Airfoil Technical Report

Kary Cabrera

Engineering Design and Development

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Abstract:

The objective of the research was to construct an airfoil and observe how aerodynamic vehicles use lift and drag forces to fly against the gravitational pull of the Earth. The first step in creating the airfoil required selecting a shape among many other models available on the Profili website. Afterward, trials were conducted on the airfoil using the FoilSim program. With this data, a 3D model and automated drawing were created using Autodesk Inventor. Furthermore, using the automated drawing, the airfoil was recreated with blue foam to test the lift and drag. In a controlled environment, the data was recorded by simulating a wind tunnel at 45mph followed by 75mph. Throughout the experiment, the lift force was greater than the drag force acting on the airfoil. For instance, 75mph and 0 degrees, the lift force reached 1.8 Newtons while the drag force was at 0.5 Newtons of force.

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Introduction:

Aviation has become one of the most efficient ways of modern transportation. Compared to land vehicles, modern aircrafts are able to travel at higher speeds and greater distances. Additionally, the ability to travel over large bodies of water far surpasses the abilities of land transportation. Consequently, air travel has become the most common method of transportation. Since the impact of the Wright Brothers, the two most influential aviation pioneers responsible for constructing the first successful motor-operated airplane, engineers have better understood the laws of aerodynamics[1]. Aerodynamics provides the basis for understanding how air moves around objects. For instance, the four forces of flight include lift, weight, thrust, and drag. Lift, opposite to weight, is the push that enables an aircraft to move upwards. Weight is the force of gravity that pulls the object down to Earth. Drag is the force that slows down an aircraft due to surface area. Lastly, thrust is the force that propels an object forward and is the opposite of drag. Moreover, there is a proportional relationship between the surface area of an aircraft and drag[2]. Thus, there are many factors to consider when building an aircraft. Several steps must be taken to select the most optimal design for an airfoil whose lift force far exceeds the drag force in order for it to fly. The goal of the study is to design and develop an airfoil that is swift and efficient using the laws of aerodynamics while being limited to classroom resources.

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[1] Crouch, T. D. (2020, March 4). Wright brothers.
[2] Dunbar, B. (2015, May 12). What Is Aerodynamics?

Methodology:

Prior to building the airfoil, three models were selected from numerous designs provided on the Profili website. Among the three designs, only one was chosen based on the data collected from the FoilSim program, which tests for lift and drag ratios. Model A18, shown in Figure 1, displayed the highest lift and drag ratios in all six trails.

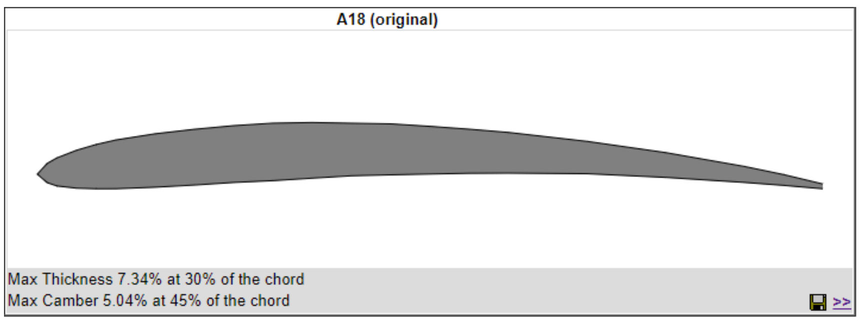

Figure 1. A18 airfoil model

Once selecting the airfoil design, the coordinate points were collected from FoilSim's Geometry tool. The A18 model was replicated on the FoilSim program by altering the mass thickness and the max chamber. As seen in Figure 2, X/C represents the x-coordinates while Y/C represents the y-coordinates. These coordinates were then transferred to an Excel file.

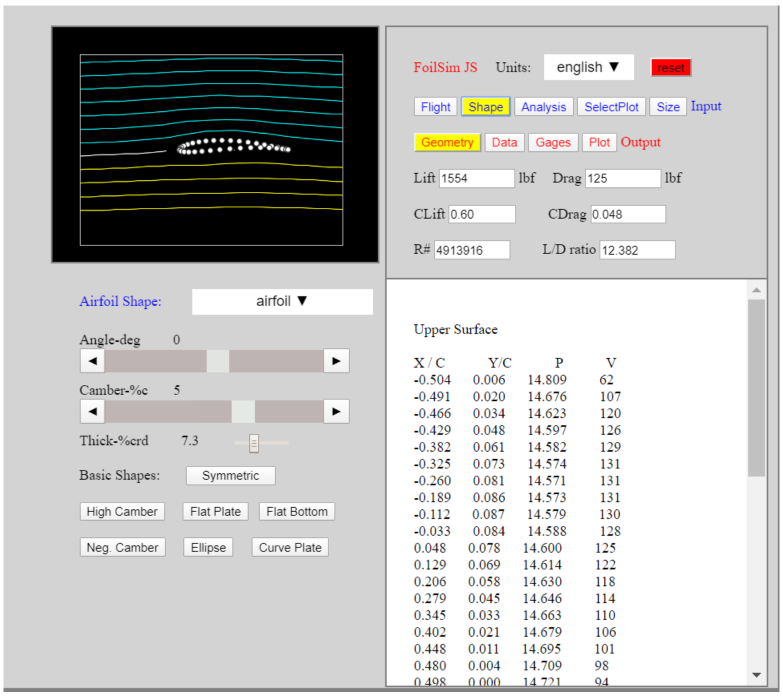

Figure 2. FoilSim Program

The coordinate points given on the FoilSim program were plotted onto an Excel file and multiplied by a scale factor of 4. Following that, the file was uploaded into Autodesk Inventor and connected. Figure 3 shows the outline of the A18 model. This outline was generated on Excel before uploading it to Inventor to ensure the points were correct.

