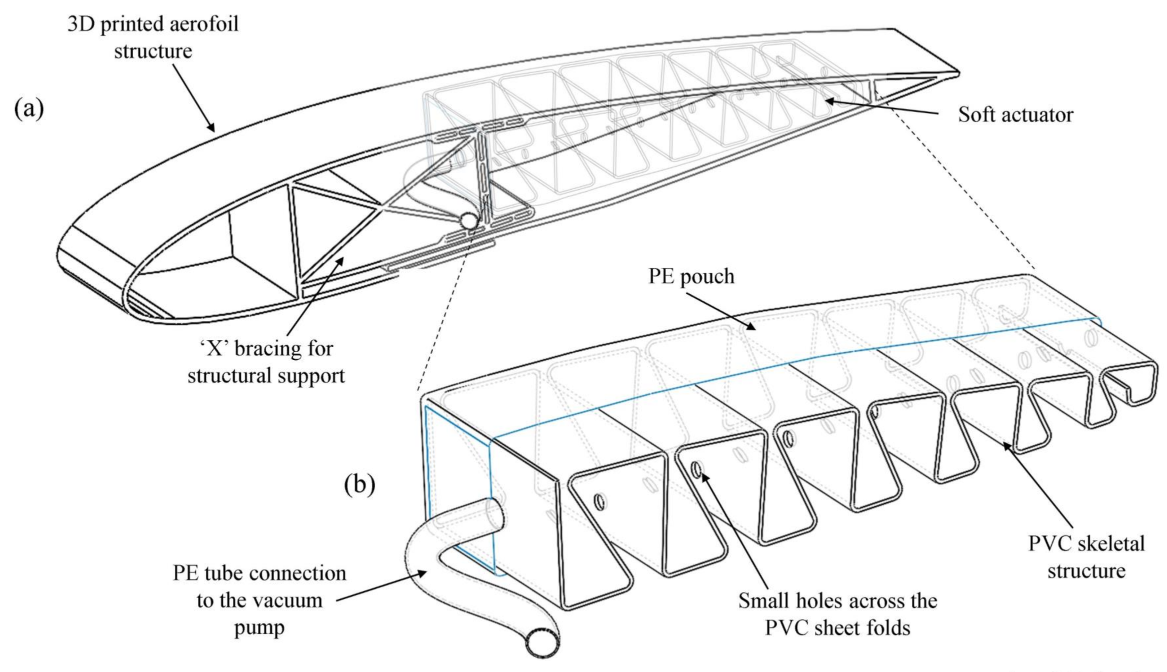
A) Spring actuator, B) Trailing edge morphing aerofoil with spring actuator

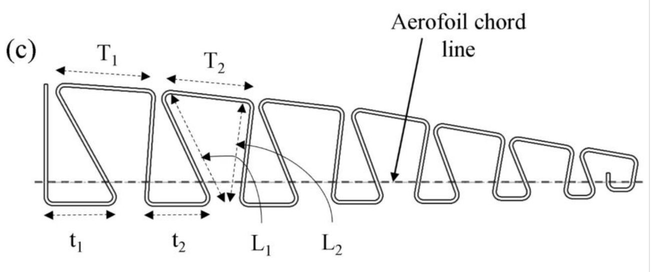
Concept 03



A) Origami-based actuator, B) Trailing edge morphing aerofoil with origami-based actuator

