Spring 2017

Study of Experimentally Blended Wings

Ray Roos 2894888
rgr13@zips.uakron.edu

Study of Experimentally Blended Wings

A Senior Design Report by:

Danny Kilkenny

Raymond Roos

Contents

List of Figures:

List of Tables:

1.0 Abstract:

This aim of this senior design project is to investigate the combination of a Selig 1223 and FX 74-CL5-140 into one profile to increase lift without significantly increasing drag.

Our project began with researching current solutions for high lift and low drag airfoils. We found two airfoils which would be the target of our research, a Selig 1223 and the FX 74-CL5-140. After learning about the Cl and Cd of the current airfoils we built and physically tested the airfoils using additive manufacturing. A pressure differential tunnel was used to validate the airfoils. After researching how to blend two airfoil profiles together, our version of a blended wing was 3D printed. We used the same wind tunnel to test our experimental airfoil. Overall, the blended wing has shown an approximately 6% increase in lift. Drag was not found due to problems in the axial force sensor of the wind tunnel.

2.0 Introduction:

For the senior design project, a look into low-speed airfoils was the focus. The Akron Aero Design team needed to improve upon their previous wing designs in reference to what airfoils are used.

The Akron Aero Design team is a student design team who designs, builds, and tests an R/C plane every year. There are static and dynamic portions of their competition which test both the knowledge of the team and their ability to apply what they learned in the classroom to design and build a winning airplane. There are two different classes in the competition which they compete in.

The first class is Target where the plane has to hold a camera, telemetry, and a weighted payload. A pilot and payload specialist work together to drop the weighted payload onto a target as close as possible within two passes of the drop zone.

Next is passenger and payload where the goal is to lift as much as possible while still being able to take off within 200 feet. Points are awarded to the team who is able to lift the most within the 200-foot limit. After finishing 2nd in payload and passenger/payload they wanted to get ahead of the competition by using a blended profile design to increase lift without significantly increasing drag.

Our project involves the study of low-speed aerodynamics with the application being Akron's Aero Design team. Low speed (or subsonic) aerodynamics is the study of fluid motion in flows slower than the speed of sound at any point in the flow. Our tests were run at an average speed of 30 MPH per the average speed of the airplane.

Our basic goals were to increase the lift of the Passenger/Payload plane to allow it to lift more weight. However, we had to limit the drag of the plane because we were constrained by the length of the runway. If the plane had too much drag, then it would not take off until after the 200-foot mark, thus disqualifying the run.

3.0 Blended Wing Design:

Blended airfoil wings have been used to customize the amount of lift needed for different applications. It is also a growing experimental field for researchers as they seek more efficient wing designs to save fuel. The reason is because when you blend airfoils into one wing shape, you can customize the amount of lift needed. If you use a high lift (high camber) profile only, then it will only be good at takeoff but your drag will increase significantly throughout the duration of the flight. The opposite is true of a low lift (low camber) wing. When you combine these together, you can achieve an improved lift to drag ratio. Boeing and NASA are currently working on a plane that blends different profiles into one wing to improve the efficiency of their plane.

Figure 1: Boeing X-48B: Experimental blended wing aircraft.

They are not the first company to do this. Below are just a few examples of blended wing shapes and profiles for various applications.

Figure 2: Mobil One Le Mans Corvette C-7. (Note: widebody design)

Figure 3: Petronas F-1 rear wing.

Figure 4: Aérospatiale/BAC Concorde, supersonic passenger jet.

4.0 Trade Studies:

The design project was limited by various factors, cost and time being the major ones. In order to limit the scope of the project, we performed trade studies. Options for the test wing were the airfoils used in the test, the planform of the wing, and manufacturing method. The base Selig 1223 airfoil was used to originally prove testing, while a blended wing between the FX 74-CL5-140 and the Selig 1223 was the experiment. A rectangular planform was selected to make manufacturing simpler and both test sections would be made via 3D printing.

We researched three airfoils, the Selig 1223, Eppler 423, and the FX 74-CL5-140. The Akron Aero Design team has had the most experience with both the Selig and the Eppler. The FX airfoil, however, shows promise by having comparable lift and superior drag values. The first consideration in selecting airfoils was the raw performance, which would be the coefficient of lift, C_L. The Selig has the highest lift coefficient of 2.3 at 13° angles of attack (AOA), while the FX and the Eppler have a value of approximately 2.05 at 9° and 11°, respectively. Another major consideration was the efficiency (C_L/C_D) of each airfoil. Again, the FX and Eppler were similar with each around 120 and the Selig around 100.