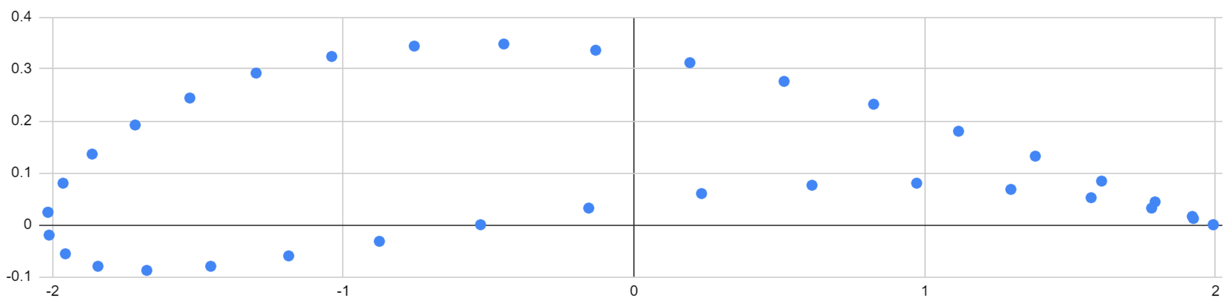

Figure 3. Airfoil created using plotted points from FoilSim

Once verifying that the points on Excel were correct, the Excel file was uploaded into an Inventor part file. The points were then connected using the spline tool. Figure 4 shows the outline of the A18 model after being connected with the spline tool.

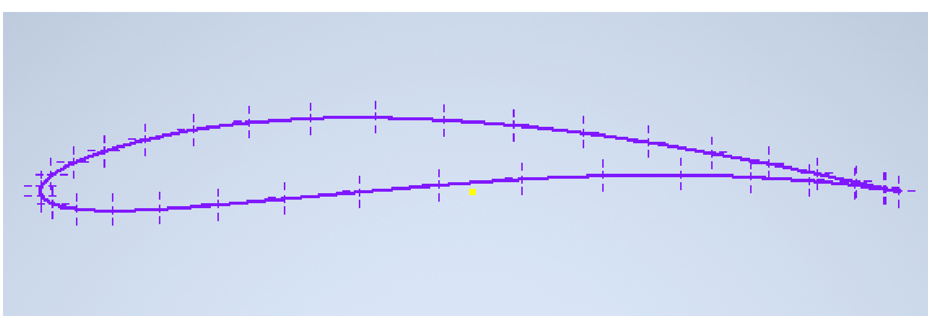

Figure 4. Airfoil points plotted on Inventor

The purpose of collecting coordinate points and plotting the airfoil was to create a blueprint using Inventor. With the blueprint, the A18 model could be cut out using a foam cutter. Prior to this, the two copies blueprint were printed on paper and cut out into four separate templates. Figure 5 shows the blueprint of the airfoil.

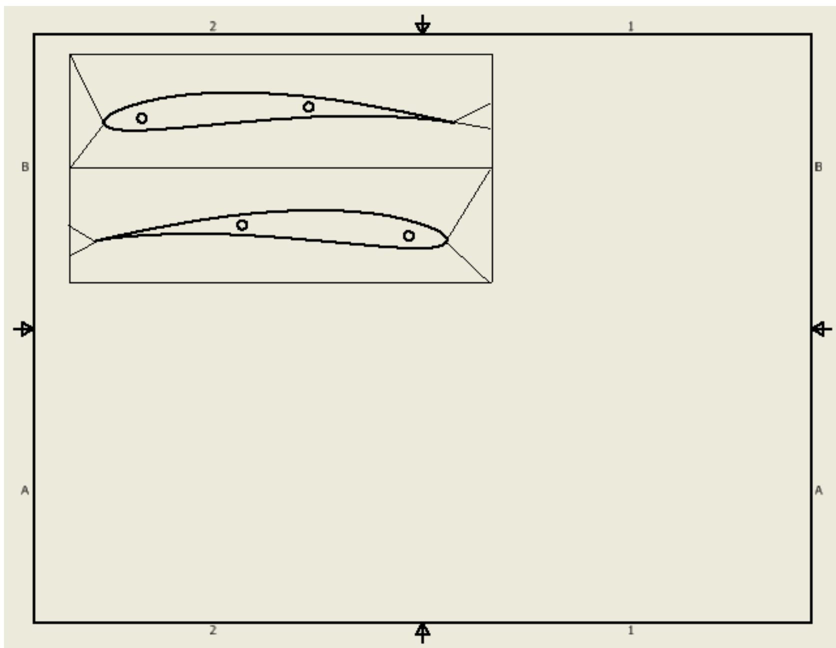

Figure 5. Blueprint of the A18 airfoil

The templates were used as guides to cut out the shape of the airfoil using the foam cutter. Afterwards, the rough shape of the airfoil was sanded down to reduce drag. Figure 6 shows the completed airfoil model after being cut out and sanded. A metal mounting tab was attached to the bottom of the airfoil. This would allow for the airfoil to be securely placed inside the wind tunnel.

