Design of Aero Experiments Project: Airfoil Design

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April 25, 2021

EAS 3810C
Design of Aerospace Engineering Experiments
Spring 2021

Lab Section 14: Saturday 7:30 am

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Group Number: 1

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Methods:

In this project, the goal was to optimize an airfoil such that it achieves the highest aerodynamic performance when looking at lift-to-drag ratios and stall angle with minimum volume. The geometries considered are the even numbered airfoils from NACA 0006 to NACA 0026 airfoils. The airfoils chosen to compare are symmetric; having no camber. In the project setup, the iterated value is the ratio of the thickness to chord length - from 8% to 26% - thus correlating to the NACA 0008 to 0026 airfoils in this analysis. This ratio is directly correlated to the area of the airfoil. Due to the fact that we are analyzing the effects of volume on airfoil characteristics, this varying thickness to chord length ratio will provide the necessary values needed for discussion and optimization of the airfoil selection as volume of the airfoil is the area of the cross section per unit span.

The tool we used to find the airfoil performance data is XFLR5. This computational analysis program allows for analysis of lift and drag coefficients at varying angles of attack. It also allows for comparison between different airfoils to understand what a different chord length, thickness, and cambered ratio have on an airfoil's performance characteristics. The airfoils analyzed - NACA 0006 to NACA 0026 - were run on XFLR5 with 150 panels, at a Reynolds number of 3e6 and a Mach of 0, taking into account viscous flow as well.

For the analysis and to differentiate the airfoils, a python code was created and is referenced in appendix B. The code sorts through the results of XFLR5 and determines the stall angle, maximum lift to drag values and average lift to drag for each of the airfoils analyzed. These values were correlated with respect to the area since volume is the cross sectional area per unit span, thus both are directly correlated. To find the area, a function for plotting symmetric 4-series NACA airfoils is used. [1]

$$y_t = 5t[0.2969 * \sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4$$

Where y_t is the 'height' of the airfoil, t is the max thickness as a fraction of the chord, and x is the percentage of the position along the chord of the airfoil from 0 to 1. A midpoint Riemann sum is then used to approximate the area under the curve.

$$A = \sum_{i=0}^{n} y_{t,mp}(x_i) * \Delta x \quad \text{where, } n = \frac{x_f - x_0}{\Delta x}$$

$$y_{t,mp} = 0.5[y_t(x_{i+1}) + y_t(x_i)]$$

$$x_i = x_0 + i * \Delta x$$

The width of each iteration was $\Delta x = 0.001$ over the domain of $x \in [0, 1]$. This value is multiplied by two since the function for plotting an airfoil only produces its top half.

When analyzing the lift to drag values, the XFLR5 results produces a value per angle of attack iteration for each airfoil. A mean value of the lift-to-drag for each airfoil was then taken, which is equivalent to its overall performance. This is done in order to make the sets equivalent in size to take a two variable correlation. A correlation coefficient for lift to drag vs NACA area using the mean of each of the NACA airfoil's lift to drag was then created. Ultimately the correlation for lift to drag vs area mean was created from the individual mean values.

Results:

Lift to drag vs alpha and the coefficient of lift to alpha was obtained for NACA series 00XX airfoils from NACA 0006 to the NACA 0026 airfoils. Values were obtained from an alpha value of -5 to angle of attack of 25.

The data obtained is given in the following table.

	NACA Areas	Stall Angles	L/D Mean	L/D Max
NACA0006	0.04110249	8.5	6.29617863	74.31784
NACA0008	0.05480332	15	27.84546629	90.08781
NACA0010	0.06850416	17.5	33.00460869	96.3696
NACA0012	0.08220499	18.5	40.3946709	100.2697
NACA0014	0.09590582	19	40.08009981	101.1387
NACA0016	0.10960665	19	41.39124239	100.9734
NACA0018	0.12330748	20	41.81412644	100.9667
NACA0020	0.13700831	19.5	39.07064529	100.753
NACA0022	0.15070914	19	37.51713181	98.0125
NACA0024	0.16440997	20	35.45243885	93.04664
NACA0026	0.1781108	20	31.70901564	86.36459

Table 1: NACA airfoils with Area, Stall Angle, L/D Mean and L/D Max values

These values were tabulated and correlation curves were created and plotted below in figures 1 and 2. The max lift to drag vs alpha was obtained and values were tabulated in figure 3.