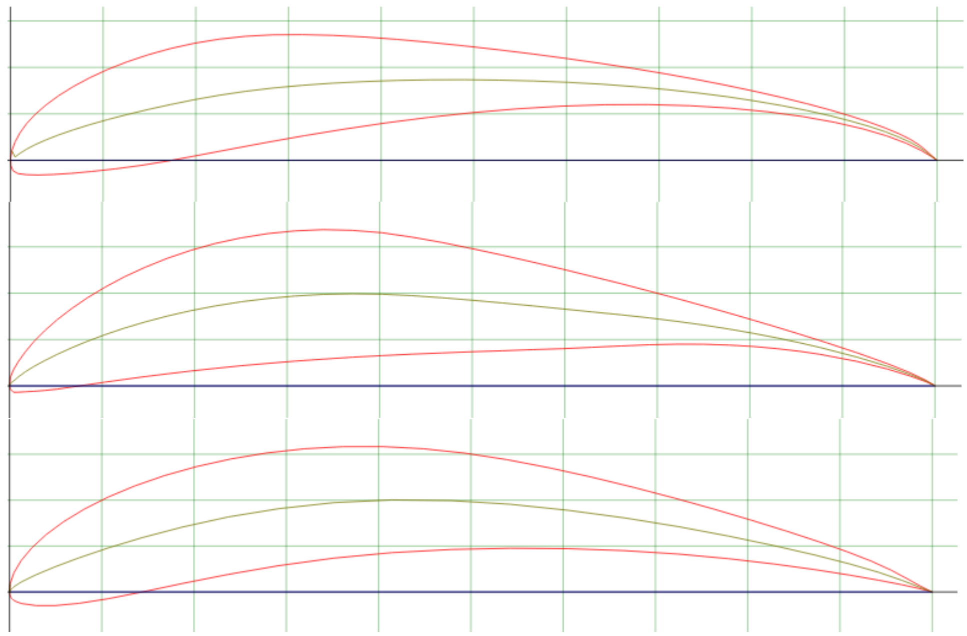


Figure 5: Top: Selig 1223, Middle: FX 74-CL5-140, Bottom: Eppler 423.

Ultimately, the Selig and FX airfoils were chosen to create the blended wing for multiple reasons. The Selig 1223 was chosen for the tips for the higher C_L and stall characteristics, mitigating tip losses and preventing tip stall, a difficult phenomenon to try and save an aircraft from. The FX 74-CL5-140 operates optimally within a lower range of AOAs, which will perform better at the cruising condition of the aircraft and has a higher efficiency than the Selig.

Once the airfoils were selected, the planform of the wing had to be selected. Options included rectangular, partially tapered, or a semi-elliptical shape; all three had been used by the Aero team in previous aircraft designs. The most efficient shape, the semi-elliptical was considered initially for a final design to simulate a ‘real world' scenario but was ultimately removed from the list due to the complexity of both design and manufacturing. A partially tapered planform suffered from the same issues as the semi-elliptical design, as it would provide a higher efficiency, but is more difficult to manufacture than the final option. The rectangular planform was decided upon due to the simplicity of design and manufacturing. A straight wing eliminates the use of tapers and complex curves other than the airfoil itself.

As a final consideration, three types of manufacturing methods were selected: molded carbon fiber, machined Renshape, and 3D printing. A carbon fiber mold was deemed too expensive and difficult due to the creation of a mold. Machined Renshape became the choice as it was accurate, easy to machine, and material was easy to acquire at the time. However, the Renshape became unavailable so 3D printing became the final selection. It was an adequate choice from the beginning as it was a free service through the university and allowed for virtually any shape to be created with a certain degree of accuracy.