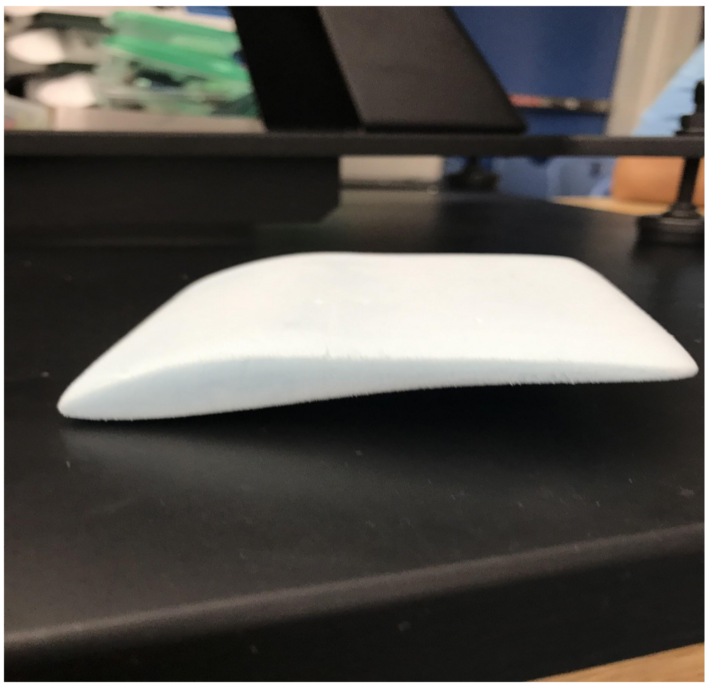

Figure 6. Completed airfoil

The airfoil was then placed in a wind tunnel, as shown in Figure 7, to collect data. The data includes the lift and drag ratios of the airfoil. Data is collected using a pressure plate, which collects the levels of lift and drag of the airfoil.

Figure 7. Airfoil inside wind tunnel

Results:

Two programs were used to measure the lift and drag force of the A18 model. The first, FoilSim, was a virtual simulation that took into account the percentage of thickness and chamber in order to measure lift and drag. The second was the wind tunnel, which required a physical model of the airfoil to test lift and drag using a pressure plate. Figure 8 shows the lift and drag calculated by the Profili website. The Cd graph demonstrates the coefficient of drag while the Cl graph shows the coefficient of lift. Notably, the Cd graph shows an increase in drag as the angles increase; the overall shape of the graph resembles a parabola. Similarly, the Cl graph shows an increase in lift. However, lift is increasing approximately at a linear rate.

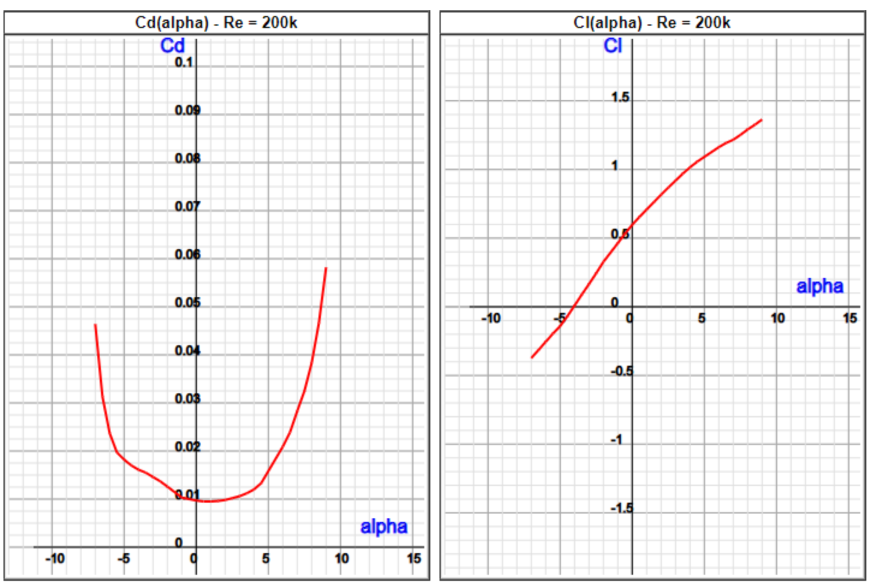

Figure 8. Lift and drag predicted by FoilSim

The data shown below in Table 1 represents the data from FoilSim for the A18 model. In all six trials, the A18 model yielded strong results. Additionally, only the angle of attack (AoA) was changed during each trial. In aerodynamics, AoA represents angle between upcoming wind and the flight path coming from the reference line of the aircraft. The lift, drag, and lift/drag ratio were measured in pound-force.

AoA	Lift	Drag	Lift/Drag
-5	42	22	1.913
0	706	36	19.493
5	1285	105	12.263
10	1820	209	8.691
15	2055	298	6.896
20	1509	328	4.604

Table 1. A18 data from FoilSim

Subsequently, the constructed airfoil was placed in a wind tunnel running at -5, 0, 5, 10 ,15 and 20 degrees. This was done to simulate the lift and drag forces acting on the airfoil in order to determine its efficiency. Shown in the graphs below, the red line represents the lift force and blue represents the drag force acting on the airfoil. Figure 9 shows the lift and drag of the airfoil at -5 degrees. As shown in Figure 8 the lift and drag forces are nearly equivalent.

