# Morphing Airplane Wing with Variable Dynamic Properties

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## Problem definition

Design a Morphing airplane wing prototype and study the effects of the shape of airfoil on the lift and drag coefficients in flight.

## Abstract

An airplane wing model capable of changing shape in-flight was designed, built, and tested in a sub-sonic wind tunnel. The goal was to see if the airfoil shape could be changed sufficiently so that lift force could be dynamically controlled. One application would be to decrease lift during landing without the need for spoilers.

The bottom surface of the wing was changed using two stepper motors that move an internal frame deforming the wing skin and increasing the wing's thickness. A motorized system to change the angle of attack of the airfoil in the wind tunnel was also designed and built. Lift and drag forces on the wing were measured using a force transducer which was incorporated with the motorized mounting system. The forces on the wing were measured for different speeds and angles of attack. Lift and drag forces were calculated twice, with and without expansion of the lower surface. Both results were compared to each other and to the Clark Y airfoil to see the effects of increasing the thickness of the airfoil on the lift and drag coefficients.

Measurements show that moving the bottom wing surface a mere of 0.5 inches was sufficient to decrease lift by 19% . These results show that an internal structure is capable of morphing the wing shape so that lift force can be varied in flight.

## Introduction

The four main forces that act on an aircraft when it is up in the air are thrust, weight, drag and lift. Our Project will be focusing on only two of those forces; Lift and drag. As shown in figure 1, both drag and lift forces act opposite to thrust and weight respectively. Lift is an aerodynamic, forces generated between fluids and objects, force that acts perpendicular to the flow direction (flight path), while drag is also an aerodynamic force that acts along the flight path.

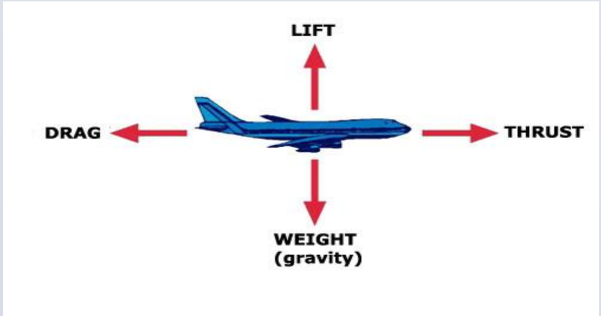
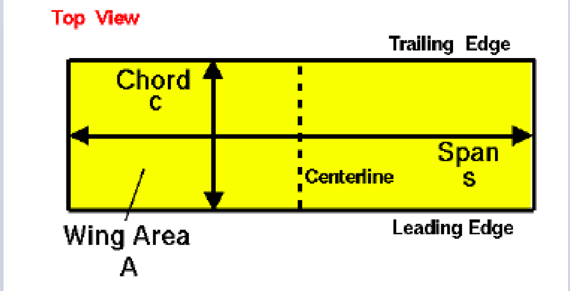



*Figure 1: Aircraft (Darling)*

The wing is the primary lifting part of the aircraft. An Airfoil is a structure with a curved surface and is used as the cross sectional shape of wing. As shown in figure 2, the chord is the line connecting the leading edge (Front of the wing) to the trailing edge (back of the wing). The ends of the wing are called the wing tips, and the distance from one wing tip to the other is called the span. The thickness of the airfoil is the most interesting part of the airfoil when it comes to our project. Because we tested how changing the shape of the wing by changing the thickness of the airfoil in flight effects the lift and drag coefficients, which therefore effect the lift to drag coefficient.