Selected Actuator Design



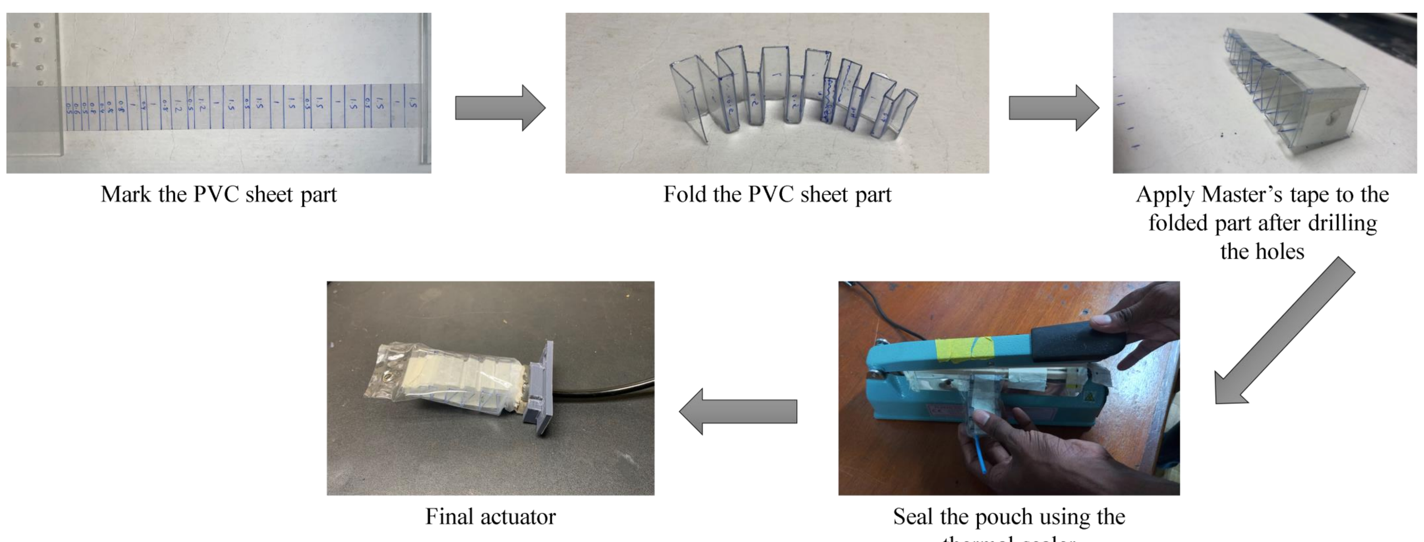


A flexible aerofoil structure (a) is proposed, capable of internal actuation to achieve multiple shapes through a soft pneumatic bending actuator based on an origami-inspired folding pattern (c). [1] The actuator's enclosed volume (b) allows for controlled bending motion by evacuating the air. The length reductions during transitions T1 to T2, t1 to t2, and L1 to L2 are 2 units and 1 unit, with an initial folding part length of 20 millimetres for Actuator 1.

$$\text{Morphing Section Ratio (MSR)} = \frac{c_m}{c} = 0.55$$

Where c_m is the morphing section chord length and c is the aerofoil chord length.