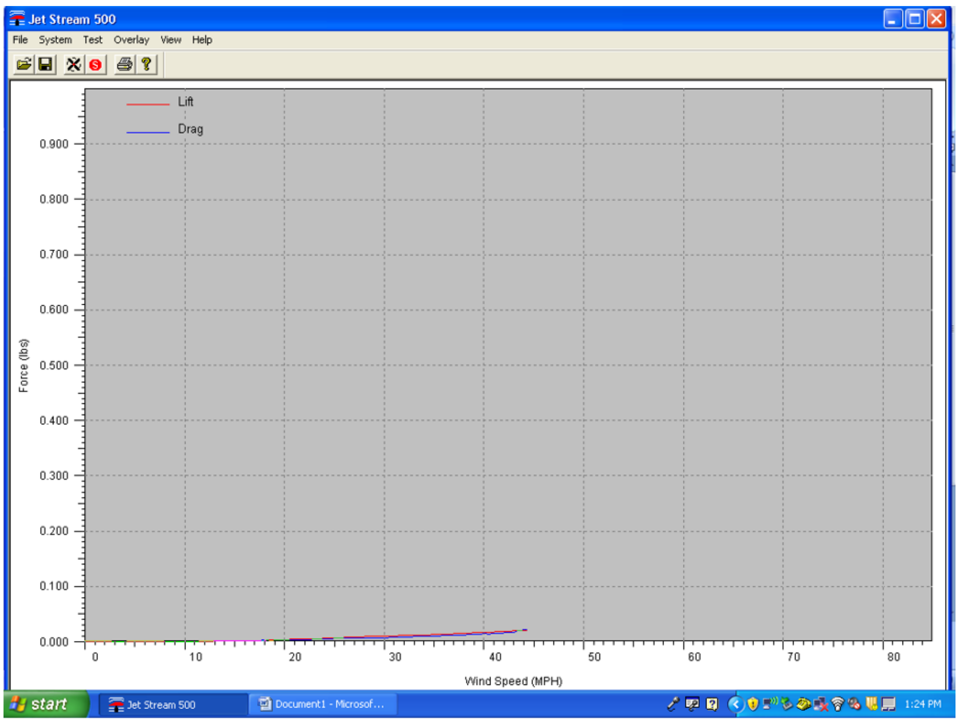

Figure 9. Airfoil running at -5 degrees

After testing the airfoil at -5 degrees, the angle of attack was changed to 0 degrees. Figure 10 shows the wind tunnel running at 0 degrees. As seen, the distance between the lift force and the drag force on the graph increased from the previous trial. It was observed that the lift force became increasingly higher than the drag force at 45pmh.

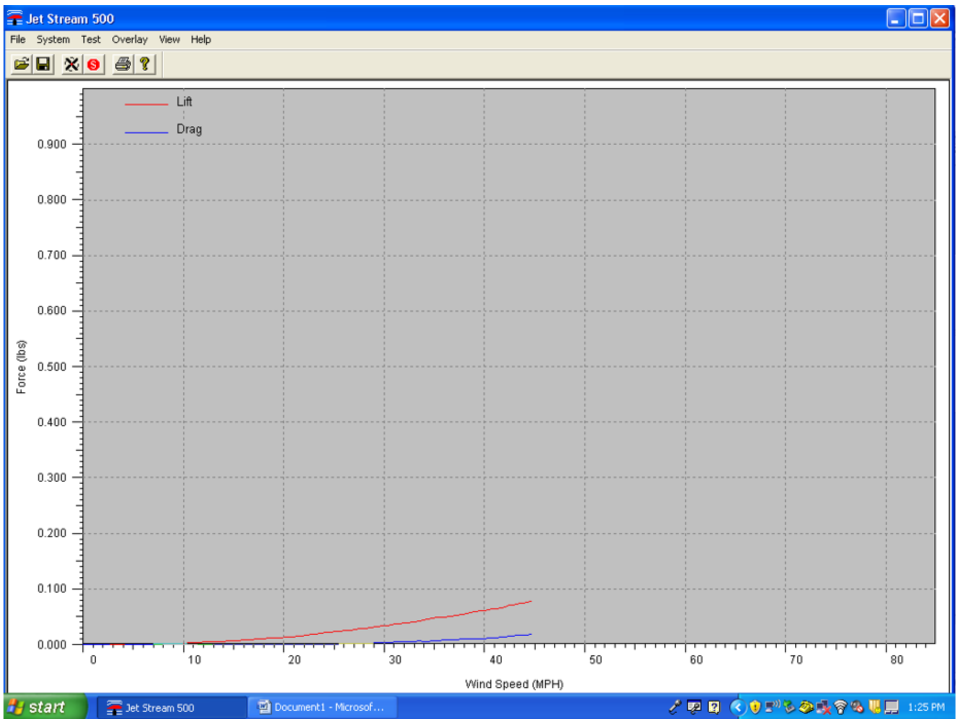

Figure 10. Airfoil at 0 degrees

The airfoil was then tested at 5 degrees at 45mph. Figure 11 shows the results of the airfoil at 5 degrees. Interestingly, the difference between the lift and drag force drastically increased when changing the angle to 5 degrees. At 45mph, the lift force was nearly 0.2 Newtons while the drag force was less than 0.05 Newtons.