*Airfoil Top View(NASA. NASA)*

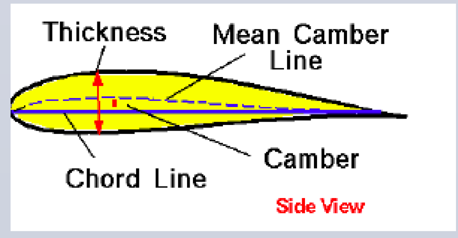



*Figure 2: Airfoil side view (NASA. NASA)*

## Lift and Drag Coefficient

- *Lift to drag Equation:*

$$\frac{Lift\ Coefficient}{Drag\ Coefficient}$$

*Coefficient of Lift Equation ("The lift Coefficient"):*

$$\frac{2F_l}{\rho * A * V^2}$$

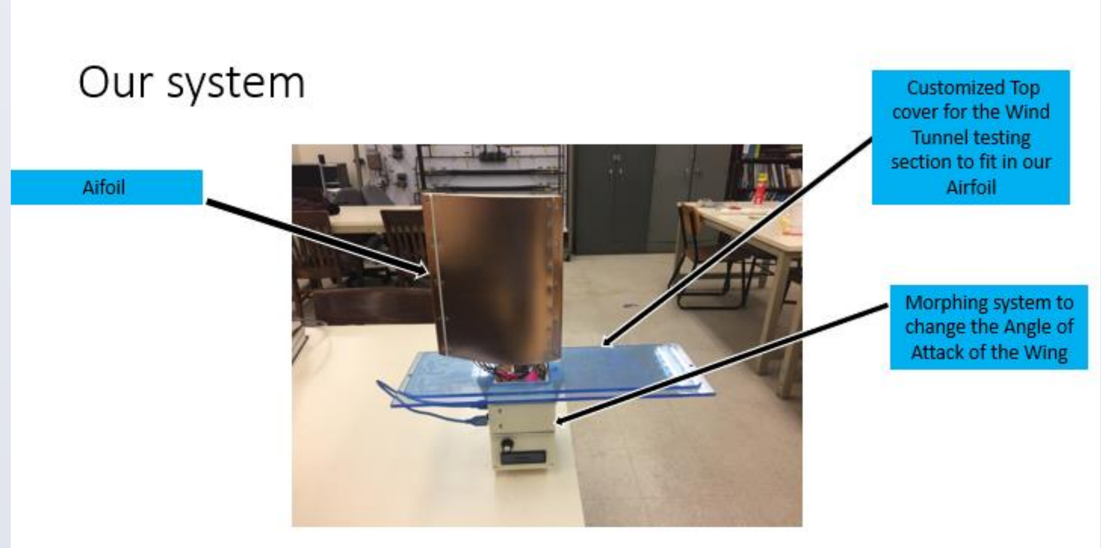
- *Coefficient of Drag Equation ("The Drag Coefficient"):*

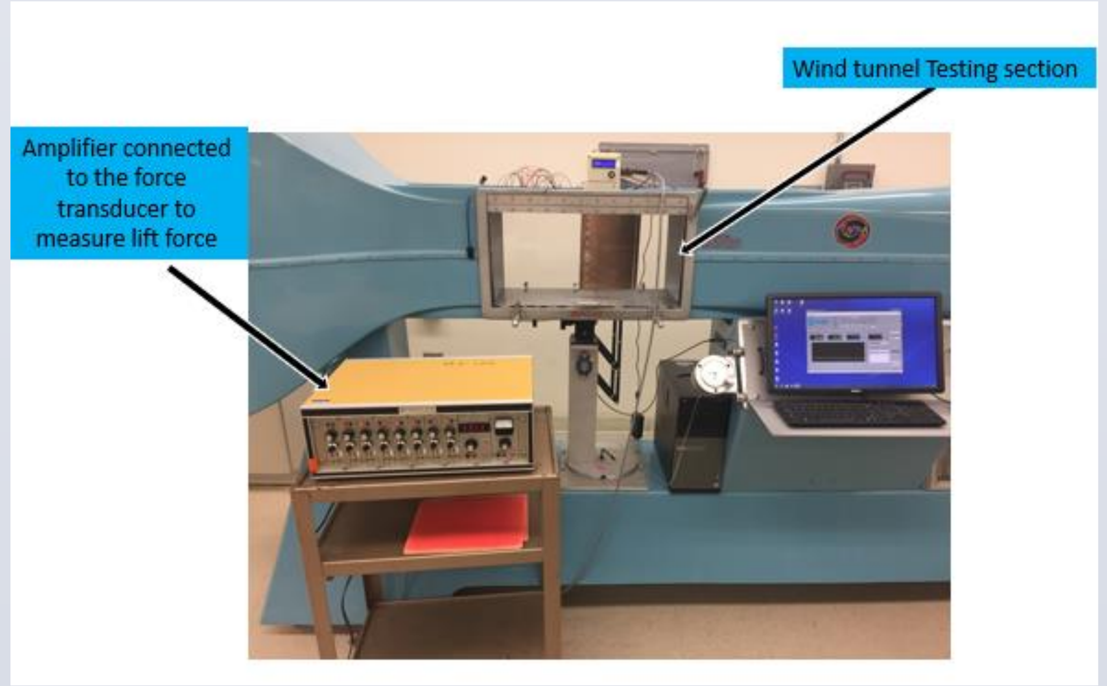
$$\frac{2F_D}{\rho * A * V^2}$$

Where,

- $F_L$ = lift force, $F_D$ = drag force, $\rho$ = density of the fluid (air) , V = velocity of the fluid relative to the object, and A = wing area (span *chord length)

