EECS/BioE/MechE 106A/206A

Project Proposal Template

Fall 2025

1 Team Information

Name	Background
Andrew	Andrew is a Computer Science & Data Science Major.
Marissa	Marissa is a Computer Science & Data Science Major.
Sonali	Sonali is a Mechanical Engineering Major.
Sophia	Sophia is an EECS Major.

2 Abstract

This project focuses on the design, construction, and control of a morphing airfoil capable of adapting its shape in real-time to changing wind conditions. We are developing a complete robotic feedback loop where a servo-driven tendon mechanism modifies the wing's camber. The system will use a load cell to sense aerodynamic lift and a differential pressure sensor to measure airspeed. A micro controller will run a PID or hill-climbing algorithm, using this sensor data to plan and execute actuator commands. Our goal is to demonstrate stable, closed-loop lift control in a fan-based test rig, proving the airfoil can autonomously adjust its camber to maintain a target lift as airflow speed varies.

3 Project Description

What are your project goals? Our goal is to design, build, and control a morphing airfoil whose camber actively adjusts in real time to maintain a desired lift level under changing airspeeds. By developing a functional mapping between airspeed and optimal camber, the wing will dynamically reshape itself—curling or flattening as airflow varies. This will be demonstrated using a flexible trailing-edge structure actuated within a wind tunnel environment (e.g., Hesse Lab) where airspeed is actively tuned. Through this system, we aim to show how aerodynamic performance can be optimized via adaptive geometry. The broader objective is to implement a full robotic feedback loop, integrating sensing (airspeed/lift) → planning (camber decision) → actuation (morphing response).

How will you design your project in terms of software/hardware architecture (at a high level)? The system consists of four major subsystems, summarized in Table 1.

How does your project incorporate sensing, planning, and actuation?
Sensing:

- A load cell mounted in-line with the wing sting estimates lift.
- A differential pressure sensor and Pitot tube measure airflow speed.
- An encoder or servo telemetry tracks the airfoil's current camber.

Planning:

- A control algorithm determines how to adjust camber to reach a target lift level or maintain lift under changing airspeed.

Subsystem	Hardware	Software Role
Morphing Wing	3D-printed leading edge, 3D-printed ribs, laser cut trailing edge flexure,	Responds to camber commands
Actuation	High-torque servo or stepper-driven tendon mechanism with encoder feedback	Converts camber commands into physical deformation
Sensing	Load cell (lift), differential pressure sensor (airspeed), encoder (camber)	Provides real-time aerodynamic response data
Controller/Planner	ROS2-based control node running on a microcontroller or SBC	Computes optimal camber for desired lift or stall avoidance

Table 1: High-level hardware/software architecture.

- A PID or optimization-based hill-climbing method modulates camber in response to sensor feedback.

Actuation:

- A servo or stepper-driven tendon system bends the trailing edge of the airfoil to produce variable camber.
- Closed-loop control ensures the airfoil reaches the commanded shape accurately.

How will you test or assess your project? What constitutes a success? What are some realistic goals? What are some reach goals?
Testing Approach: We will evaluate system performance using a fan-based airflow setup. The airfoil will undergo:

1. Camber calibration (shape vs actuator input)
2. Lift measurement under constant camber (baseline curves)
3. Closed-loop lift tracking (controller adjusts camber to reach lift target)
4. Airspeed sweep to track variation in lift

Success Metrics (Realistic Goals):

- Demonstrate that changing camber measurably affects lift
- Accurately read lift and airspeed with calibrated sensors
- Achieve stable closed-loop lift control using camber adjustment
- Maintain lift within $\pm 10\%$ of a target under changing airspeed
- Produce a clear graph showing lift vs. camber vs. airspeed

Reach Goals (If time allows):

- Develop a planner that adaptively selects camber to maximize efficiency (L/D)
- Incorporate pressure taps along the wing to characterize suction distribution
- Demonstrate a stall-avoidance mode that dynamically reshapes the wing before stall occurs

4 Tasks

Here, list out different major and minor tasks of the project, along with when you plan to achieve them. Keep in mind the checkpoint dates (11/9 and 11/29).

