Wing Optimization
ME 271E

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0.1 Part 1: Airfoil Optimization

0.1.1 Select New Airfoil

Midterm Ressults: $C_L = 0.57; Re = 338{,}400; Ma = 0.035$
Based on my midterm results, I knew I wanted nd an airfoil that was already optimized for low Reynolds numbers. In addition, due to our nal design, I was looking for an airfoil that had a nearly zero pitching moment, so could be stable as a purely ying wing. Based on the *UIUC Low-Speed Airfoil Data Book* Volume 2, I found the S5010[1] is both optimized for low Reynolds number and satis es this additional important pitching moment requirement. While satisfying this pitching moment constraint does constrain the airfoil performance, making this airfoil have overall higher drag as compared to airfoils with similar lift, I believe it is worth it, as stabilizing a y-ing wing can be extremely challenging. Note the S5010 was the airfoil we chose for our Week 8 Lab.

0.1.2 Determine the Range of Lift Coe cients

From the *UIUC Low Speed Airfoil* Volume 2, I found the C_l curve for my given Reynolds number of 338,400 (see Figure 1). Hence, $C_{lmax} = 1.15$, since this is the stall condition. However, similarly to the midterm, we want to take our maximum allowable C_l to be $C_l < 0.9 \; C_{lmax} = 1.0$, so that there is no chance of reaching this stall condition. I also determined from the midterm, the $C_{Lmin} = 0.57$.

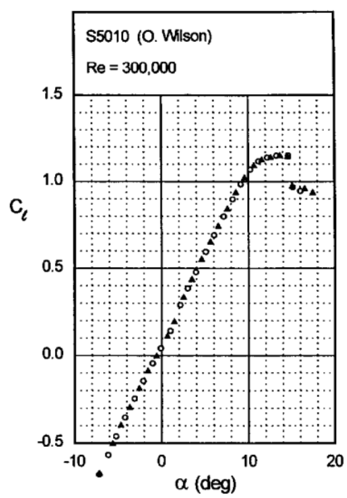

Figure 1: C_l Curve

[1]Selig, M.S., Lyon, C.A., Gigure, P., Ninham, C.N., and Guglielmo, J.J., *Summary of Low-Speed Airfoil Data*, Vol. 2, SoarTech Publications, Virginia Beach, VA, 1996, 252 pages. Wind tunnel data on 25 airfoils tested at Reynolds Numbers ranging from 40,000 to 400,000.

From here, we know the sectional lift coefficient is as follows

$$C_l = \frac{l}{qc} \tag{1}$$

Where q is the fluid dynamic pressure, c is the chord length, and l is the lift force per unit span of the wing. In addition, we know the equation for the lift coefficient as seen in Equation 2a which can be rearranged to Equation 2b.

$$C_L = \frac{L}{qS} \tag{2a}$$

$$L = C_L qS \tag{2b}$$

Where L is the lift force, and S is the surface area. Lastly, we can approximate the section lift as

$$l = \frac{Lc}{S} \tag{3}$$

Plugging Equation 2b and Equation 3 into Equation 1 gives us the following:

$$C_l = \frac{l}{qc} = \frac{\frac{Lc}{S}}{qc} = \frac{\frac{C_L qSc}{S}}{qc} = \frac{C_L qSc}{Sqc} = C_L \tag{4}$$

In essence, this states that in my simplified model, the section lift coefficient is constant across the span of the wing, and can in fact be simplified to C_L. Hence, for each of the locations specified the range of allowable C_l values will be the same. What an amazing result!!

Root: $C_{l_{min}} = 0.57; C_{l_{max}} = 1.0$

Midspan: $C_{l_{min}} = 0.57; C_{l_{max}} = 1.0$

Tip: $C_{l_{min}} = 0.57; C_{l_{max}} = 1.0$

0.1.3 Max and Min Coefficients of Lift

Based off my 2D wing analysis, I found that the coefficient of lift will be constant across the wing. Hence, to be safe, I would want the maximum and minimum section lift coefficient to match those above, as we would know those parameters will satisfy the design parameters.

Max lift coefficient optimization:1.0

Min lift coefficient optimization:0.57

0.1.4 Optimization Parameters

To best suit our mission, of maximizing ight time and ight range I had three goals:

1. **Maximize the power factor:** Since the required battery power is inversely proportional to the power factor, maximizing the power factor, will decrease the required battery power. This will ultimately increase our ight time, which is something important when we are delivering packages.

2. **Maximize of hold constant glide ratio:** We know that range is proportional to glide ratio. Hence, I do not want to decrease our glide ratio, and if possible would like to increase it as well, to maximize our range. Note: I also felt like I could increase glide ratio in the 3D wing optimization

3. **Minimize Cm:** Lastly, due to our ying wing con guration, it is crucial that Cm remains very close to zero, if we am going to be able to stabilize our wing.

0.1.5 5 Iteration steps

Below, I have summarized the ve most signi cant changes I made to the airfoil. However, note, that I included some of other changes, and the graphs of my progress in Appendix A, and even that does now cover all the changes I tried.