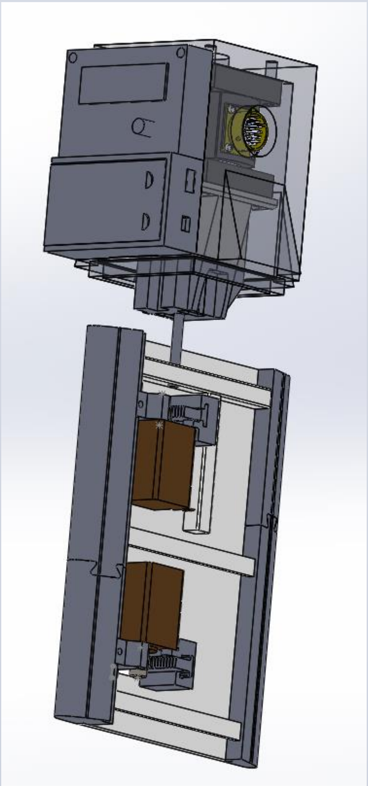
## Our System



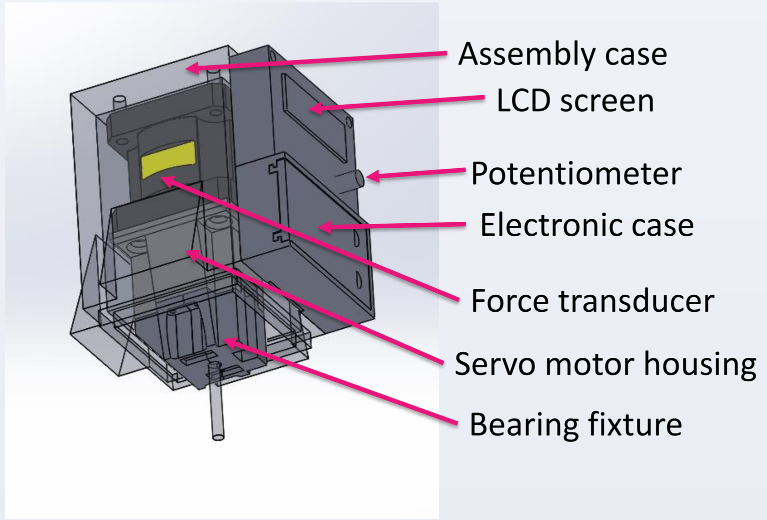



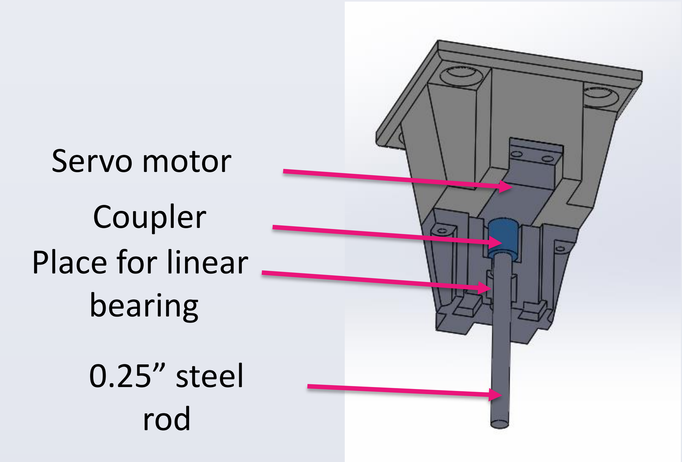

## Methods and materials

- The airfoil was all designed and 3-D printed using the Trinity College 3-D printer. The upper and lower surfaces of the airfoil are made from 3003- h14 Aluminum. The lower surface is moved by two stepper motors (Nema 40), both programed by Ardunio Uno and stepper driver.
- The motorized system to change the angle of attack is also controlled by Ardunio and a servo motor.