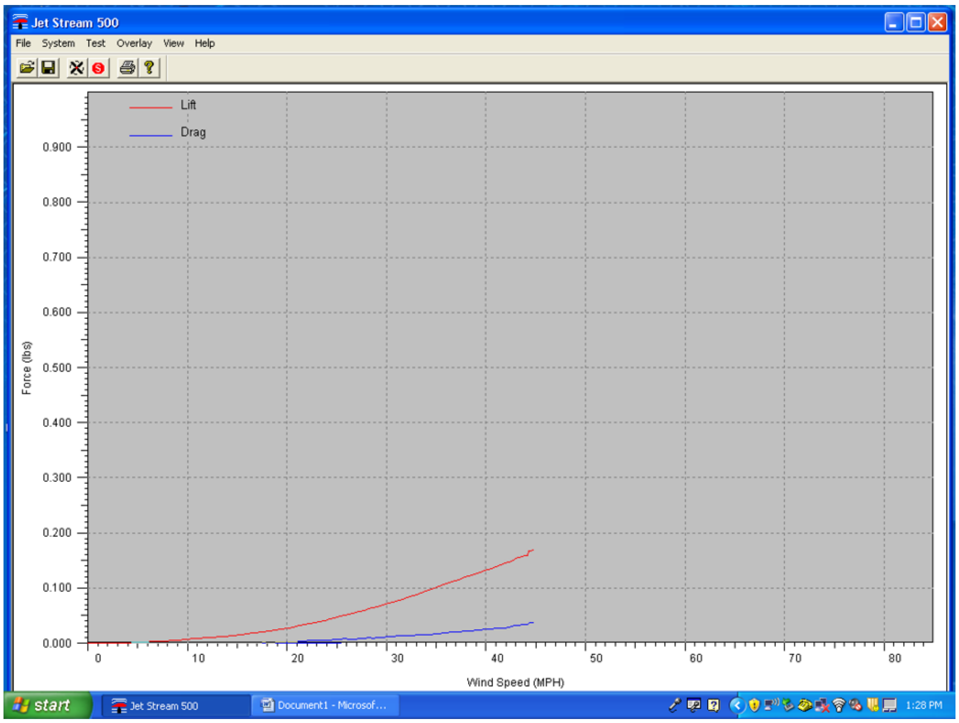

Figure 11. Airfoil at 5 degrees

After changing the angle from 5 degrees to 10 degrees, the lift force increased to roughly 0.25 Newtons. Meanwhile, the drag force stayed the same. Figure 12 shows the graph of the airfoil at 10 degrees.

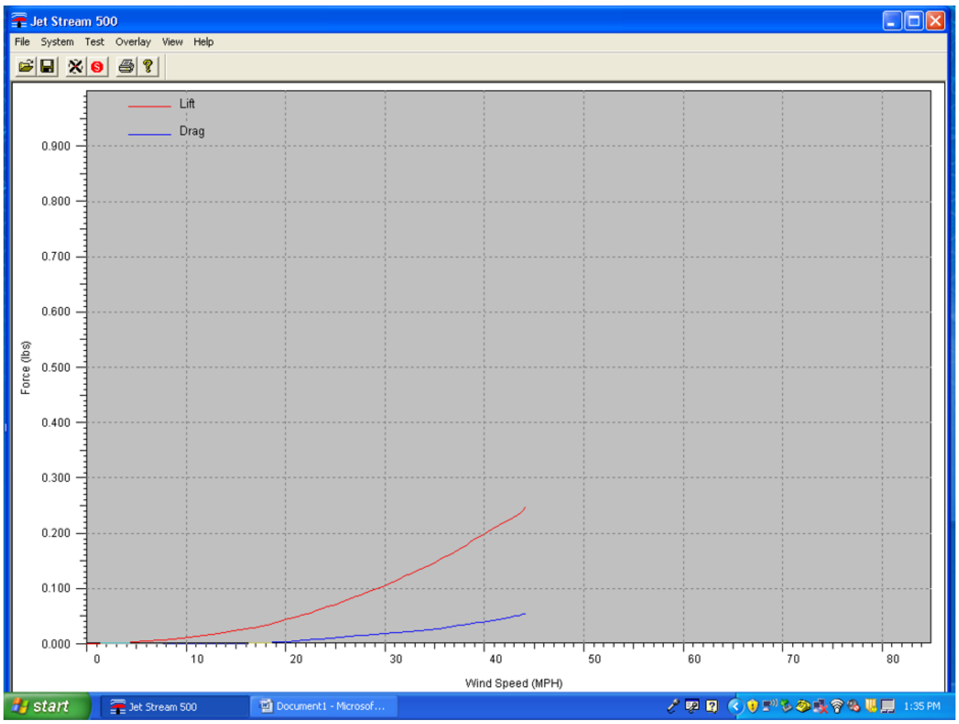

Figure 12. Airfoil at 10 degrees

At 15 degrees, the lift force had the largest increase from 0.25 Newtons at 10 degrees to nearly 0.35 Newtons at 15 degrees. Likewise, the drag force increased to exactly 0.1 Newtons. Figure 13 shows the results of the airfoil at 15 degrees.