Iteration #	Description of Change	E ect on Glide Ratio	E ect on Moment	E ect on Power Factor
1	Increased Thickness to increase the power factor	Decreased	Decreased	Increased
2	Included Cusped Trailng Edge to decrease the drag	Decreased	Increased (Absolute value)	Increased
3	Added Re exed Edge to decrease the magnitude of the moment	No E ect	Decreased (Absolute Value)	Decreased
4	Decreased Leading Edge to increase lift and decrease drag	Increased	No E ect	Negligible E ect
5	Smoothed Cusped and Re exed Edge to decrease drag	Increase	No E ect	Increase

In the following gures, I have shown the di erences I made from the original airfoil design, to my ultimate optimization. In these drawings green shows the original airfoil and pink shows my optimized foil. Figure 2 shows the overall di erences between the two designs. However, since the changes are slight, and hard to see, I thought I would zoom in other sections. Figure 3 shows the increased cusped edge from the original to nal design. In addition, Figure 4 shows the increased re ex between the original to optimized design.

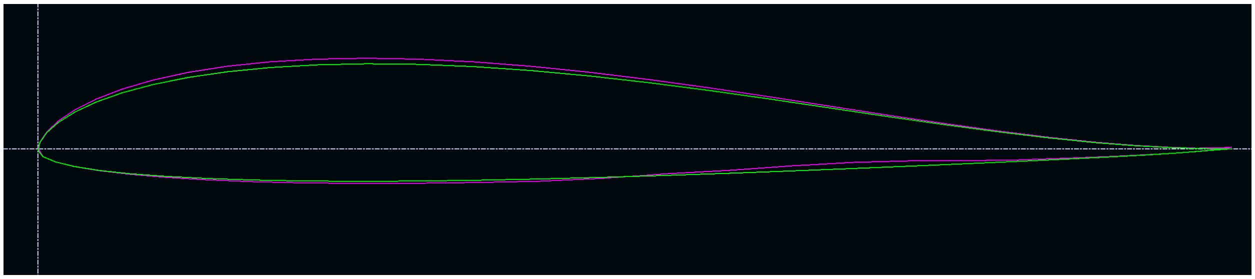

Figure 2: Overall Design Changes

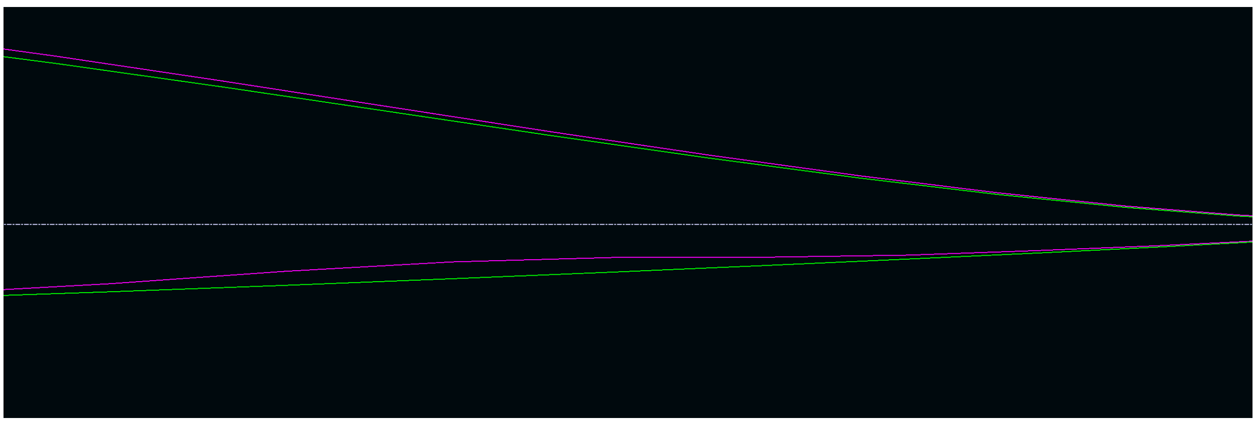

Figure 3: Cusped Changes

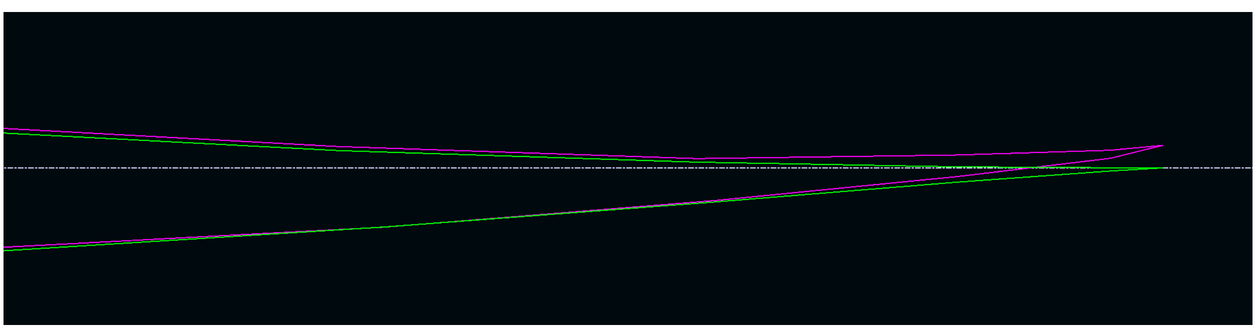

Figure 4: Re ex to Tail Changes

0.1.6 Polars of original and optimized foil

In the beginning, I had three goals, as you can see in the polars below, I was able to increase the power factor at my given Reynolds number, increased the maximum Glide ratio slightly, and decrease the value of Cm.