## Airfoil mount closer view




## Analysis and Results

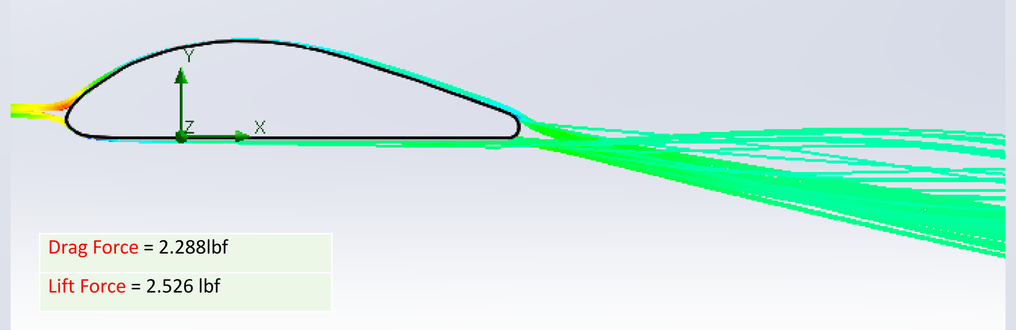



*Figure 4: Flat lower surface airfoil*

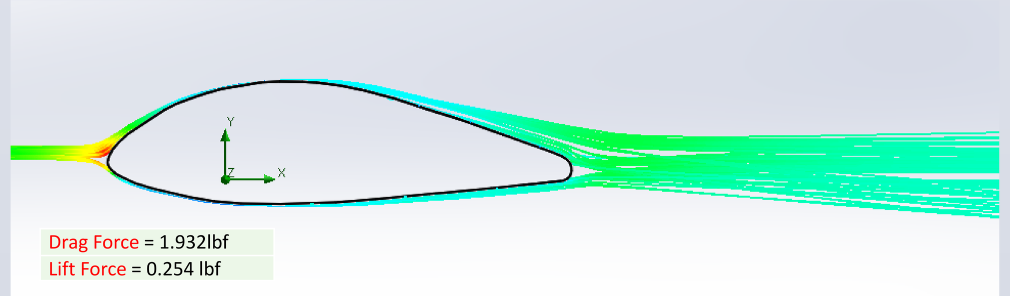
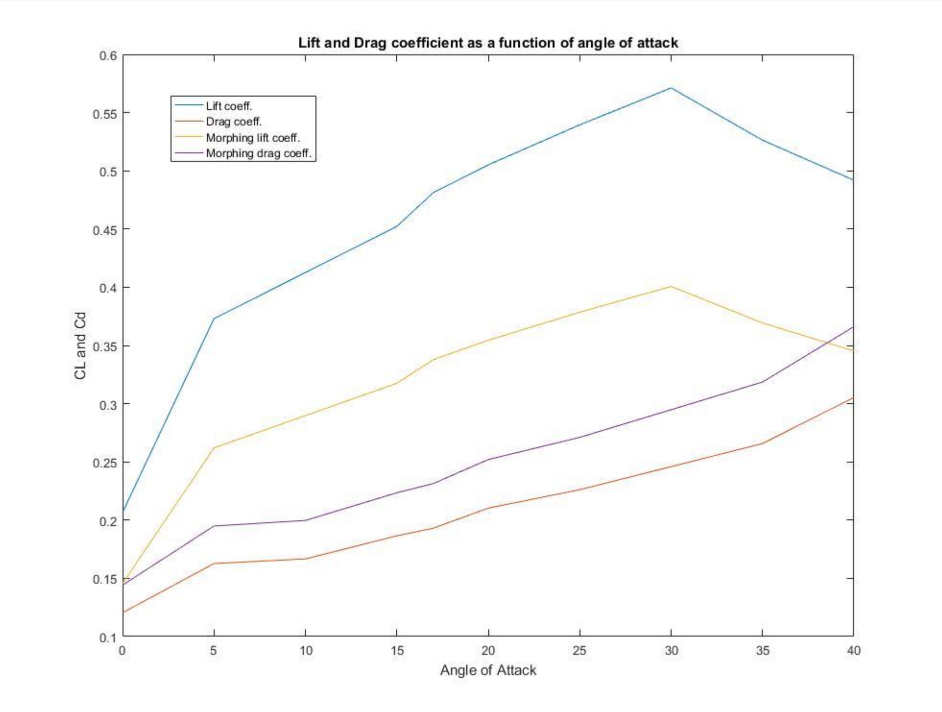



*Figure 5: more symmetrical lower surface airfoil*

- Figure 4 shows the Solidworks simulation for the airfoil before moving the lower surface (flat surface airfoil). The simulation results was 2.29 lbf. for drag force and 2.53 lbf. for lift force. While, figure 5 shows the simulation for the morphed airfoil (after moving the lower surface) with values of 1.93 lbf. lift force and 0.254 lbf. for drag force
- Lift force of the morphed airfoil was less than the lift force of the flat surface by 89%.




- Graph 1 shows our experimental results the lift and drag coefficients are plotted as a function of different angles of attack with a speed of 50 mph for both the original airfoil (without moving the lower surface) and the morphed airfoil( with the movement of the airfoil).

## Conclusion

- Several tests were performed for the airfoil with extended lower surface for different angles of attack. The results of the lift and drag coefficients were compared to the flat surface (original) airfoil. Our results, shown in graph 1, show that moving the lower surface of the airfoil a mere of 0.5 inches was sufficient to decrease lift coefficient by 19% and increase the drag coefficient by also 19%. These results show that a wing, capable to change its shape, can vary its lift force and drag force in flight.
- Our experimental results for lift coefficient agreed with our initial Solidwork simulation. The lift Coefficient decreased as increased the thickness of our airfoil by moving the lower surface.

## References

Darling, David. "Factor." *The Worlds of David Darling*. N.p., n.d. Web. 01 Oct. 2017.

"Wing Geometry Definitions." *NASA*. NASA, n.d. Web. 24 Oct. 2017

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