Actuator Fabrication



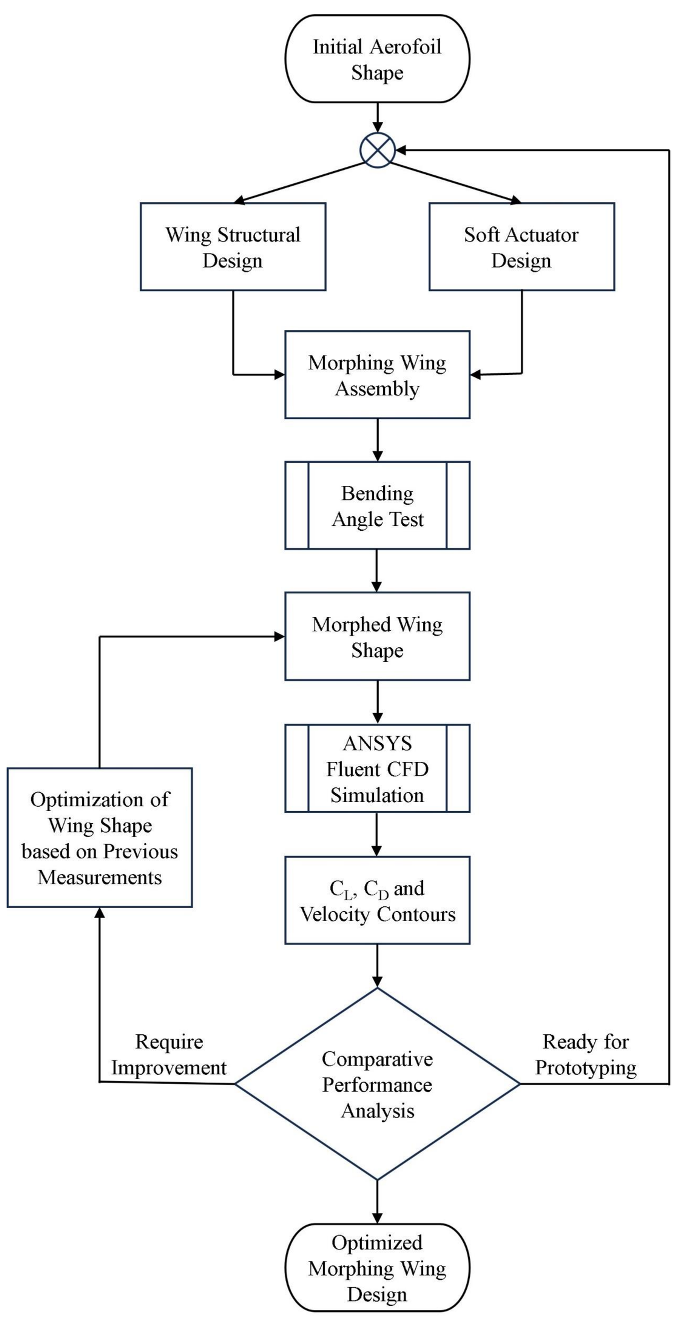
Future Works

- Evaluating more experiments using wind tunnels for a more detailed analysis of morphing aerofoils.
- Evaluating more experiments with more MSR value aerofoils.
- Evaluating CFD and FEA both together to find loads that need to be morphed with external conditions.
- Possibility of developing a control system with a closed loop system to automate the system.
- Evaluating experiments for leading-edge morphing aerofoil design.

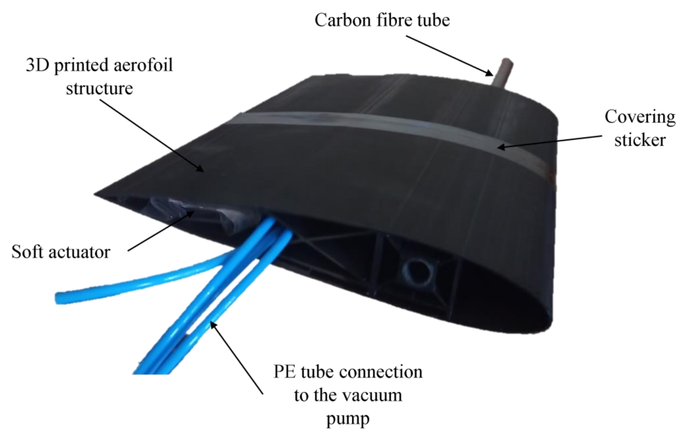
References

1. S. Himaruwan, C. L. Tennakoon, and A. L. Kulasekera, "Development and characterization of an origami-based vacuum-driven bending actuator for soft gripping,", 2023.
2. B. C. Moulton, '3D-Printed Morphing Wings for Controlling Yaw on Flying-Wing Aircraft', 2021,