All of my decisions in conjunction helped get this ultimate result. Creating the cusped trailing edge decreased drag, but also led to a much larger Cm. I then had to counteract this by adding a more re exed edge. This worked to decrease the Cm, but did also decreased the the e ect of the cusped edge.In addition, direct design changes I made such as increasing the thickness, and decreasing the leading edge helped to create the new optimized foil you see below.

Note: below, I plotted polars at my operating Reynolds number, as well as a few around it.

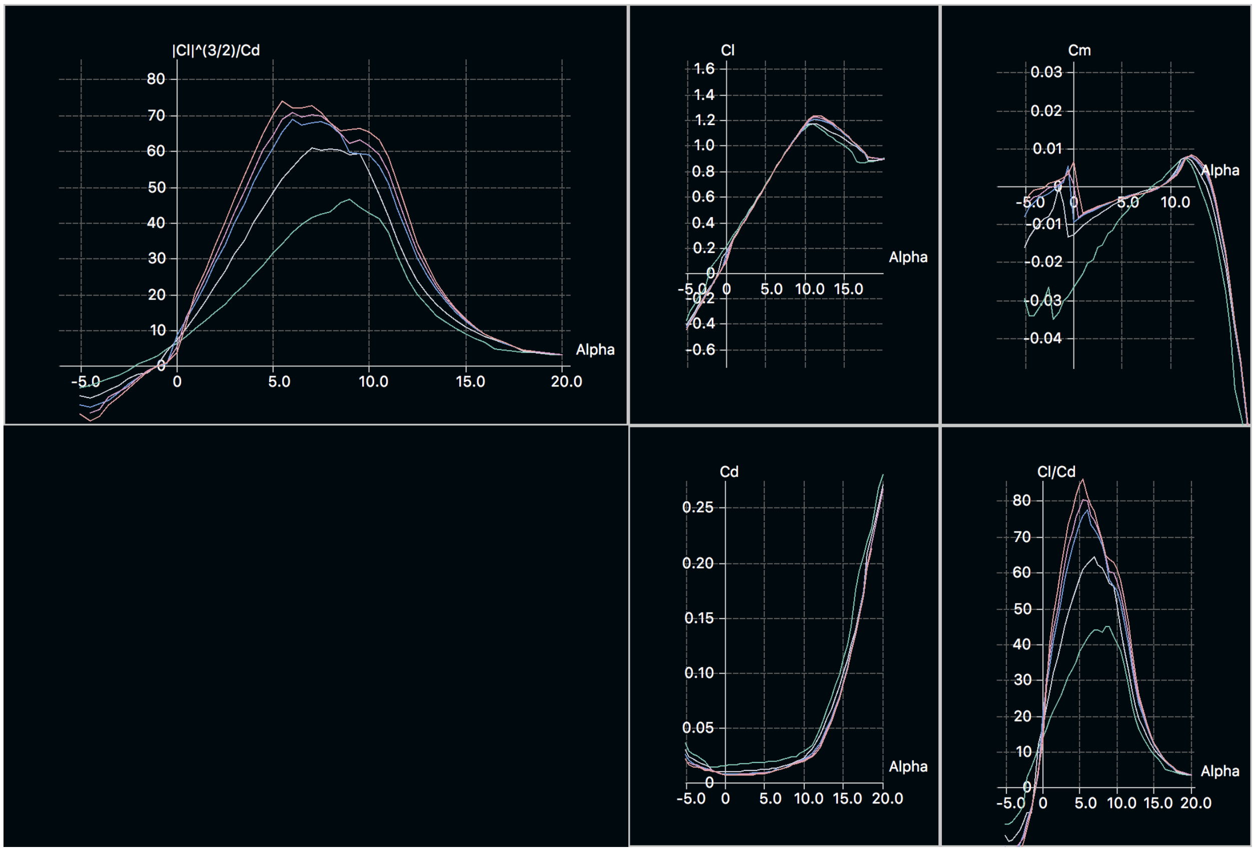

Figure 5: Original Polars

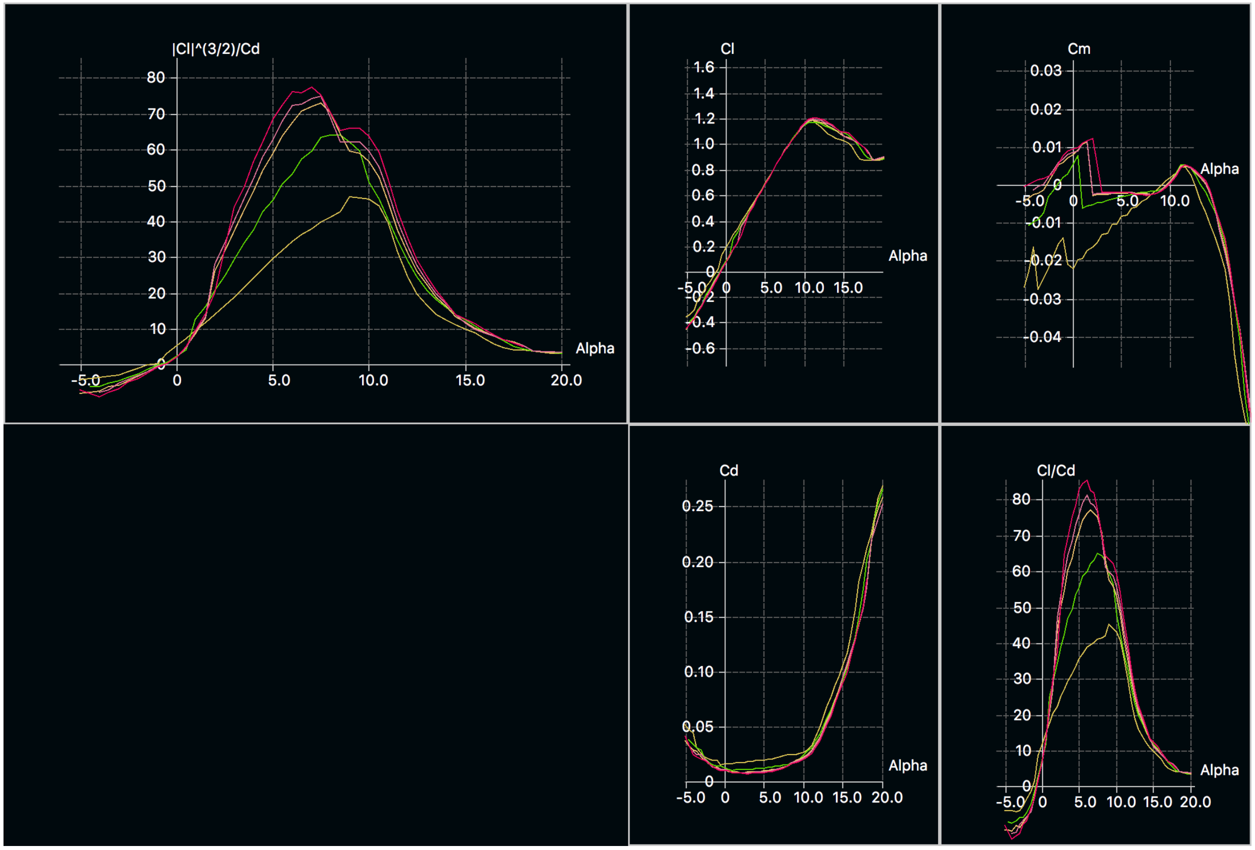

Figure 6: Final Polars

0.2 Part 2: 3D Wing Iteration

0.2.1 3 Iterative Steps

Before starting the process below, I had to alter my original team design to provide the necessary wing lift coe cient. After that, I was able to alter this three times to try to improve the drag performance.

Iteration #	Description of Change	E ect on Lift	E ect on Drag	E ect on Moment
1	Increased the twist, because this can help with stability and aerodynamic performance	Increased	Decreased	Decreased
2	Increased the Sweep Slightly to increase aerodynamic performance by delaying shock waves	Increase	Increase	Decrease
3	Increased Wing Taper (as de ned in XFLR5) because this can also help increase lift	Increase	Decrease	Decrease