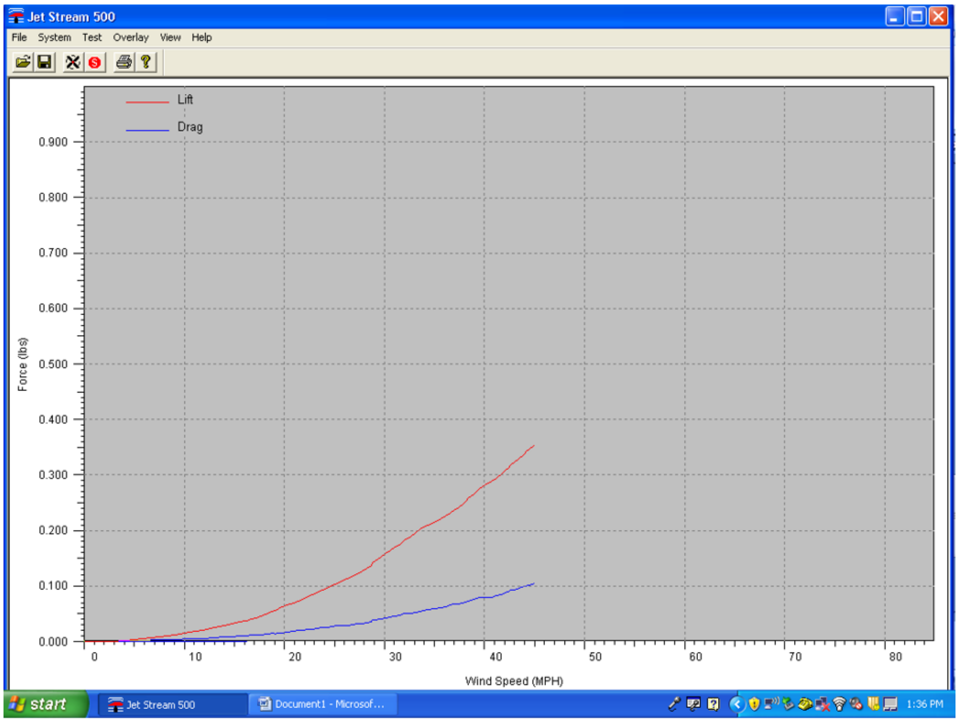

Figure 13. Airfoil at 15 degrees

Finally, the airfoil was tested at 20 degrees. At 45mph, the lift force was nearly 0.45 Newtons while the drag force increased to 0.15 Newtons. The results of the airfoil at 20 degrees are depicted in Figure 14. It can be noted that in all trials, the lift force was always greater than the drag force.

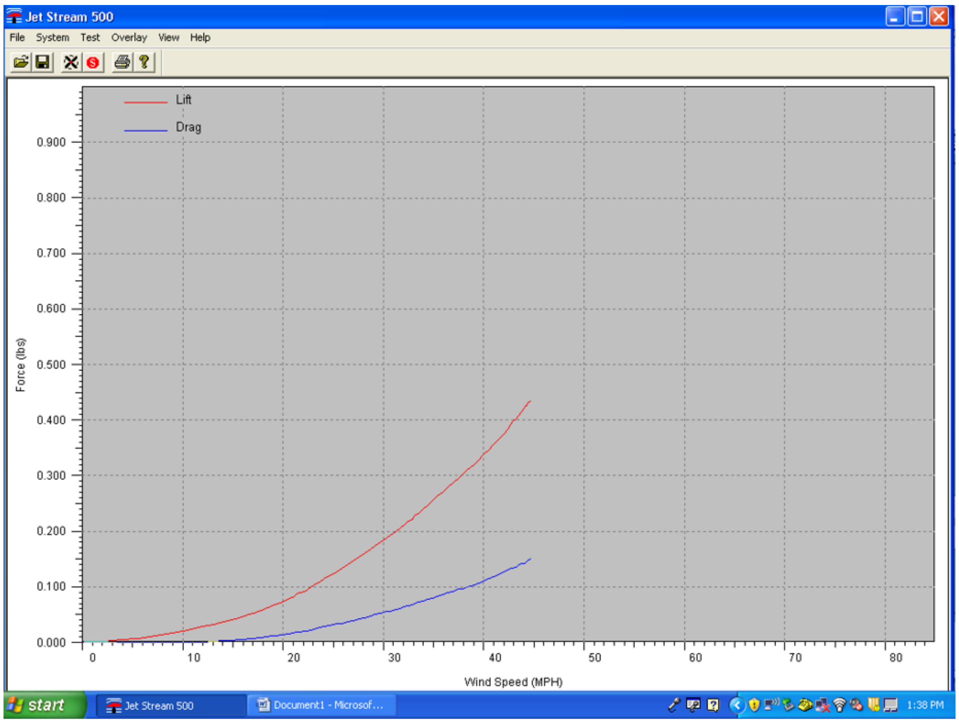

Figure 14. Airfoil at 20 degrees

After testing the airfoil at different degrees, the speed was changed from 45mph to 75mph. As shown in Figure 15, the wind tunnel ran at 75mph with an angle of 0 degrees. Even at 75mph, the lift force was significantly greater than the drag force.

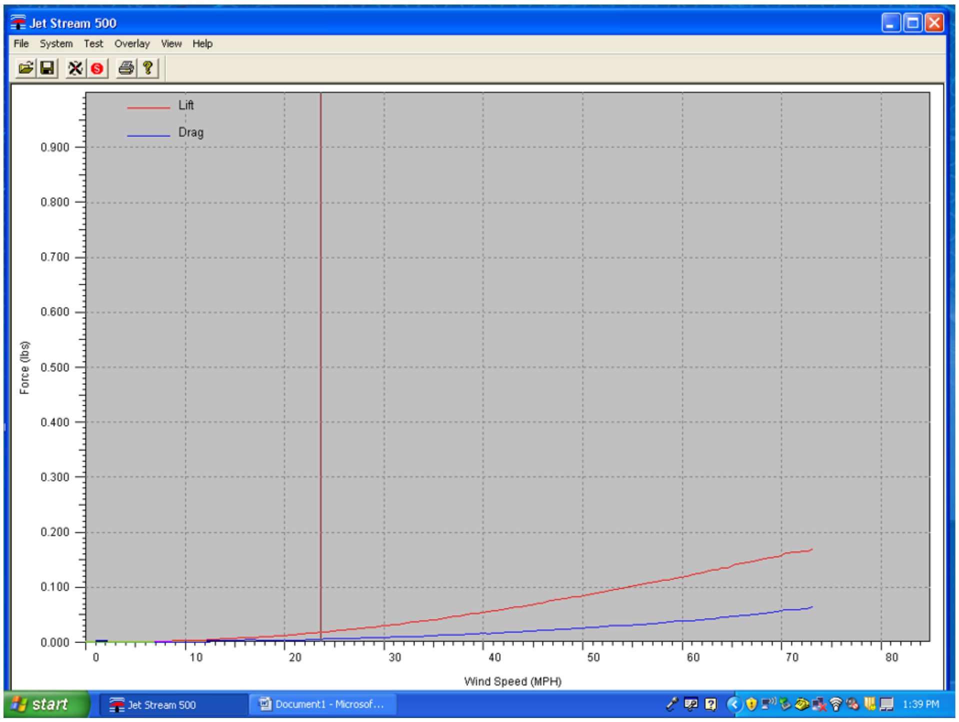

Figure 15. 7mph at 0 degrees

It can be noted that changing the speed of the airfoil did impact the results of the wind tunnel. When running at 0 degrees and 45mph, the lift and drag force were smaller than the results shown in Figure 15.