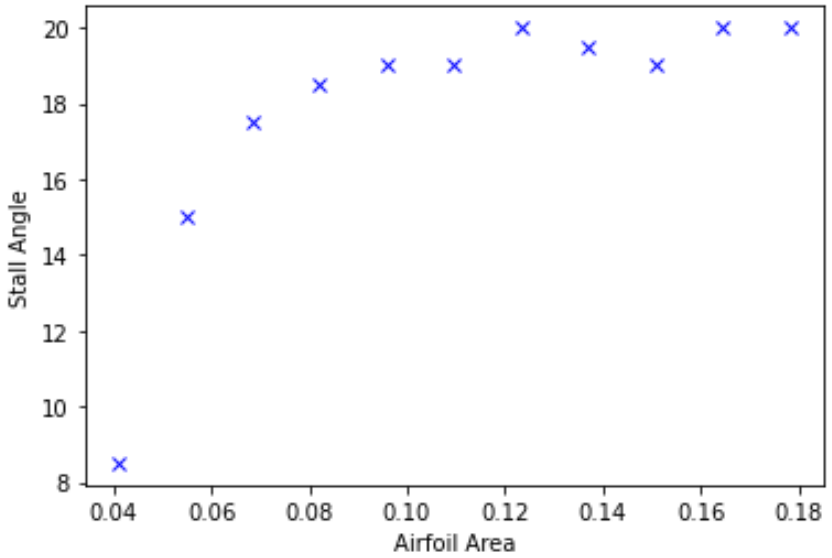


Figure 1: Stall Angle vs Airfoil Area

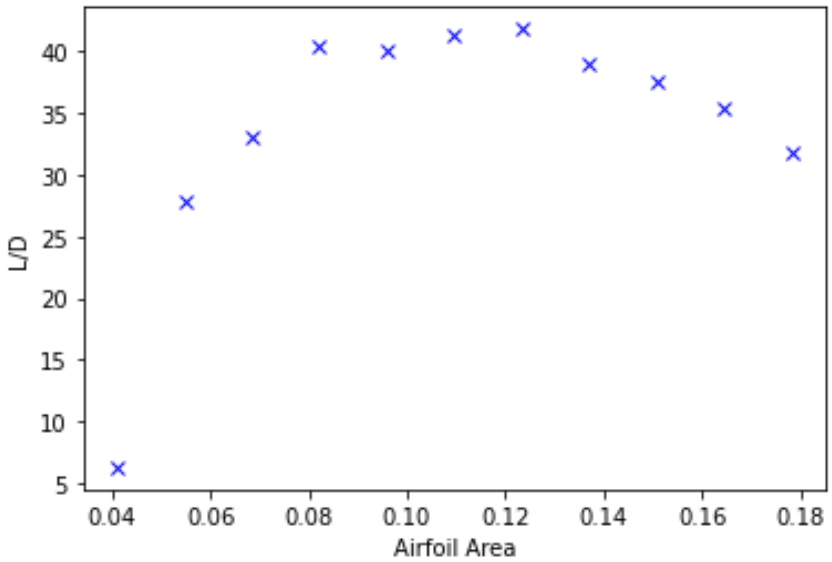


Figure 2: Lift to Drag ratio vs Airfoil Area

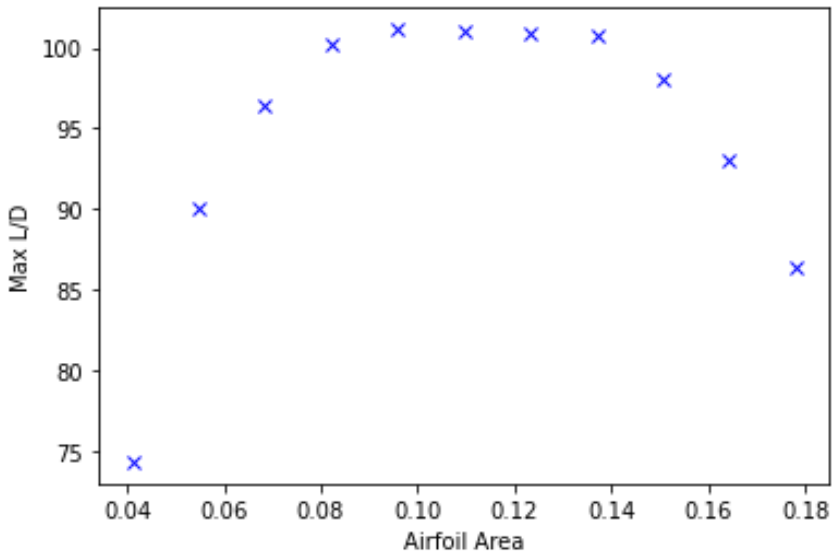


Figure 3: Max Lift to Drag ratio vs Airfoil Area

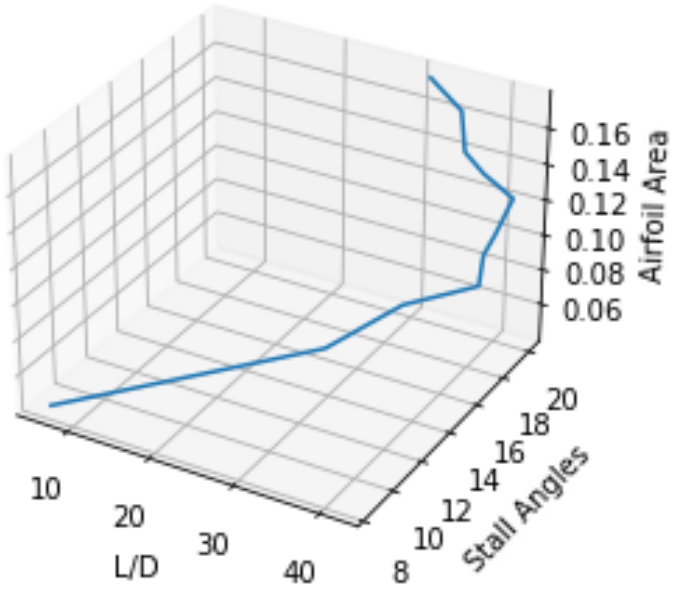


Figure 4: Lift to Drag ratio vs Airfoil Area vs Stall Angle

Discussion:

When analyzing the values obtained we can see that aerodynamic performance and stall angle both have a positive correlation to airfoil area. Both graphs seemed to follow a second degree polynomial curve. In Figure 4, stall angle has a correlation coefficient of 0.7504, while the aerodynamic performance has a correlation coefficient of 0.5017. We saw the largest stall angle with the NACA 0018 airfoil. The NACA 0024 and NACA 0026 foils had similar stall angles, but they are much thicker and have lower overall aerodynamic performance and as such can be ruled out for the optimal airfoil in this analysis. When looking at the Max Lift to Drag ratio vs airfoil area as is shown in figure 3 it is clearly evident that the NACA 0012 to the NACA 0020 airfoils have the highest values all above 100. The NACA 0014 has the highest value at 101.1 giving it the largest overall value. The max L/D value shows minimum drag and maximum glide speed, which is shown by the NACA 0014. Looking at the average aerodynamic performance values, we can see that the NACA 0018 is the top performer again. So one could say that the NACA 0018 airfoil is the optimal configuration out of the batch. However, the NACA 0012 has a very similar average aerodynamic performance, with less than a 4% difference. When we look at the NACA 0012's stall angle it is less than 2 degrees smaller than the NACA 0018. This is about a 10% decrease. While the NACA 0018 does have a slight edge in performance, it is roughly 1.5 times larger in area than the NACA 0012. For this reason, one could argue that the NACA 0012 airfoil does a better job at maximizing stall angle and aerodynamic performance, while minimizing the airfoil area. The NACA 0012 should be chosen over the NACA 0018 if the desired goal is to minimize the overall aircraft weight. Both airfoils show promising data, but ultimately it comes down to which metric is valued most over the other; maximum performance, or minimum area.