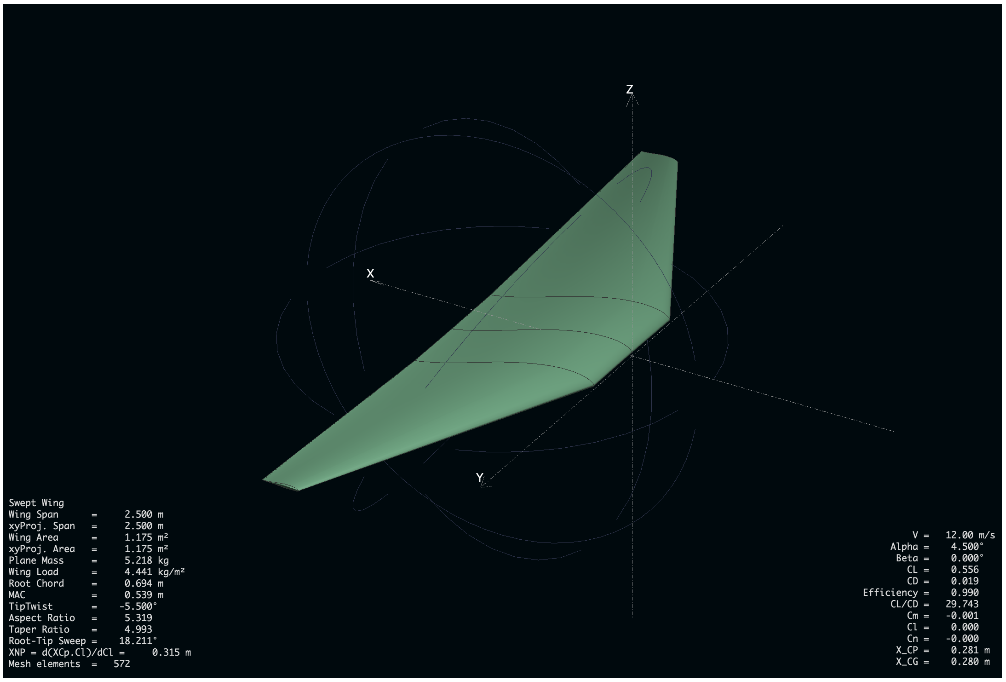

Figure 7: Original Planform

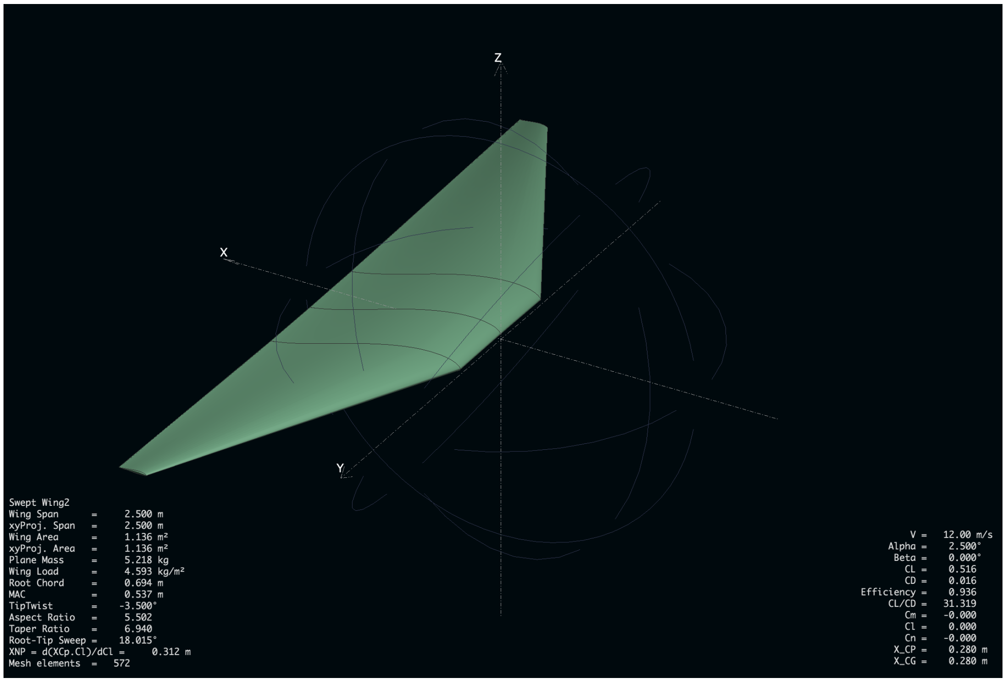

Figure 8: Final Planform

0.2.2 Polars

Overall, I was able to increase the glide ratio, when at a zero Cm. I think all of my changes, including increasing twist, sweep and taper ratio, helped achieve this. However, the aspect where I saw the greatest improvement was with increasting twist.