5.0 Testing:

To begin design, the test sections would need to be sized according to the atmospheric data in Akron. Historic weather data from Akron-Canton airport was used to initially size the wings. The air conditions in the basement of Auburn Science and Engineering Center (ASEC) turned out to be different from the outside air due to a lower temperature and air pressure. The wings were sized according to this data and the approximate Reynolds numbers that the Aero design team's aircraft fly at a range of 200,000 to about 400,000. The wind tunnel, however, limited the range that the wing could operate at with the limits of the load sensor maxed out. A Reynold's number of about 200,000 for a wing with an 8-inch chord was the limit of the wind tunnel testing, which fell into our estimated range. In order to reduce tip losses, an “infinite wing” was simulated by making the wingspan almost the width of the tunnel, for a length of 15 inches. With an area of 120 in^2, the wing was estimated to create 2.62 lbs of lift and 0.04 lbs of drag.

The design of the test sections was done in Solidworks to create a 3D profile. This allowed us to visualize the part and ensure that it would be able to be manufactured. Each of the wings had to be divided into three separate sections in order to be 3D printed, which were made using a Makerbot Replicator +. Preliminary finite element analysis was performed to ensure the parts would not fail under load in the wind tunnel. The expected lift would be around 5 pounds so the 3D printed PLA would be able to withstand the forces with a sufficient factor of safety. The printed parts were then assembled using a two part epoxy which has been proven to be sufficient for the aircraft by the made by the Aero Design team.

Once the parts were printed and assembled, each was placed on the mount in the wind tunnel for testing. The wings went through pitches changes ranging from -5° up to 18°, the maximum of the wind tunnel. Three different airspeeds were used as well: 30, 40, and 50 mph. At each angle, the part was held and then 10 samples over 0.1 seconds were taken. The average of these samples were used in the plotting of the lift curves of the wings. Each wing was tested 3 times. The data was compiled using Excel and plotted.

Figure 6: Selig wing mounted in wind tunnel.

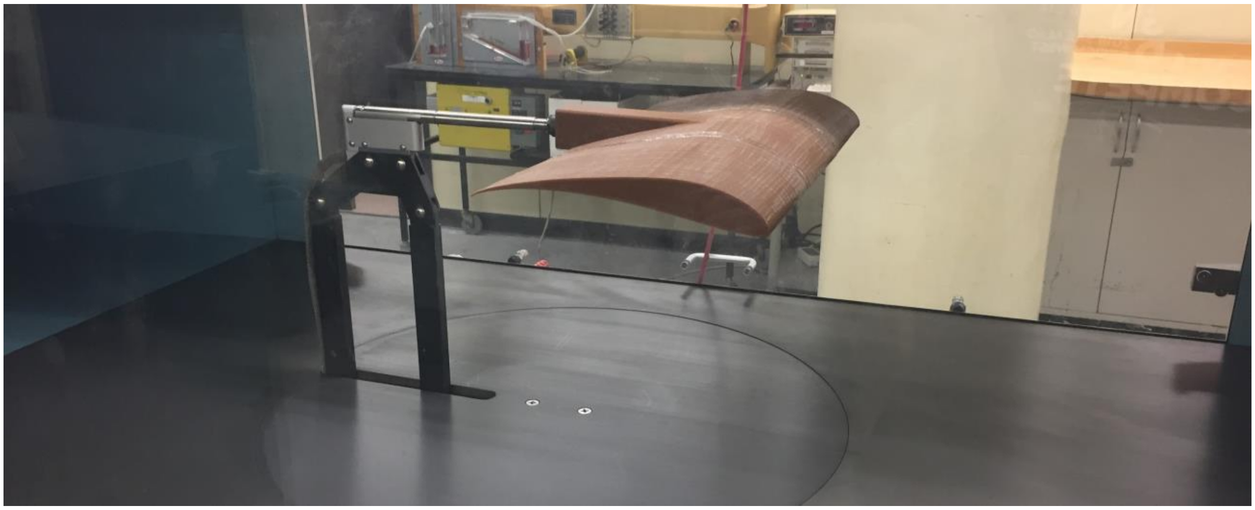


Figure 7: Blended wing mounted in wind tunnel.

