Improving the Aerodynamic Efficiency of Airplanes using a Nature-Inspired Adaptive Wing

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Abstract

Through natural selection over millions of years, birds have perfected the art of flying. The key to their aerodynamic efficiency is their ability to constantly adapt the shape of their wing and body to maximize lift and minimize drag. In this project, two adaptive wing designs (AW2 and AW3) were built and tested in a home-made wind tunnel setup. AW2 had one movable section, while AW3 had two independently movable wing sections. The designs used servos embedded within them controlled by an arduino nano processor, to adjust the wing's shape. Lift and drag curves for these wings were measured. The AW3 design was found to have superior aerodynamic performance and control compared to the AW2 design. The aerodynamics of these airfoils were tested using a Computational Fluid Dynamics (CFD) simulation. All of the hypotheses set out in the research plan were tested.

Introduction

From the dawn of time, humans have dreamt of flying. On December 17th of 1903 in Kitty Hawk, North Carolina, we lifted up into the skies. Planes are amazing feats of engineering, but they burn a large amount of fossil fuels, which contribute to climate change. To address this important problem, airplane designers are constantly trying to improve the aerodynamic efficiency and find alternate power sources, including electric propulsion.

Birds are some of the best flyers in nature, as they were naturally selected through evolution for millions of years. To achieve this mastery in flight, they have to be able to constantly adjust their bodies to maximize their aerodynamic characteristics by maximizing their lift and minimizing their drag [Figure 1]. We can learn from them, and make a more adaptive airplane wing, to improve the plane's efficiency.

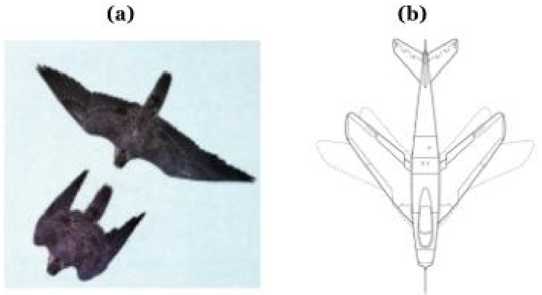

Figure 1: An example of nature-inspired adaptive wing . (a) The photo shows several postures of a peregrine falcon diving for prey. As the falcon's wings are drawn in and folded back, the drag decreases and the bird's airspeed can reach almost 200 miles per hour [6]. (b) An engineering drawing of the Bell X-5 showing the variable sweep wing concept [7].

Conventional flight control mechanisms use hinges that result in the disruptions, and in some cases, separation of the airflow and vortices, contributing to the drag [1]. A study found that an adaptive wing design could increase fuel efficiency by 3 - 6% [2] and have a drag reduction of 5 - 12% [3]. Even a 1% reduction in drag would save the U.S. fleet of wide-body transport aircraft approximately 140 million dollars per year [2]. These changes could help the environment and lead us to a more sustainable future.

In this project, multiple adaptive wing designs were made and tested in a wind tunnel setup. All of the designs used servos, embedded within them, that were controlled by an arduino nano processor, to adjust the wing's shape. Then, a computational fluid dynamics (CFD) simulation, programmed in JavaScript, was used to see how different changes to the airfoil shape affect its aerodynamics. Using these models and devices, the following experimental hypotheses were tested.

- A more cambered, steeper airfoil shape will generate more lift, which is useful for takeoff and landing, but a flatter wing will generate less drag and be better for cruising.
- Morphing will be more efficient in comparison to the traditional flaps, spoilers, slats, and ailerons
- The computer model will be able predict what wing shapes can generate more lift and less drag

Materials and Methods

In this project, 3 different adaptive wings were made. For all of them, first, the template of the Clark Y airfoil was used to cut out the wing from a block of styrofoam. To do this, a styrofoam cutter was used. Now for the first design, this wing was used to curve a heat bending plastic into the shape. Then, a small piece of the airfoil was cut out from the middle and the plastic connected the two resultant pieces.

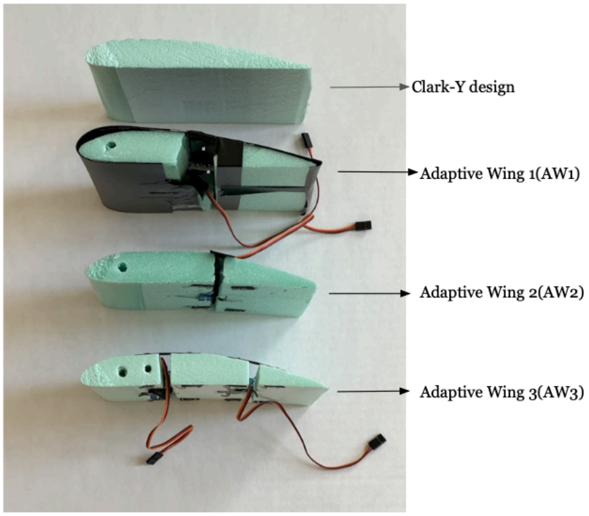

Fig. 2: Four different wing types built and tested in this project. From the top to bottom these are the reference Clark Y design, the Adaptive Wing 1 (AW1), Adaptive Wing 2 (AW2), Adaptive Wing 3 (AW3)