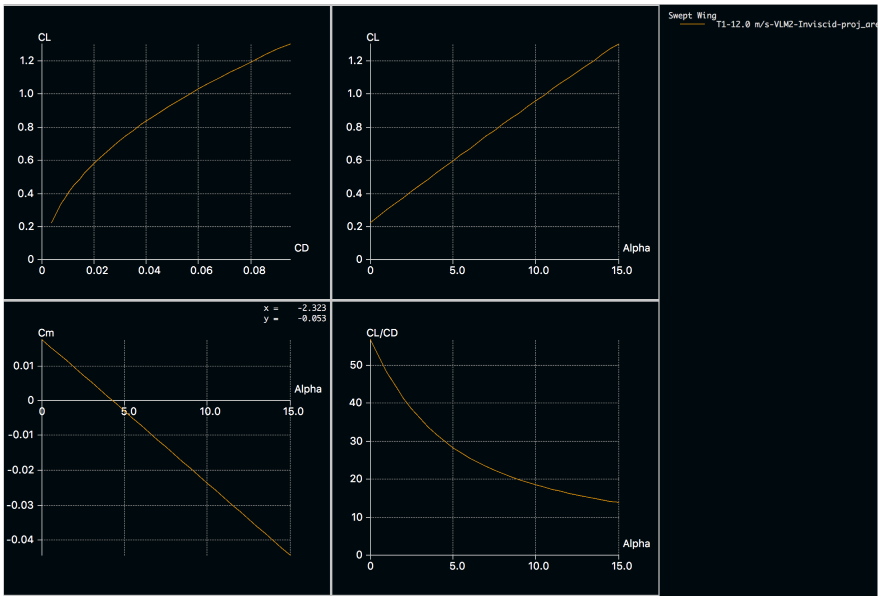

Figure 9: Original Polars for Planform

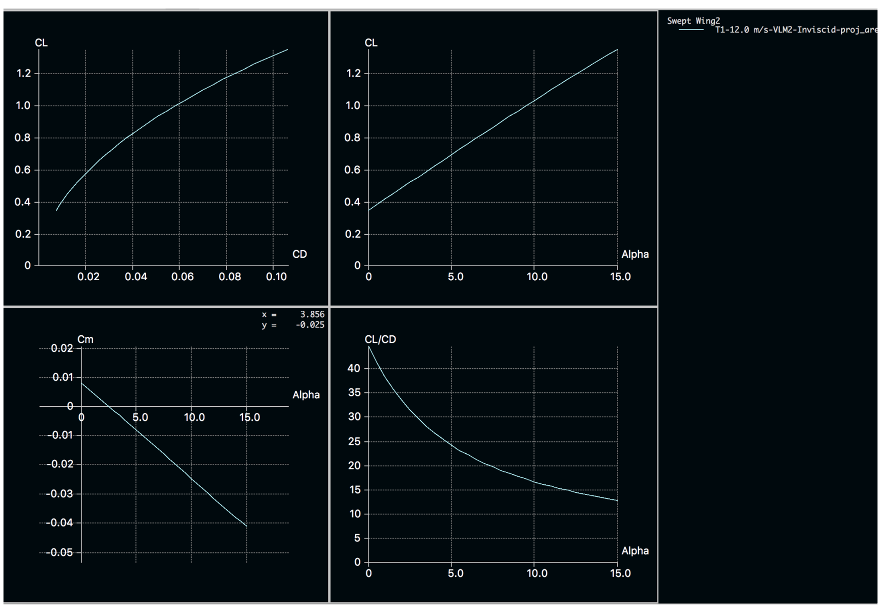

Figure 10: Final Polars for Planform

0.2.3 Touch-up Alterations

I did not need additional alterations. Since my foil design was heavily constrained by the fact that I wanted to have a near zero pitching moment for my ying wing con guration, any changes I made to the foil had to be minimal. Any large changes I made resulted in large changes to the Cm which was highly undesirable. I think this helped with the fact that when I optimized this foil in the 3D setting, I did not need to go back afterwards to make any changes to the foil.

0.3 Appendix A: Progress of Key Parameters Over Iterations

Iteration	Power Factor Max	Cl at Max Power Factor	Cd at Max Power Factor	AoA at Max Power Factor	Cm at Max Power Factor	Cl_max	Stall AoA	Thickness	Camber	L/D at Max Power Factor	AoA delta from max PF	Change from Previous and Reason
1	68.661	0.786	0.01	6	-0.0025	1.2	11.5	9.82	2.2	77.078	5.5	Base
2	70.53	0.942	0.013	7.5	-0.00025	1.18	11	9.99	2.27	75.8	3.5	Increased Thickness
3	73.417	1	0.014	8	-0.0003	1.2	11.5	10.49	2.34	76.77	3.5	Increased Thickness
4	73.5	1	0.014	8	-0.0004	1.229	12	10.49	2.34	75.7	4	Changed Points directly to include a cusped edge
5	74.08	1.005	0.014	8	-0.003	1.23	11.5	10.49	2.34	75.8	3.5	Changed Points directly to include a cusped edge
6	73.566	1	0.0135	8	-0.001	1.223	11.5	10.49	2.34	75.3	3.5	Changed Points Directly to include more Reflexed Edge
7	73.779	1	0.013	8	-0.002	1.223	11.5	10.49	2.34	75.5	3.5	Added more cusped edge and Reflex
8	73.446	0.93	0.013	7.5	-0.002	1.178	11	10.46	2.34	76.7	3.5	decreased leading edge radius by 0.9 % of old-- smoothed out curve
9	71.7	1.071	0.015	8	-0.019	1.3	12	15.64	2.19	69.934	4	Tried Inverse design on top surface-- led to foil without closed edge
10											0	Closed the open Airfoil-- Then no points converged