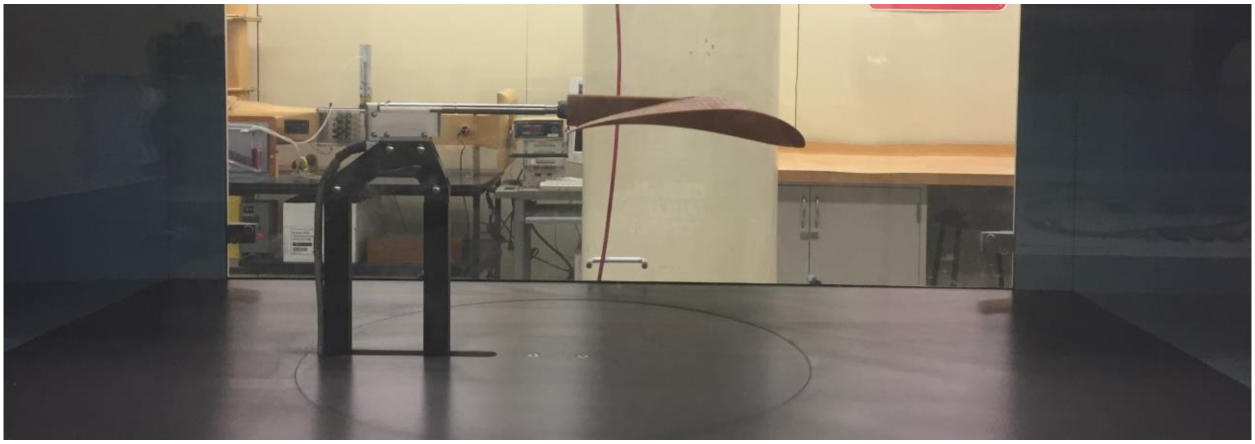


Figure 8: Side profile of blended wing.

6.0 Results:

With testing complete, it was found the blended wing performed marginally better than the wing with only the Selig airfoil. The table below shows the average lift produced by each wing over a range of AOAs at three speeds.

Table 1: Lift values from Selig and blended wings.

	Selig 1223			Blended Wing		
	30 mph	40 mph	50 mph	30 mph	40 mph	50 mph
-5	0.093	0.277	0.410	0.263	0.597	0.868
0	0.910	1.996	3.498	1.130	1.989	3.774
5	1.834	3.518	5.914	1.837	3.688	6.464
10	2.583	4.932	8.238	2.616	5.242	8.755
15	3.340	6.325		3.496	6.689	
18	3.744	6.971		3.932	6.996	

Table 2: Percentage of lift increase of blended design over Selig.

AOA	30 mph	40 mph	50 mph
-5°	184.173%	115.663%	111.798%
0°	24.258%	-0.384%	7.880%
5°	0.164%	4.852%	9.294%
10°	1.304%	6.293%	6.272%
15°	4.650%	5.744%	
18°	5.021%	0.363%	
	AVG:	**5.824%**	

Both wings showed consistent lift values each time they were run in the wind tunnel. Each of the three runs is shown below in their respective charts. Drag was also expected to be experimentally found; however, the values that the sensors provided were actually negative, meaning thrust was produced. Naturally, this data was excluded from the final report and not taken into account. The blended wing lifted an average of 5.8 % more weight than the base Selig profile. This concept seems to be a promising lead into further airfoil studies. Further study into different airfoils or where the blending occurs is necessary to pull more performance from the wings. This paired with an ideal planform could create a higher performance wing than in previous years of Aero Design aircraft.

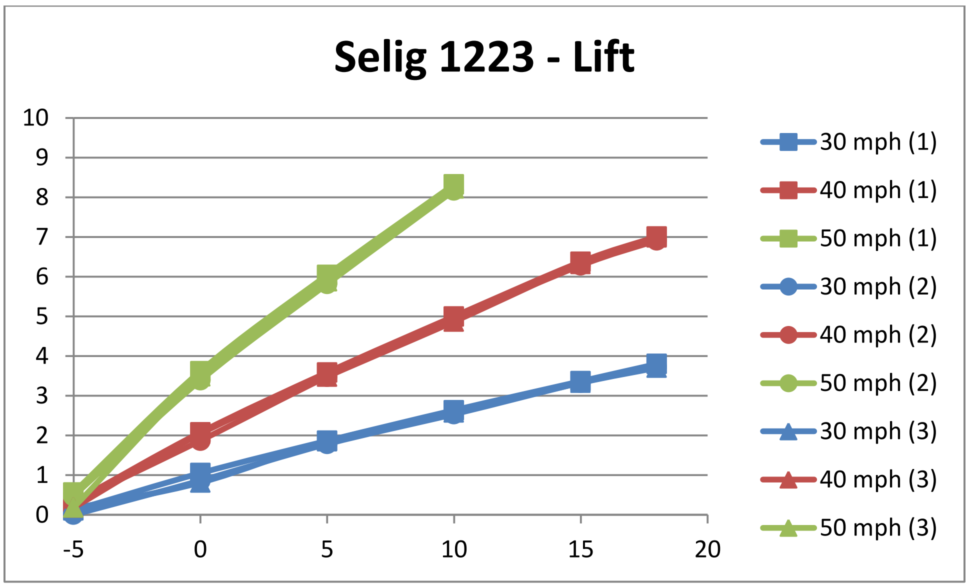


Figure 9: Selig lift curves.