References:

1. Virginia Tech Department of Aerodynamics, 'Geometry for Aerodynamicists', Available: CAtxtAppA.pdf (vt.edu)

Appendices:

Appendix A: Aerodynamic performance results from XFLR5 for NACA0006 to NACA00026

-Table 1: NACA 00XX Re3e06 Cl vsAlpha

Alpha	NACA0006	Alpha	NACA0008	Alpha	NACA0010	Alpha	NACA0012	Alpha	NACA0014	Alpha	NACA0016	Alpha	NACA0018	Alpha	NACA0020	Alpha	NACA0022	Alpha	NACA0024	Alpha	NACA0026
-5	-0.5531348	-4.5	-0.5011708	-5	-0.5427622	-5	-0.5500568	-5	-0.5551196	-5	-0.5579766	-5	-0.5584043	-5	-0.5566441	-5	-0.5515867	-5	-0.5417782	-5	-0.5238444
-4.5	-0.5004706	-4	-0.4371111	-4.5	-0.4883145	-3.5	-0.3882028	-4.5	-0.5008387	-4.5	-0.5033605	-4.5	-0.5038059	-4.5	-0.5021332	-4.5	-0.4975725	-4.5	-0.4892073	-4.5	-0.4731022
-4	-0.4478947	-3.5	-0.3752516	-4	-0.4357749	-3	-0.3334751	-4	-0.4461673	-4	-0.4482557	-4	-0.4486789	-4	-0.4471715	-4	-0.4432779	-4	-0.4357852	-4	-0.4227892
-3.5	-0.396054	-3	-0.320756	-3.5	-0.3829567	-2.5	-0.2785093	-3.5	-0.3913234	-3.5	-0.3928709	-3.5	-0.3934698	-3.5	-0.391975	-3.5	-0.3887982	-3.5	-0.3819314	-3.5	-0.3713951
-3	-0.34868	-2.5	-0.2691265	-3	-0.329395	-2	-0.2232131	-3	-0.3360756	-3	-0.3374092	-3	-0.3377342	-3	-0.3366368	-3	-0.3338505	-3	-0.3278832	-3	-0.3191241
-2.5	-0.2691023	-2	-0.2165427	-2.5	-0.2753817	-1.5	-0.1675934	-2.5	-0.2804441	-2.5	-0.2817712	-2.5	-0.2818855	-2.5	-0.2811032	-2.5	-0.278462	-2.5	-0.2735973	-2.5	-0.2660227
-2	-0.2080158	-1.5	-0.1630868	-2	-0.2208807	-1	-0.1118575	-2	-0.22466	-2	-0.22568	-2	-0.2257664	-2	-0.2250168	-2	-0.2228991	-2	-0.2192543	-2	-0.2133053
-0.5	-0.05316573	-1	-0.1090822	-1.5	-0.1659971	-0.5	-0.05596417	-1.5	-0.1687396	-1.5	-0.1693434	-1.5	-0.1694602	-1.5	-0.1686466	-1.5	-0.1672062	-1.5	-0.1646661	-1.5	-0.1605716
0	-9.71E-11	-0.5	-0.05460903	-1	-0.1108701	0	-1.38E-12	-1	-0.1125996	-1	-0.1129177	-1	-0.1130765	-1	-0.1126812	-1	-0.1114243	-1	-0.1098812	-1	-0.1074588
0.5	0.05316602	0	-8.58E-10	-0.5	-0.05549015	0.5	0.05596449	-0.5	-0.05632956	-0.5	-0.05659539	-0.5	-0.05653488	-0.5	-0.05661404	-0.5	-0.05570017	-0.5	-0.05496721	-0.5	-0.05404591
1	0.10542231	0.5	0.05460934	0	-3.11E-14	1	0.1118588	0	1.14E-11	0	3.41E-11	0	8.12E-11	0	-1.57E-10	0	-5.33E-10	0	3.87E-09	0	3.17E-09
2	0.20801782	1	0.10908335	0.5	0.05549044	1.5	0.1675963	0.5	0.05632991	0.5	0.05659578	0.5	0.05653533	1	0.1126833	0.5	0.05570078	0.5	0.05496802	0.5	0.05404698