Discussion:

In order for an object to achieve flight, the lift force must be greater than the drag force.

As lift balances the weight of an aircraft, aircrafts move higher when the lift force is greater than the weight. Furthermore, the shape of an airfoil influences the amount of lift and drag force acting on it. Round surfaces experience less drag compared to flat surfaces. Similarly, curved airfoils deflect air and alter the wind pressure around them due to the air's natural inclination to move in a straight line[3]. Figure 16 illustrates how lift and pressure act on an airfoil.

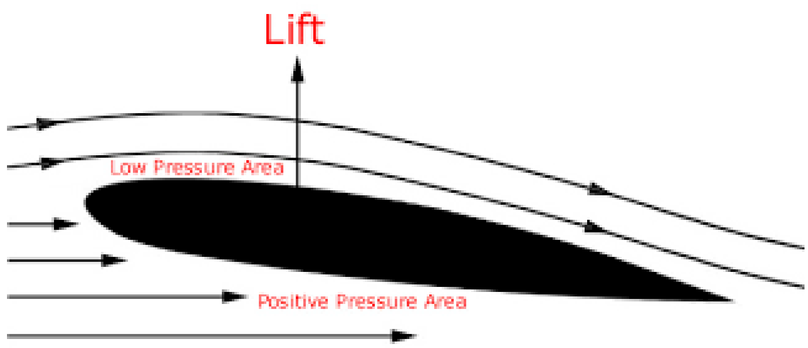

Figure 16. Diagram illustrating lift and pressure

In the trials shown previously, the lift force was always greater than the drag force regardless of the angle and the speed. Additionally, the drag force never exceeded .15 Newtons. Given that the A18 model was curved on the top and bottom, it was able to deflect the air moving around it. Ultimately, this increased the strength of the lift force while decreasing the impact of the drag force, which proved the previous studies mentioned correct. In order to compare the results of

[3] Poudel, A., Noskowicz, S., Poudel, A., & Young, T. (2020, March 16). Aerodynamics Forces: How does an Aircraft Fly?

the FoilSim calculations to data provided on the Profili website, two graphs were created. Figure 17 demonstrates the coefficient of lift according to the angle of attack, which was found using FoilSim. This data uses information provided by Table 1 in the Results section. Compared to the graph provided on the Profili website, Figure 17 shows a curved function as opposed to the linear graph shown in Figure 8.

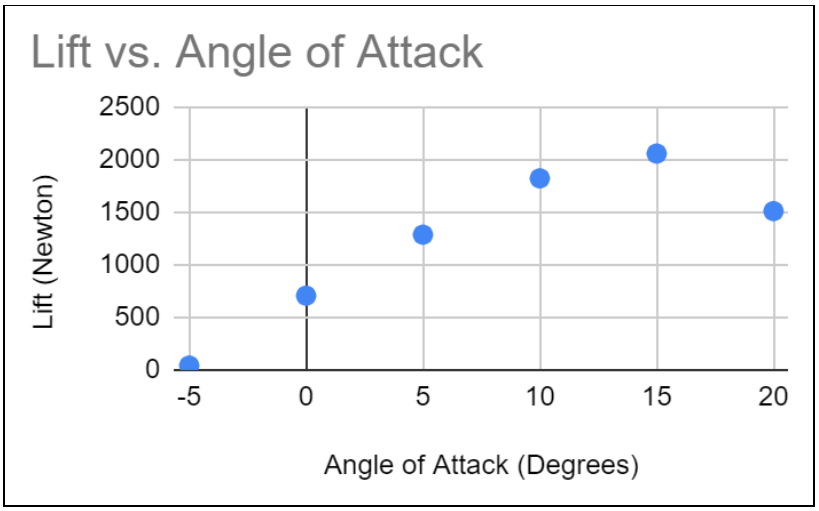

Figure 17. Lift measurements provided by FoilSim

Figure 18 shows the graphed coefficient of drag using the same data found in Table 1, which was measured using FoilSim. The graphed coefficient of drag shown on the Profili website shows a parabolic function. The graph shown in Figure 18 does not resemble a parabola but rather a square root function.

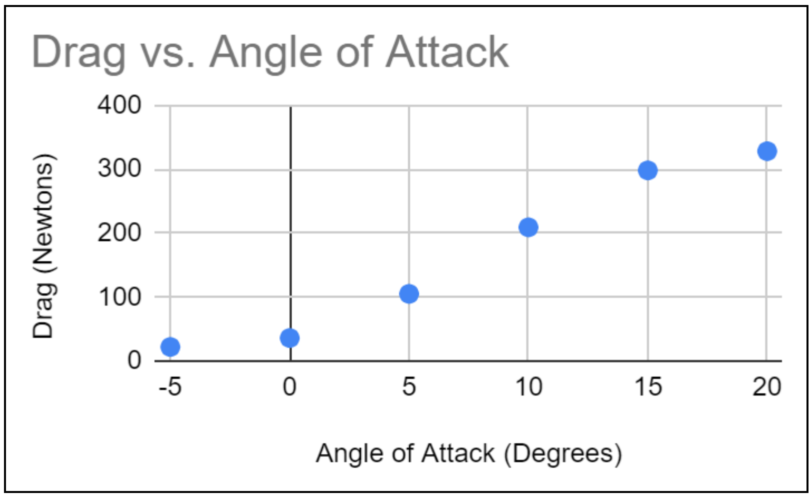

Figure 18. Drag measurements provided by FoilSim

Utilizing this information, it can be concluded that there is a distinct difference in the lift and drag measurements found using Profile and FoilSim. Nevertheless, both programs still prove the A18 model to be an efficient design. It should be taken into account that FoilSim and Profili used different units of measurement for lift and drag.