In the front piece, a small cavity was made, where a servo motor, specifically the Tower Pro SG90 servo, was secured. To control the servo, it was connected to an Arduino Nano controller, which was also connected to a joystick to control it, and a display to tell the angle. This servo was connected to the pipe inside of a pen, which was connected to the other part of styrofoam in the back. This meant that when the servo turned, the back portion would bend up or down, changing the angle of attack. I soon replaced the joystick with a potentiometer, as it gave me more control and didn't return to zero when let go. After some changes, this worked, but it had some issues. First of all, the heat bending plastic provided too much resistance for the servo. To combat this, much of the plastic was cut away, leaving just a tiny portion. However, there was another issue. There are two fulcrums, the fulcrum of the servo, and the place where the plastic bends. As none of the parts can change in length, this prevents the wing from changing very much. This was one of the limitations of a pure rotation technique.

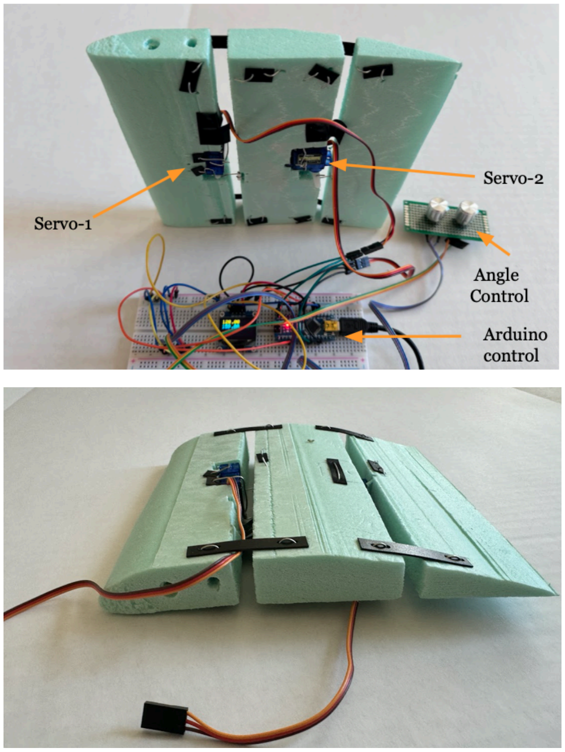

Fig. 3: Final wing design, AW3, which is divided into three sections and has two servos that can independently change the angle, providing greater flexibility

In the second design, the same Clark Y wing was cut out and was cut into two pieces from near the trailing edge. Now, from the last experience, rather than surrounding the entire top surface of the wing with the heat bending plastic, only thin ribs of the plastic were used to join the two parts of the wing, providing less resistance. Also, rather than using tape, a thin metal wire was bent so that it could secure the ribs, and the servo in place. Before, a simple turning method was made.

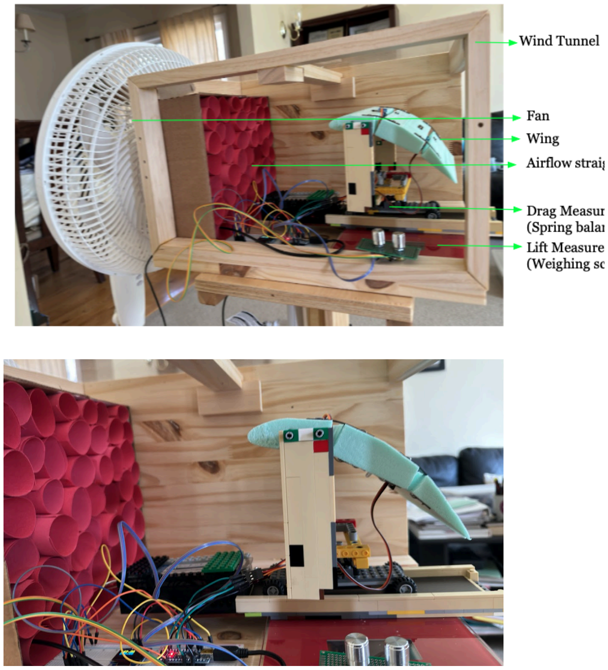

Fig. 4: Wind tunnel with AW3

Results

The main results from the airfoil measurements are (1) lift vs. angle of attack and (2) drag vs. angle of attack for three different airfoils. Multiple measurements were taken for each wing, then the averages were plotted.

Lift Curves

Fig. 5 shows the lift curves of AW2 and AW3. From the graph, it is clear that for both wings, there is an upward trend in lift with angle. This because a higher angle of attack causes the air to be deflected more, generating more lift.