2.5	0.26910 36	1.5	0.16308 97	1	0.11087 13	2	0.22321 83	1	0.11260 1	1	0.11291 93	1	0.11307 83	1.5	0.16865 14	1	0.11142 69	1	0.10988 44	1	0.10746 31
3	0.33487 43	2	0.21654 8	1.5	0.16599 99	2.5	0.27851 77	1.5	0.16874 27	1.5	0.16934 69	1.5	0.16946 43	2	0.22502 55	1.5	0.16721 21	1.5	0.16467 37	1.5	0.16058 18
3.5	0.39602 45	2.5	0.26913 44	2	0.22088 57	3	0.33348 74	2	0.22466 57	2	0.22568 64	2	0.22577 37	2.5	0.28111 67	2	0.22290 98	2	0.21926 79	2	0.21332 38
4	0.44786 86	3	0.32076 55	2.5	0.27538 95	3.5	0.38821 98	2.5	0.28045 33	3	0.33742 42	2.5	0.28189 7	3	0.33665 66	2.5	0.27847 89	2.5	0.27361 9	2.5	0.26605 21
4.5	0.50045 29	3.5	0.37525 95	3	0.32940 63	4	0.44258 26	3	0.33608 9	3.5	0.39289 14	3	0.33775 12	3.5	0.39200 26	3	0.33387 52	3	0.32791 49	3	0.31916 74
5	0.55312 57	4	0.43711 76	3.5	0.38297 19	5	0.55009 12	3.5	0.39134 17	4	0.44828 28	3.5	0.39349 31	4	0.44720 89	3.5	0.38883 23	3.5	0.38197 56	3.5	0.37145 7
5.5	0.60554 67	4.5	0.50118 77	4	0.43579 38	5.5	0.60291 93	4	0.44619 18	4.5	0.50339 58	4	0.44871 04	4.5	0.50218 16	4	0.44332 38	4	0.43584 45	4	0.42287 48
6	0.65684 3	5	0.56657 47	4.5	0.48833 51	6	0.65549 35	4.5	0.50087 06	5	0.55802 14	4.5	0.50384 6	5	0.55670 5	4.5	0.49763 24	4.5	0.48928 55	4.5	0.47321 66
6.5	0.70331 84	5.5	0.62807 31	5	0.54278 14	6.5	0.70954 77	5	0.55515 94	5.5	0.61199 36	5	0.55845 61	5.5	0.61057 21	5	0.55166 32	5	0.54187 93	5	0.52399 29
7.5	0.76201 48	6	0.67768 95	5.5	0.60252 58	7	0.76772 63	5.5	0.60918 35	6	0.66620 76	5.5	0.61282 23	6	0.66394 58	5.5	0.60487 05	5.5	0.59370 38	5.5	0.57217 61
8	0.80131 78	6.5	0.72805 37	6	0.66629 09	7.5	0.83121 39	6.5	0.71585 83	6.5	0.71965 06	6	0.66651 18	6.5	0.71696 53	6	0.65768 28	6	0.64458 37	6	0.61478 02
8.5	0.85985 22	7	0.77938 3	6.5	0.73050 9	8	0.89395 01	7	0.76808 47	7	0.77280 07	6.5	0.72019 81	7	0.76972 87	6.5	0.71001 5	6.5	0.69453 1	6.5	0.66127 74
10.5	0.76011 79	7.5	0.83036 01	7	0.79541 42	8.5	0.95864 28	7.5	0.81964 81	7.5	0.82532 88	7	0.77327 04	7.5	0.82157 59	7	0.76124 98	7.5	0.78813 43	7	0.70993 04
11	0.76346 07	8	0.88237 01	8	0.90379 93	9	1.02168 8	8	0.87327 6	8	0.87672 79	7.5	0.82569 31	8	0.87285 25	7.5	0.81186 88	8	0.83380 73	7.5	0.75734 27
11.5	0.76603 35	8.5	0.93463 62	8.5	0.95067 24	9.5	1.07504 9	8.5	0.93057 93	8.5	0.92718 04	8	0.87756 03	8.5	0.92292 91	8	0.86122 43	8.5	0.87969 38	8	0.80345 92
12	0.74466 23	9	0.98651 29	9	0.99964 64	10	1.11769 9	9	0.99331 4	9	0.97706 5	8.5	0.92818 46	9	0.97187 03	8.5	0.90935 67	9	0.92557 32	8.5	0.85098 52
12.5	0.73641 05	9.5	1.03733 9	9.5	1.04957	10.5	1.16159	9.5	1.05467 5	9.5	1.02929 2	9	0.97833 08	9.5	1.01981 3	9	0.95353 1	9.5	0.97209	9.5	0.94010 94