1. **Hardware Procurement and Assembly.**
   (a) **Order parts.** Order load cell, HX711, servo, and microcontroller (ESP32/Arduino). [by 10/25]
   (b) **Design and build physical rig.** Design a simple frame (e.g., laser-cut wood or 3D printed) to mount the servo, load cell, and anchor points. [by 11/1]
   (c) **Assemble and wire components.** Connect the load cell to the HX711, HX711 to the microcontroller, and servo to the microcontroller. [by 11/6]
2. **Software Development and Integration.**
   (a) **Sensor node.** Write and test code to get stable, calibrated readings from the load cell and airspeed sensor. [by 11/9 - Checkpoint 1]
   (b) **Actuator node.** Write and test code to control the servo to specific positions (PWM control). [by 11/13]
   (c) **Control loop.** Implement a basic P (Proportional) control loop integrating the load cell and actuator. [by 11/20]
   (d) **PID tuning.** Implement the full PID controller and begin tuning the Kp, Ki, and Kd gains for a stable response. [by 11/27]
3. **Testing and Refinement.**
   (a) **Integration testing.** Test the full system's response to disturbances and setpoint changes. [by 11/29 - Checkpoint 2]
   (b) **Reach goal implementation.** If time permits, implement real-time plotting or a potentiometer for setpoint control. [by 12/3]
   (c) **Final report and video.** Document results and prepare final presentation. [by 12/9]

5 Bill of Materials

5.1 Use of Lab Resources

Please include all lab resources you plan to use so we can ensure that all teams have sufficient access to hardware. Please indicate which robot end effectors / grippers you plan to use, if applicable.

Item	Quantity
UR7e (w/ parallel gripper)	0
RealSense Cameras	0
3D Printer / Laser Cutter	As needed (for rig)

5.2 Other Robotic Platforms

You may already have access to other robots, via a lab you work in (or a quadcopter hobby). If you plan to use them, please list them here. (If you plan to use your lab's hardware for the project, make sure to clear it with the PI first!)

Item	Quantity	Owner/Location
N/A		

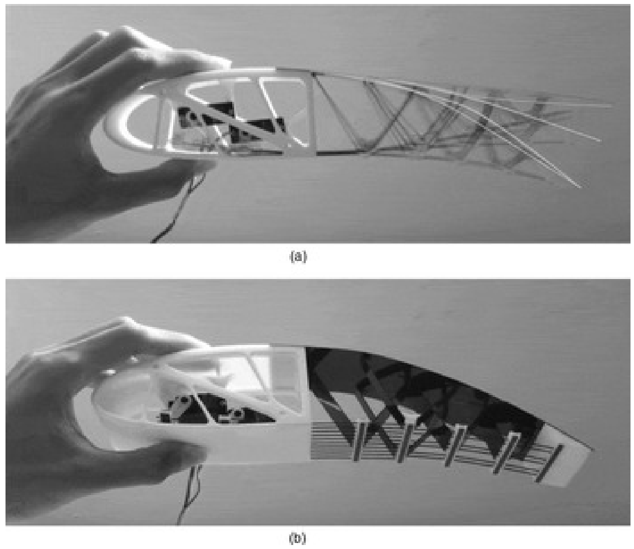

Figure 1: Morphing Aerofoil

5.3 Other Purchases

Remember to fill out the form on the Final Project Guidelines if you want ESG to purchase anything for you with your $55 budget! Anything beyond that will be up to you to buy.

Item	**Quantity**	**Justification**
ESP32 or Arduino Uno R4	1	Microcontroller for processing and control.
Standard Servo (e.g., MG996R)	2-4	Actuator to apply tension.
Load Cells	2-4	Sensor to measure tension.
HX711 Load Cell Amplifier	1	Required to amplify and digitize the load cell signal.
Jumper Wires / Breadboard	1	Prototyping and connecting components.
Small Spool / Lever Arm	1	To be attached to the servo for actuation.

6 Other

We were primarily inspired by *hybrid morphing airfoil architectures* like the one shown in Figure 1. Unlike fully compliant trailing-edge designs that rely solely on material elasticity, this approach integrates internal linkage mechanisms within a flexible skin. This hybrid configuration enables controlled, smooth deformation of the trailing edge while preserving structural stiffness. As a result, camber can be precisely modulated, allowing for independent tuning of lift and pitching moment in response to changing aerodynamic conditions. Additionally, we aim to build on extensive research into how airfoil shape should adapt under different airflow conditions. Through preliminary research, we have identified several useful sources listed below:

- Wu, R., Soutis, C., Zhong, S., & Filippone, A. (2017). A morphing aerofoil with highly controllable aerodynamic performance. *The Aeronautical Journal*. Link

- Aminjan, K. K., Ghodrat, M., Heidari, M., Rahmanivahid, P., Naghdi Khanehachah, S., & Escobedo-Diaz, J. P. (2023). Numerical and experimental investigation to design a novel morphing airfoil for performance optimization. *Propulsion and Power Research*. Link

- Namgoong, H. (2005). *Airfoil Optimization for Morphing Aircraft* (Ph.D. Dissertation). Purdue University. Link

- Ochi, S. (2024). Aeroelastic simulation and experimental validation of a 3D-printed passive morphing airfoil. *AIAA Journal*. Link