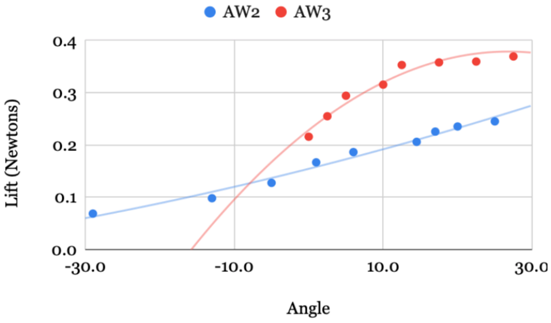

Fig. 5: Measured lift curves of AW2 and AW3

On the graph, it is also clear that AW3 generates more lift than AW2. This is because its contour has a less abrupt change than that of AW2, reducing the flow separation and vorticity. Also, AW3 has a higher range of possible angles, allowing it to work in more conditions.

Drag Curves

Fig. 6 & 7 shows the drag curves of AW2 and AW3 respectively. The drag curve shows how the measured drag changes with respect to the angle. The drag increases with the angle of attack. This is because at higher angles, more air particles hit the wing, creating more drag.

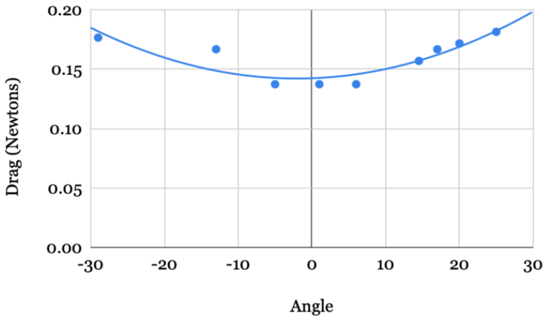

Fig. 6: Measured drag curve of AW2

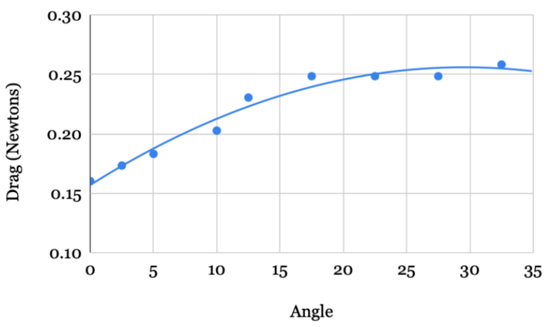

Fig. 7: Measured drag curve of AW3

Here, the drag for both wings is increasing with the magnitude of the angle (both for more negative and positive angles). This is because the deflection of air also has a horizontal component, leading to the generation of drag. The more angled the wing is, the more drag is produced.

CFD Model

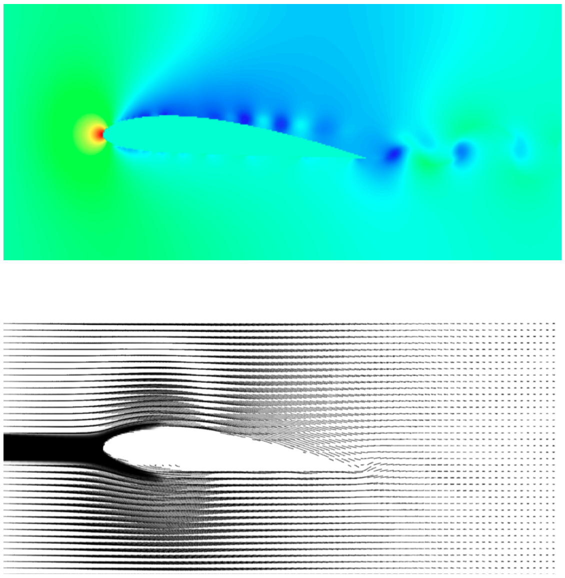

Fig. 8: CFD simulation of air pressure (top) and streamlines (bottom) of a Clark Y airfoil. The low pressure (blue) region is clearly visible on the top surface of the airfoil, which results in lift.

These simulations were derived from another fluid simulation of a circular object. Using the formula for NACA airfoils and implementing it into the simulation, by using a function for the camber line and thickness, made it possible to adjust the simulation for airfoils.

Conclusions and Future Work

With these models and experimental results the research questions can be answered.

Can the wing be changed from a more cambered to a flatter airfoil profile?

Yes. This has been confirmed from the measurement results comparing AW2 and AW3 airfoils

Will an adaptive wing improve the efficiency (lift-to-drag ratio) of the plane?

Yes. This has been experimentally confirmed.

Can a computer model predict the performance of the adaptive wing?

This has been qualitatively demonstrated for the Clark Y airfoil by a CFD simulation.

Can a single wing structure be built that can seamlessly change its shape?

Yes. This has been demonstrated in the AW2 and AW3 adaptive wing designs.

Morphing will be more efficient in

comparison to the traditional flaps, spoilers, slats, and ailerons

This could not be clearly demonstrated in this project, but will be studied in the future projects.

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