Design Optimization

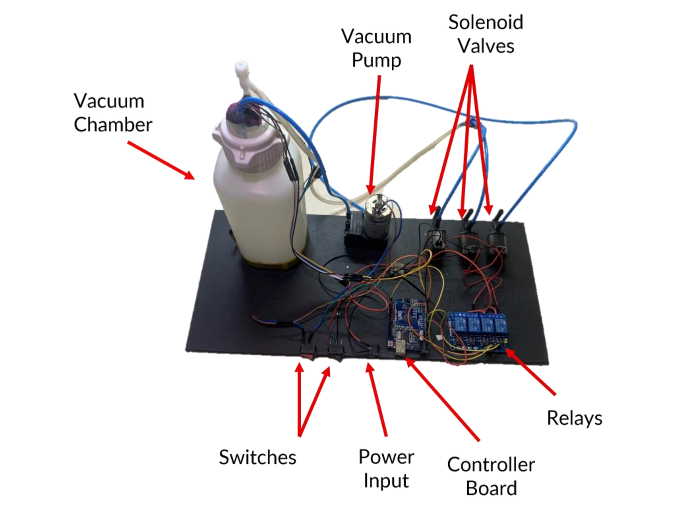


Completed Morphing Aerofoil



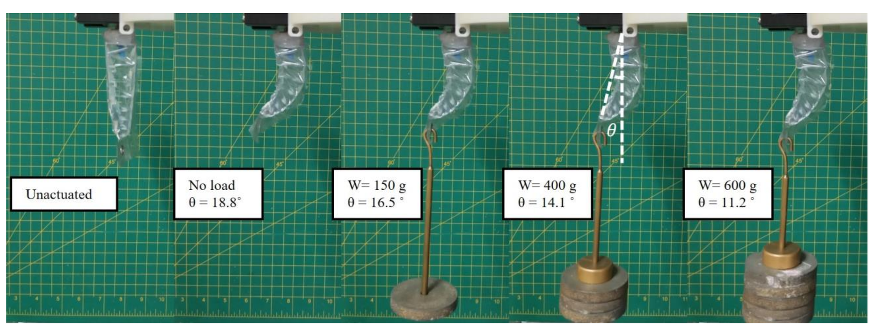
PLA Material | **20 cm** Chord Length | **30 cm** Span | **4** No. of Actuators | **11.1°** Bending Angle