13	0.74181 21	10	1.08294 6	10	1.09949 6	11	1.20826 8	10	1.11857 3	10	1.08727 4	9.5	1.02680 3	10	1.06611 2	9.5	0.99768 01	10	1.01523 5	10	0.98585 63
13.5	0.74955 45	10.5	1.13244 8	10.5	1.14672 9	11.5	1.25541	10.5	1.17995 3	10.5	1.14902 4	10	1.07262 9	10.5	1.10515 9	10	1.04136 3	10.5	1.05784 3	10.5	1.02699 5
14	0.75871 95	11	1.18087 5	11	1.19659	12	1.30131 9	11	1.23131	11	1.20931 1	10.5	1.12033 6	11	1.14254 3	10.5	1.08341 8	11	1.10036 9	11	1.06928 8
14.5	0.76896 11	11.5	1.22796 1	11.5	1.24561 2	12.5	1.34585 6	11.5	1.26829 7	11.5	1.27087 8	11	1.17442 6	11.5	1.18652 1	11.5	1.16101 5	11.5	1.13814 3	11.5	1.10900 2
15	0.77968 62	12	1.27348 6	12	1.29383 4	13	1.39188 6	12	1.30624 8	12	1.32446	11.5	1.23166 4	12	1.23869 9	12	1.19852 3	12	1.17598	12	1.14759 9
15.5	0.79145 37	12.5	1.31732 6	12.5	1.34105 1	13.5	1.43633 6	12.5	1.34975 8	12.5	1.35309 4	12	1.29158 4	13	1.34402 4	12.5	1.24441 5	12.5	1.20781 6	12.5	1.18267 2
16	0.80416 86	13	1.35943 1	13	1.38657 3	14	1.47874 6	13	1.39310 3	13	1.38580 5	12.5	1.34688 9	13.5	1.36512 5	13	1.29592 4	13	1.24518 6	13	1.21522 5
16.5	0.81759 96	13.5	1.39965 5	13.5	1.43016	14.5	1.51839 8	13.5	1.43422 2	13.5	1.41505 4	13	1.35897 9	14	1.39392 5	13.5	1.34872 2	13.5	1.29027 5	13.5	1.24316 9
17	0.83170 03	14	1.43746 3	14	1.46971 2	15	1.55377 7	14	1.47109 5	14	1.44672 9	13.5	1.38916 6	14.5	1.42640 7	14	1.36906 2	14	1.34099	14	1.28146 5
17.5	0.84657 02	14.5	1.47078 2	14.5	1.49783 9	15.5	1.57783 4	14.5	1.50258 1	14.5	1.48196	14	1.42026 8	15	1.45808 6	14.5	1.39541	14.5	1.36788 6	15	1.36972 3
18	0.86239 44	15	1.48533 6	15	1.53360 7	16	1.59121 2	15	1.53500 9	15	1.51467 5	14.5	1.45 57	15.5	1.48389 6	15	1.42702 6	15	1.39454 1	15.5	1.38271 1
18.5	0.87739 96	15.5	1.44277 4	15.5	1.56196 6	16.5	1.61042 8	15.5	1.56561	15.5	1.54297 5	15	1.48722 8	16	1.51179 7	15.5	1.45253 6	15.5	1.41869 1	16	1.40611 7
19	0.89231 29	16	1.39454 2	16	1.58044 4	17	1.62896	16	1.59353 3	16	1.56705 4	15.5	1.51385 4	16.5	1.53884 6	16	1.47810 8	16	1.44259 3	16.5	1.42821 6
19.5	0.90732 53	16.5	1.35609 9	16.5	1.59389 4	17.5	1.64317 7	16.5	1.61761 5	16.5	1.59156 9	16	1.54148 1	17	1.55976 9	16.5	1.50418 8	16.5	1.46721 9	17	1.44270 3
20	0.92266 91	17	1.29198 3	17	1.60140 2	18	1.65226 3	17	1.63709 8	17	1.61643 2	16.5	1.56920 6	17.5	1.57496 5	17	1.52345 4	17	1.48493 5	17.5	1.46276 2
20.5	0.93903 66			17.5	1.60165 7	18.5	1.65479 1	17.5	1.65044 1	17.5	1.63809 7	17	1.59304 9	18	1.59094 2	17.5	1.53889 6	17.5	1.50194 5	18	1.47799 6
21	0.95540 85			18	1.59151 7	19	1.64874 6	18	1.65516 1	18	1.65482 1	17.5	1.61092 7	18.5	1.60728 1	18	1.55797 5	18	1.52030 2	18.5	1.48560 2