Figure 11: Foam Prototype of Design 3

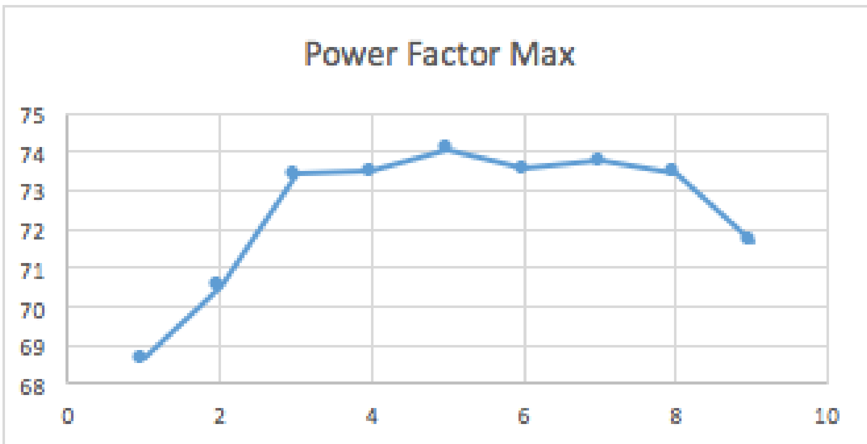

Figure 12: Foam Prototype of Design 3

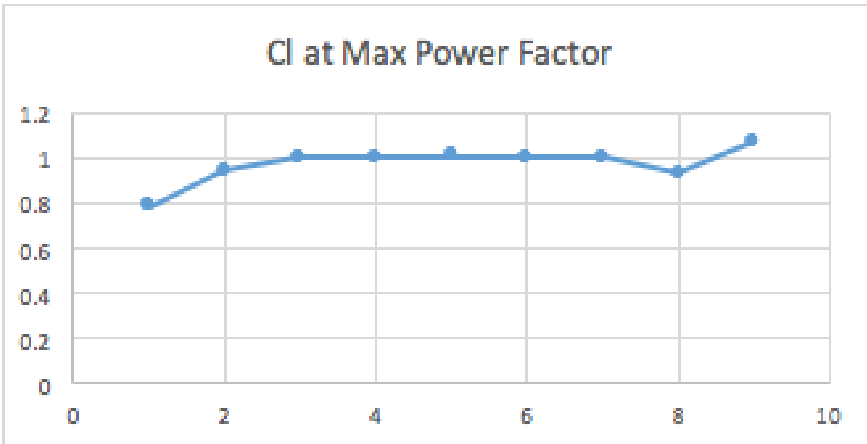

Figure 13: Foam Prototype of Design 3

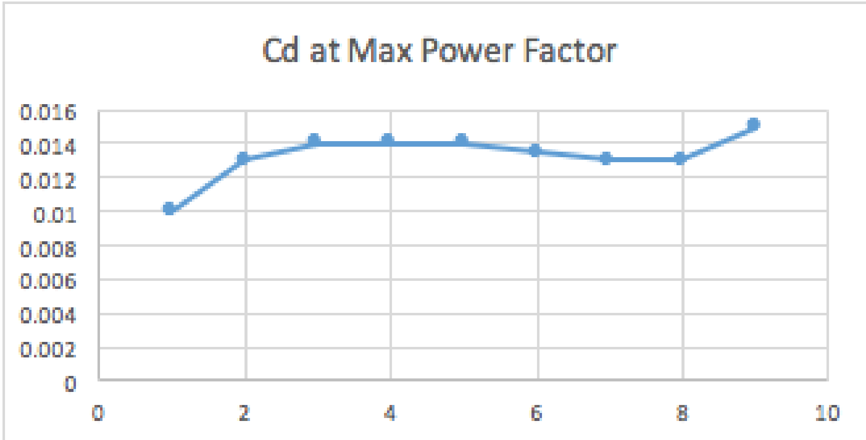

Figure 14: Foam Prototype of Design 3

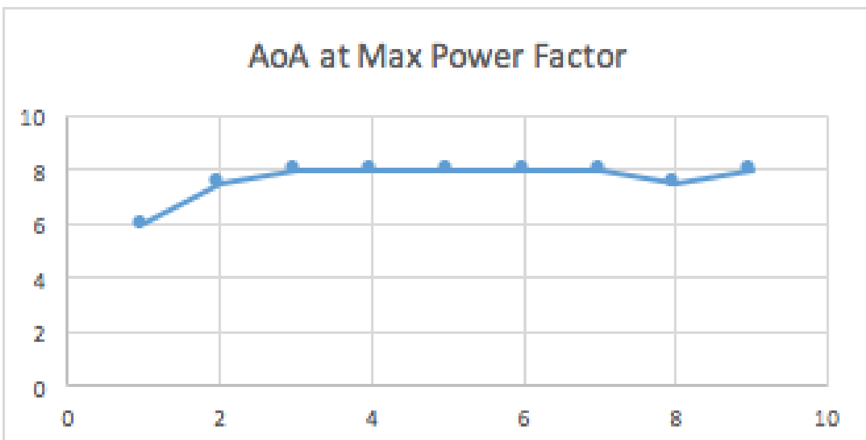

Figure 15: Foam Prototype of Design 3

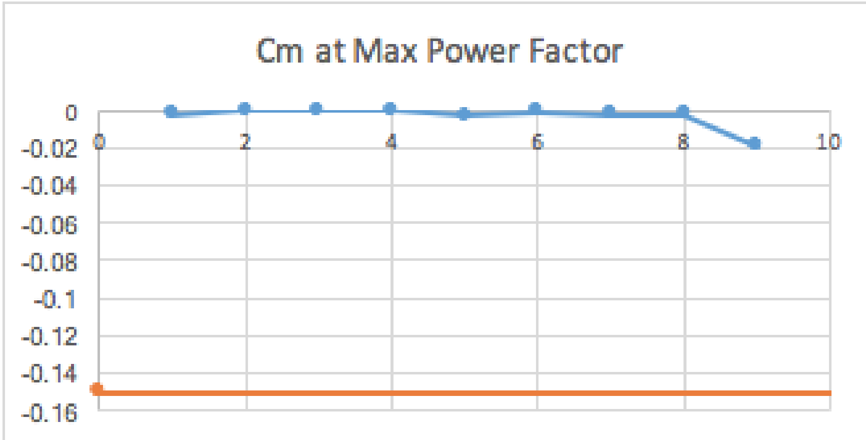