Control System

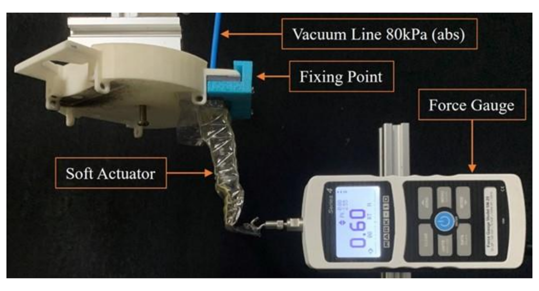


Experiments

Bending Angle with Lifting Force

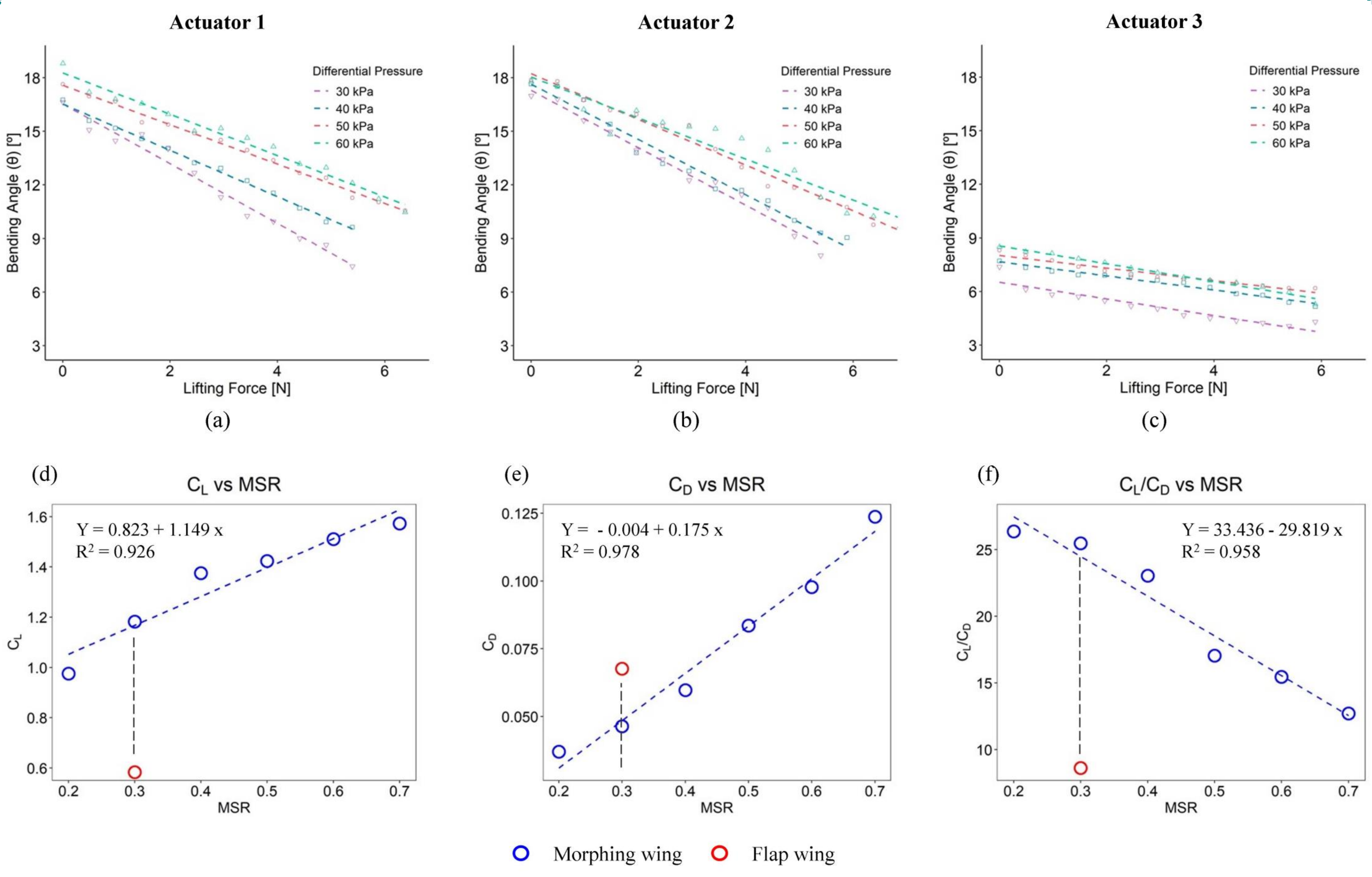


Blocked Force Evaluation

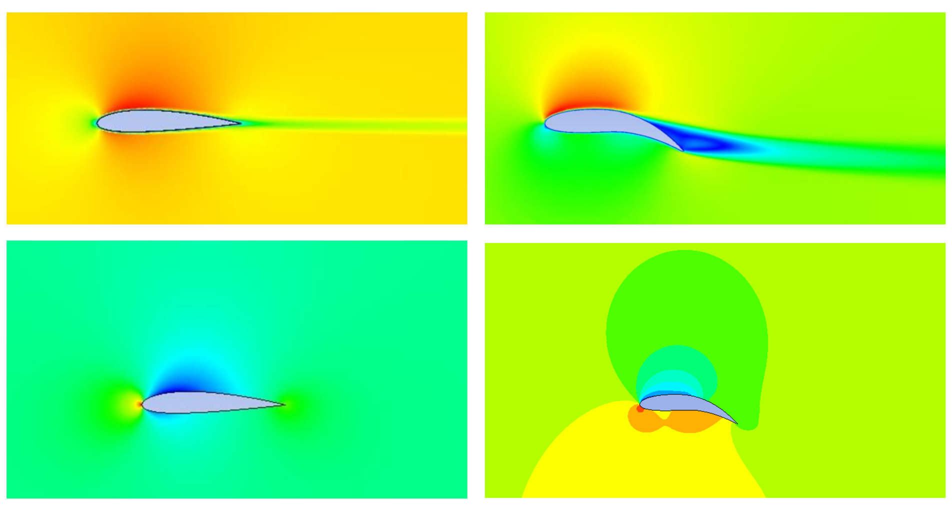


Wind Tunnel Experiment

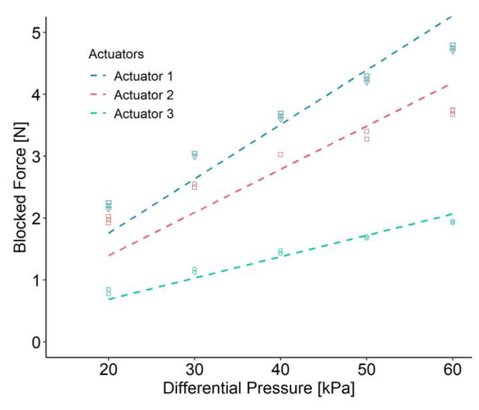
Results & Discussion



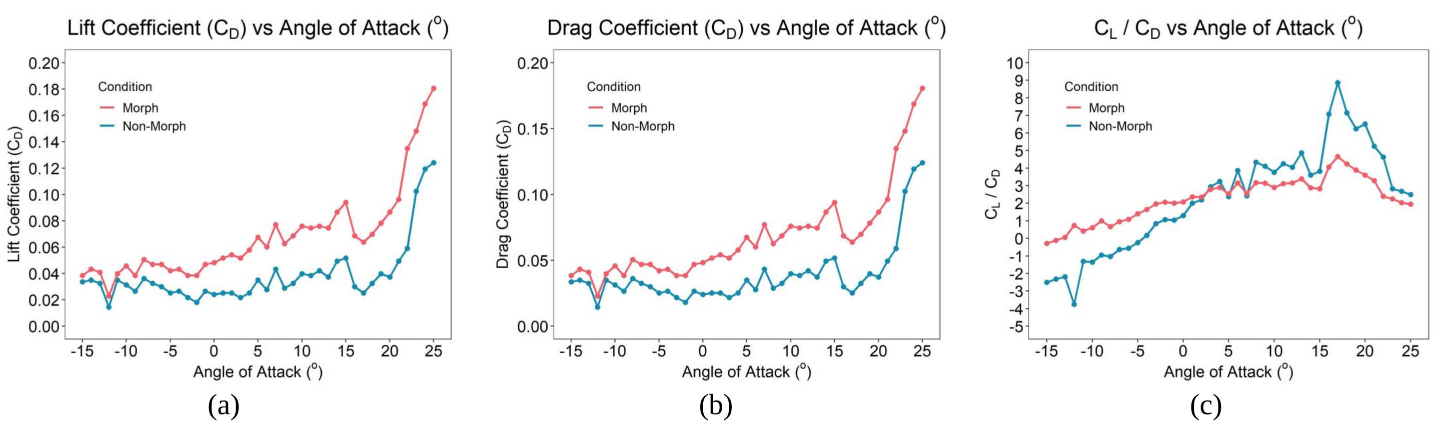
Bending angle Vs. Lifting force ((a) Actuator 01, (b) Actuator 02 and (c) Actuator 03) and C_l Vs. MSR (d) C_d Vs. MSR (e) C_l/C_d Vs. MSR (f).



CFD Simulations



Blocked Force Vs. Differential Pressure



Experimental Results [C_l Vs. AoA (a) C_d Vs. AoA (b) and C_l/C_d Vs. AoA (c)].

Conclusion

- The bending angle with lifting force showed an approximately linear relationship.
- Actuator 1 shows the highest maximum blocked force and force-to-weight ratio.
- From CFD results, C_l and C_d increased with MSR values, and C_l/C_d ratio is maximum near trailing edge morphing. MSR = 0.3 was chosen as the optimum aerofoil.
- Morphing aerofoil perform a maximum bending angle of 11.1° at 40 kPa (abs) pressure (MSR = 0.4).
- Soft actuators benefit UAVs with miniaturization, simple structure, ease of fabrication, improved aerodynamics, and energy efficiency

Department of Mechanical Engineering
University of Moratuwa