21.5	0.97135 76			18.5	1.5625	19.5	1.630653	18.5	1.663508	18.5	1.666226	18	1.623158	19	1.61743	18.5	1.572881	18.5	1.532536	19	1.4917
22	0.98669 5			19	1.491962	20	1.594243	19	1.667581	19	1.670954	18.5	1.631086	19.5	1.620584	19	1.579119	19	1.534931	19.5	1.50095
				19.5	1.271843	20.5	1.530865	19.5	1.66477	19.5	1.667787	19	1.642814	20	1.614969	19.5	1.57772	19.5	1.540882	20	1.502111
				20	1.083778	21	1.426525	20	1.652624	20	1.655581	19.5	1.649585	20.5	1.603059	20	1.579462	20	1.544852	20.5	1.490768
						21.5	1.293524	20.5	1.629773	20.5	1.633007	20	1.649882	21	1.593984	20.5	1.579275	20.5	1.542638	21	1.487425
						22	1.200366	21	1.593751	21	1.608405	20.5	1.643444	21.5	1.584399	21	1.574707	21	1.529789	21.5	1.485926
						22.5	1.152341	21.5	1.542432	21.5	1.578747	21	1.628765	22	1.567198	21.5	1.560232	21.5	1.51582	22	1.47585
						23	1.120601	22	1.477719	22	1.542493	21.5	1.603754	22.5	1.543815	22	1.538611	22	1.505042	22.5	1.455468
						23.5	1.09461	22.5	1.400898	22.5	1.495913	22	1.572055	23	1.518054	22.5	1.513928	22.5	1.494614	23	1.43 54
						24	1.075409	23	1.330346	23	1.449387	22.5	1.533763	23.5	1.486961	23	1.487769	23	1.480944	23.5	1.426028
								23.5	1.269386	23.5	1.397237	23	1.486516	24	1.450268	23.5	1.473159	23.5	1.455828	24	1.416261
								24	1.226744	24	1.352338	23.5	1.44045	24.5	1.412175	24	1.450277	24	1.430031	24.5	1.400269
								24.5	1.200867	24.5	1.312691	24	1.407643	25	1.373394	24.5	1.430799	24.5	1.403251	25	1.373247
								25	1.175341	25	1.282337	24.5	1.379211			25	1.410076	25	1.395299		
												25	1.348093								