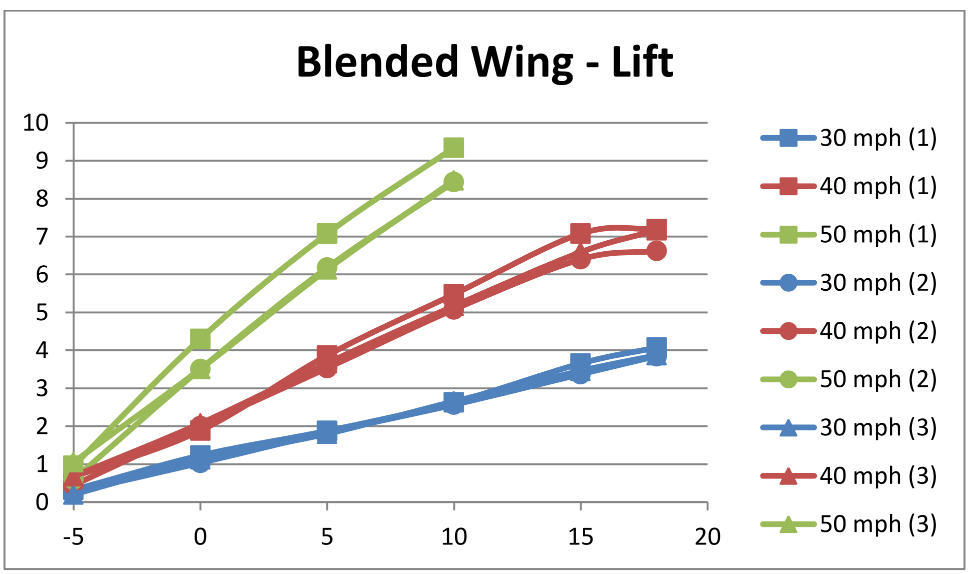


Figure 10: Blended wing lift curves.