In comparison to the data provided by the wind tunnel, there are more similarities in the data compared to FoilSim. For instance, Figure 19 shows the lift measurements found using the wind tunnel. The Profili graph for lift indicated a linear growth. In Figure 19, the graph resembles a linear function with some outliers. For Figures 19 and 20, the data for lift and drag from the wind tunnel were separated into two graphs.

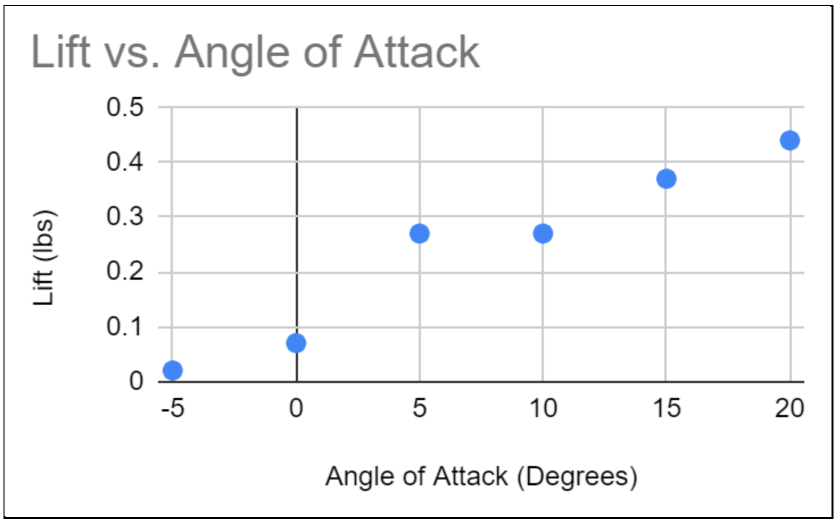

Figure 19. Lift measurements provided by the wind tunnel

Profili and the wind tunnel have very similar graphs for drag. Just as Profili showed a parabolic relationship between drag and the angle of attack, the wind tunnel graph for drag showed a parabola. Figure 20 shows the graphed wind tunnel data for drag.

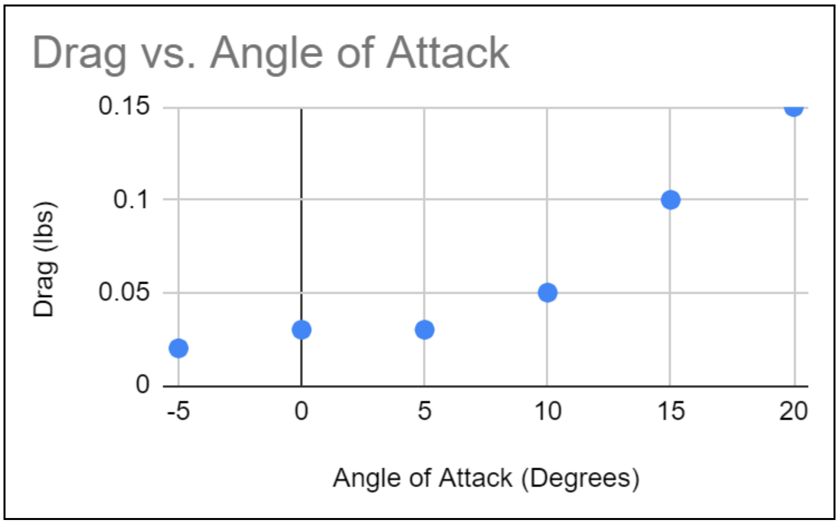

Figure 20. Drag measurements provided by the wind tunnel

Conclusion:

The A18 airfoil proved to be an efficient design. Regardless of the distinct difference found between Profili, FoilSim and the wind tunnel in data, all data indicated that lift force was greater than the drag force in every trial. Uncertainties such as random and instrumental may have contributed to the differences in data between all three programs. Nevertheless, as the laws of aerodynamics state, lift must be greater than drag in order for an object to achieve flight. The airfoil's chamber design allows for greater lift and less drag by reducing the pressure acting on it. It should be learned that lift and drag play an important role in flight. Consequently, aircrafts should use curved airfoils in order to acquire more lift, which will help achieve greater flight. If aircrafts were to use the A18 design, they would be able to travel faster compared to those using symmetrical airfoil designs.

References:

1. Crouch, T. D. (2020, March 4). Wright brothers. Retrieved from https://www.britannica.com/biography/Wright-brothers
2. Dunbar, B. (2015, May 12). What Is Aerodynamics? Retrieved from https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-aerodynamics-k4.html
3. Poudel, A., Noskowicz, S., Poudel, A., & Young, T. (2020, March 16). Aerodynamics Forces: How does an Aircraft Fly? Retrieved from https://www.geniuserc.com/how-aircraft-fly-and-aerodynamics-forces/