Figure 16: Foam Prototype of Design 3

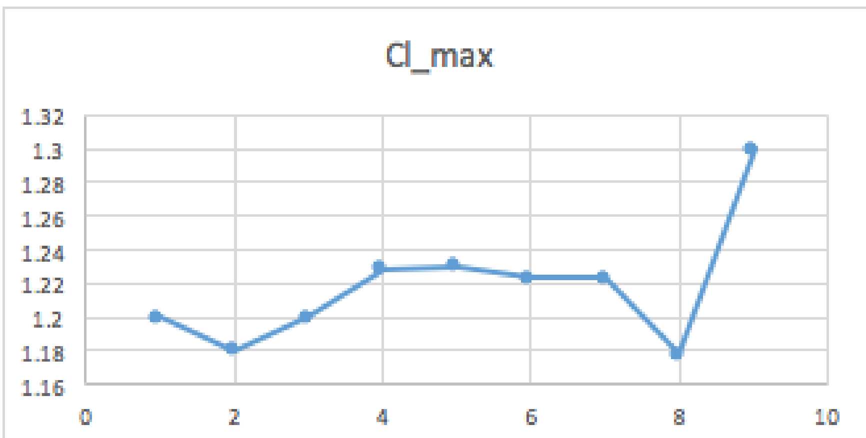

Figure 17: Foam Prototype of Design 3

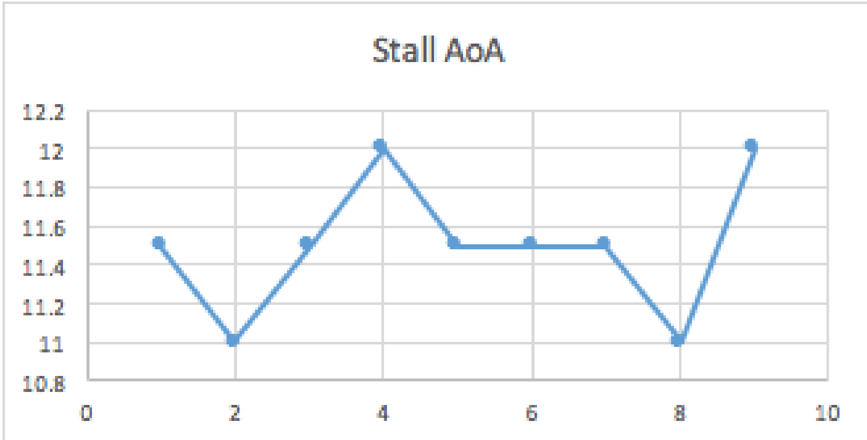

Figure 18: Foam Prototype of Design 3

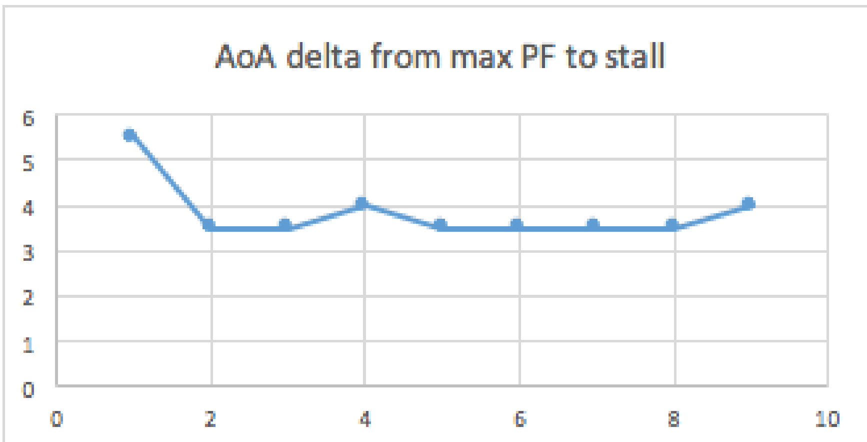

Figure 19: Foam Prototype of Design 3

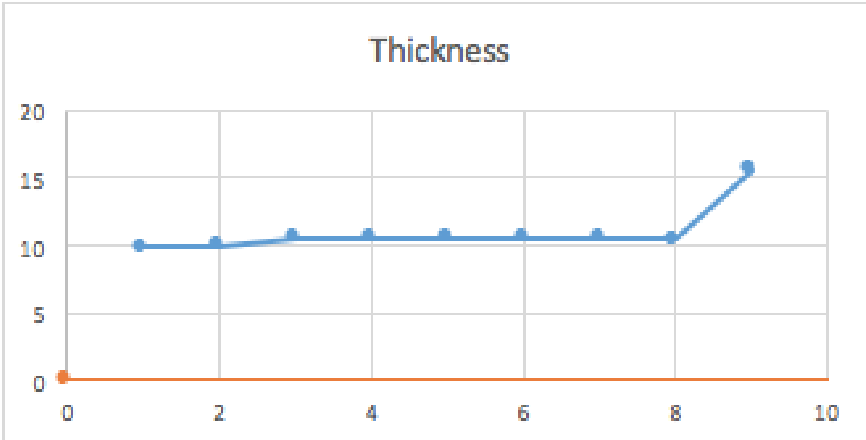

Figure 20: Foam Prototype of Design 3

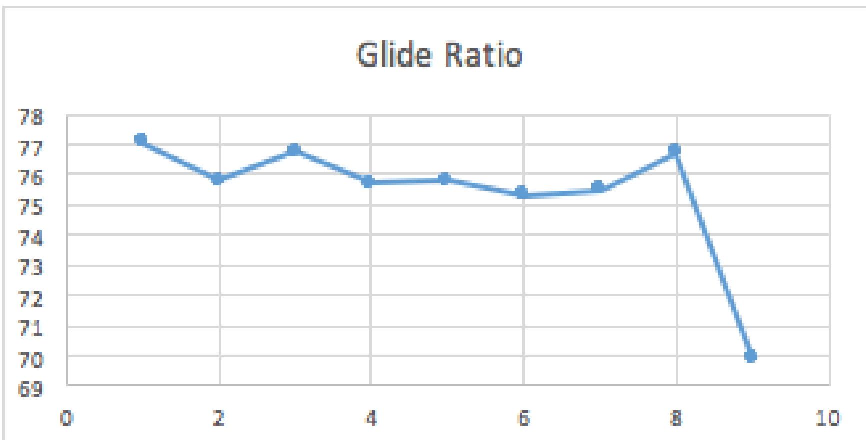

Figure 21: Foam Prototype of Design 3