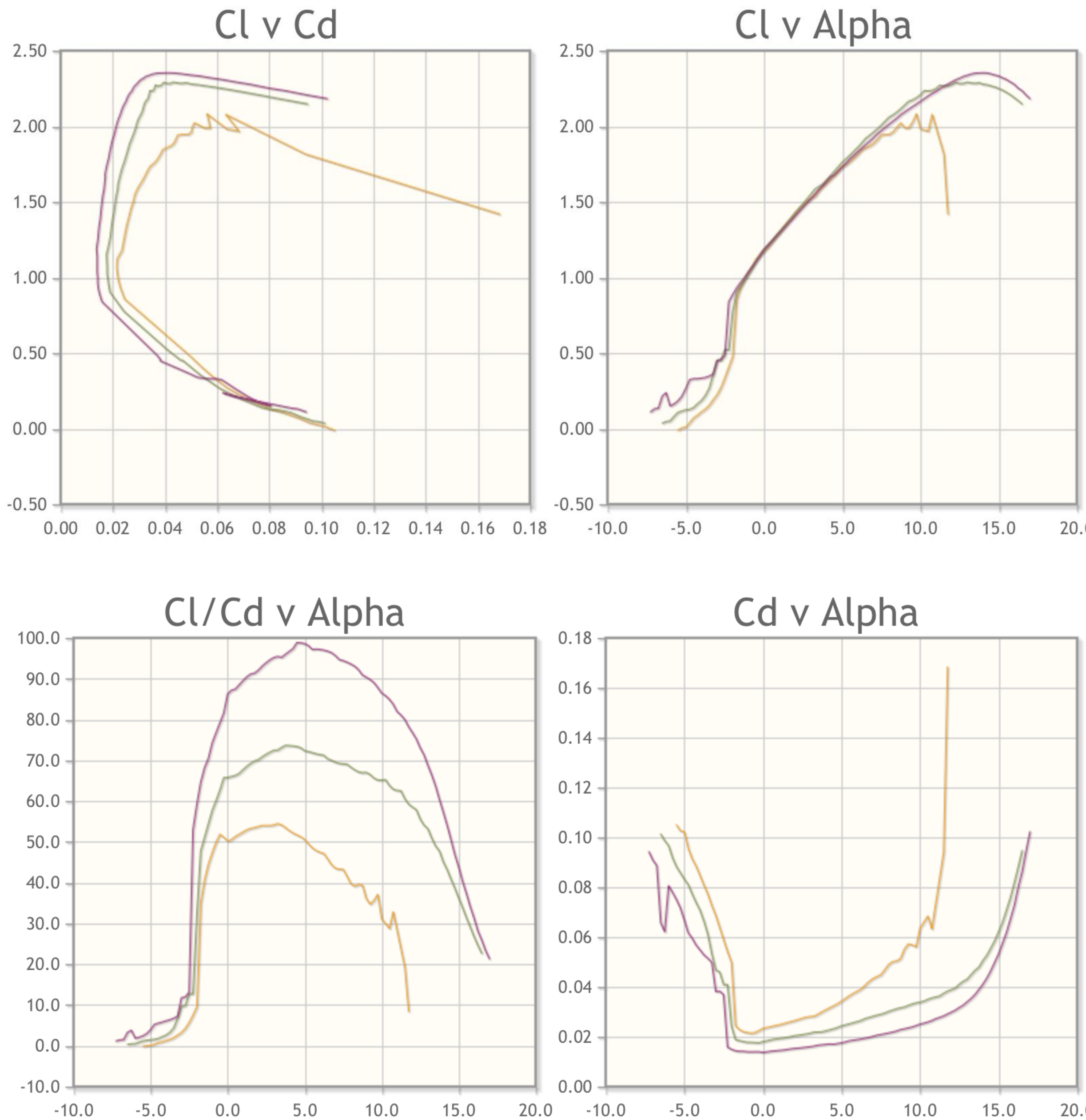
7.0 Reflections:

This research was done to investigate the potential of creating higher lift airfoils by blending different combinations of profiles together. It was done in an effort to assist the aero design team to increase the aerodynamic performance of their plane. Unfortunately, the scope of the project got smaller as time moved along. What we thought was a good plan of attack did not work how we planned as delays and unexpected events took place throughout the duration of this study. One example of this was how we relied on a student to machine the original block of renshape material we were going to use. By the time our designs were finished, it was close to the end of the semester and he was not able to machine it before winter break ended. This set us back quite a bit. This forced us to use 3D printing methods for our airfoils which were not preferred from a tolerance perspective. However, we were able to work with the technicians at the school to find a suitable printer. From these experiences, we learned about planning and acceptable contingencies.

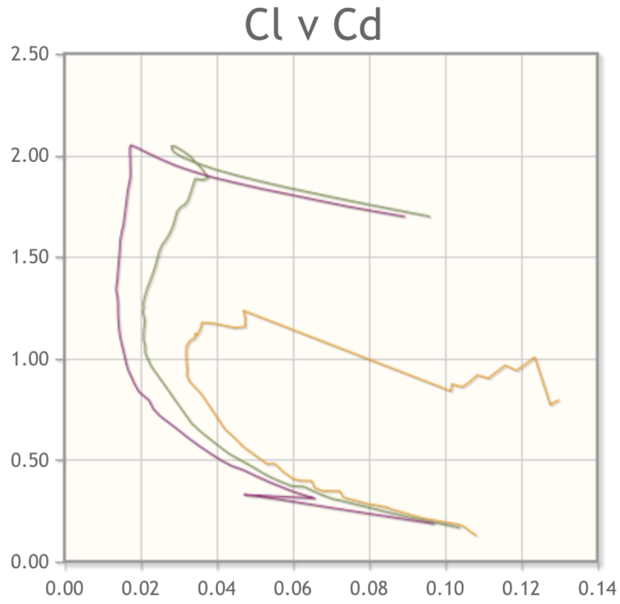
References:

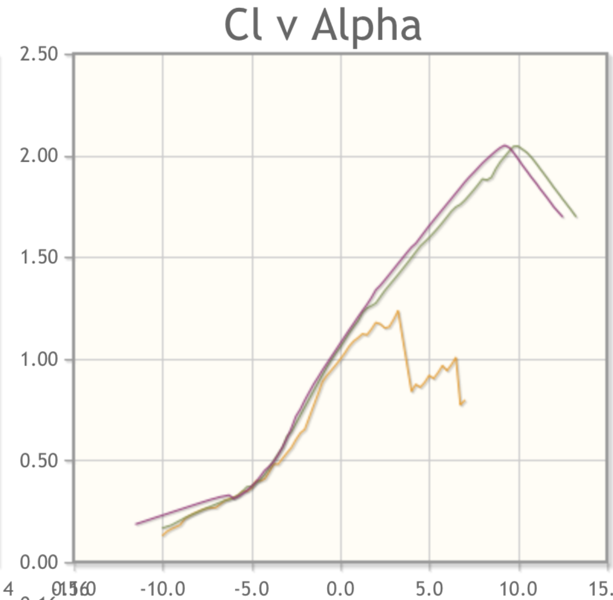
1. Abbot, Ira H., and Von Doenhoff, Albert E. (1975). Theory of Wing Sections. New York: Rupple Publications.
2. Anderson, John D. (2000). Introduction to Flight, 4 ed. McGraw Hill.
3. Eppler, Richard. (1990). Airfoil Design and Data. Germany: Springer-Verlag.
4. Selig, Martin, Donovan, John F. (1989). Airfoils at Low Speeds. Virginia: Stokely, H. A
5. Selig, Michael (1996). Summary of Low-Speed Airfoil Data: Volume 2. SoarTech Publications.

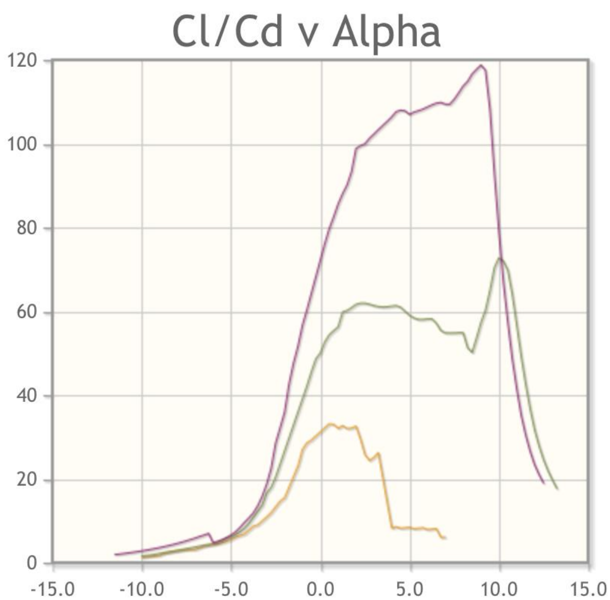
Appendix A: Selig 1223 Data Plots

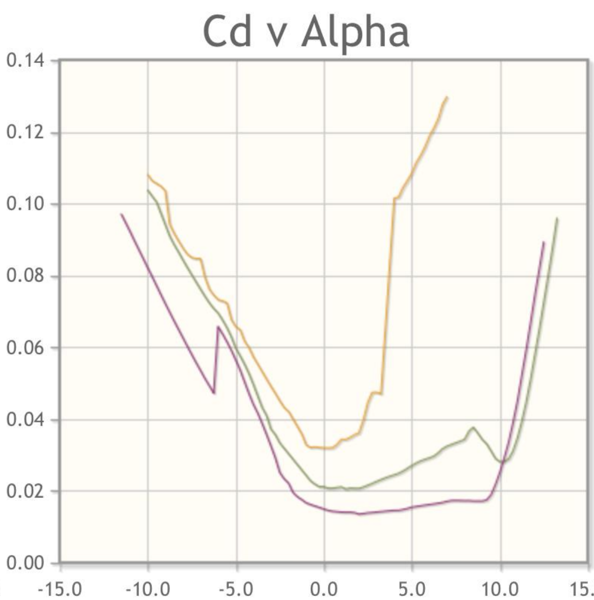


Appendix B: FX 74-CL5-140 Data Plots









Appendix C: Eppler 423 Data Plots