-Table 2: NACA 00XX Re3e06 Cl/Cd vsAlpha

Alpha	NACA0006	Alpha	NACA0008	Alpha	NACA0010	Alpha	NACA0012	Alpha	NACA0014	Alpha	NACA0016	Alpha	NACA0018	Alpha	NACA0020	Alpha	NACA0022	Alpha	NACA0024	Alpha	NACA0026
-5	-74.24174	-4.5	-75.97092	-5	-79.0253	-5	-80.59543	-5	-80.71365	-5	-79.65202	-5	-77.62625	-5	-75.05182	-5	-71.86869	-5	-68.03303	-5	-63.36107
-4.5	-74.3179	-4	-70.19329	-4.5	-75.07005	-3.5	-65.41862	-4.5	-75.85172	-4.5	-74.46368	-4.5	-72.10074	-4.5	-69.45123	-4.5	-66.29895	-4.5	-62.65074	-4.5	-58.08205
-4	-69.76076	-3.5	-64.13567	-4	-70.6109	-3	-58.54677	-4	-70.14322	-4	-68.35227	-4	-65.93622	-4	-63.13494	-4	-60.21095	-4	-56.74533	-4	-52.85185
-3.5	-65.04187	-3	-58.76067	-3.5	-65.8268	-2.5	-50.60483	-3.5	-63.81514	-3.5	-61.5075	-3.5	-59.09992	-3.5	-56.38349	-3.5	-53.66955	-3.5	-50.4496	-3.5	-47.10841
-3	-58.82955	-2.5	-53.06562	-3	-59.75092	-2	-41.72741	-3	-56.52355	-3	-54.14355	-3	-51.85958	-3	-49.41884	-3	-46.76027	-3	-43.8787	-3	-40.94458
-2.5	-51.1185	-2	-45.45528	-2.5	-52.48283	-1.5	-32.03069	-2.5	-48.34714	-2.5	-46.18121	-2.5	-43.97441	-2.5	-41.84125	-2.5	-39.52489	-2.5	-37.02495	-2.5	-34.38279
-2	-43.81419	-1.5	-36.06819	-2	-43.76716	-1	-21.66508	-2	-39.58354	-2	-37.69458	-2	-35.78388	-2	-33.8708	-2	-31.97336	-2	-29.97567	-2	-27.80142
-0.5	-14.47591	-1	-25.00916	-1.5	-33.96756	-0.5	-10.98218	-1.5	-30.27612	-1.5	-28.65706	-1.5	-27.09762	-1.5	-25.61403	-1.5	-24.17222	-1.5	-22.69433	-1.5	-21.08755
0	-2.69E-08	-0.5	-12.79942	-1	-23.25199	0	-2.71E-10	-1	-20.45932	-1	-19.24417	-1	-18.27648	-1	-17.25213	-1	-16.1882	-1	-15.23165	-1	-14.169
0.5	14.476	0	-2.03E-07	-0.5	-11.78709	0.5	10.98225	-0.5	-10.30705	-0.5	-9.7132 92	-0.5	-9.14655	-0.5	-8.695164	-0.5	-8.18166	-0.5	-7.64625	-0.5	-7.137763
1	27.25823	0.5	12.79951	0	-6.63E-12	1	21.66535	0	2.09E-09	0	5.87E-09	0	1.32E-08	0	-2.41E-08	0	-7.78E-08	0	5.39E-07	0	4.20E-07
2	43.81488	1	25.00948	0.5	11.78716	1.5	32.03126	0.5	10.30712	0.5	9.713368	0.5	9.144737	1	17.2525	0.5	8.118268	0.5	7.644753	0.5	7.137922
2.5	51.11919	1.5	36.06885	1	23.25226	2	41.72842	1	20.4596	1	19.24447	1	18.27681	1.5	25.61486	1	16.18865	1	15.23216	1	14.16964
3	58.8312	2	45.45638	1.5	33.96817	2.5	50.60635	1.5	30.27674	1.5	28.65771	1.5	27.09832	2	33.87226	1.5	24.1732	1.5	22.69551	1.5	21.08903
3.5	65.0384	2.5	53.06702	2	43.76805	3	58.54879	2	39.58456	2	37.69574	2	35.78518	2.5	41.8435	2	31.97507	2	29.97776	2	27.80409
4	69.75878	3	58.76221	2.5	52.48407	3.5	65.42118	2.5	48.34881	3	54.14608	2.5	43.97629	3	49.42191	2.5	39.52755	2.5	37.02823	2.5	34.38689

4.5	74.3178	3.5	64.1373	3	59.7524	4	71.2730	3	56.5257	3.5	61.5105	3	51.8623	3.5	56.3875	3	46.7640	3	43.8832	3	40.9505
5	74.2418	4	70.1951	3.5	65.8288	5	80.5996	3.5	63.8177	4	68.3559	3.5	59.1033	4	63.1405	3.5	53.6747	3.5	50.4556	3.5	47.1681
5.5	72.8283	4.5	75.9742	4	70.6133	5.5	84.1189	4	70.1464	4.5	74.4683	4	65.9409	4.5	69.4580	4	60.2175	4	56.7532	4	52.8632
6	68.2407	5	81.2589	4.5	75.0724	6	87.1917	4.5	75.8561	5	79.6578	4.5	72.106	5	75.0596	4.5	66.3072	4.5	62.6609	4.5	58.0965
6.5	53.6263	5.5	85.1456	5	79.0280	6.5	89.7481	5	80.7184	5.5	84.0623	5	77.6332	5.5	80.1510	5	71.8788	5	68.0461	5	63.3789
7.5	21.9519	6	87.0891	5.5	83.3362	7	92.4135	5.5	84.9229	6	88.3639	5.5	82.7193	6	84.3880	5.5	76.9797	5.5	73.0435	5.5	68.0981
8	21.3345	6.5	88.4308	6	87.0413	7.5	94.8619	6.5	91.3118	6.5	91.2606	6	86.6212	6.5	88.4163	6	81.6330	6	77.4113	6	71.7007
8.5	26.5389	7	90.0878	6.5	90.5050	8	96.6634	7	93.3804	7	94.3024	6.5	90.6530	7	91.8676	6.5	85.5963	6.5	81.1446	6.5	75.0669
10.5	6.90831	7.5	88.8063	7	93.7340	8.5	98.8162	7.5	95.0818	7.5	96.3605	7	93.7210	7.5	94.7378	7	89.1520	7.5	87.7912	7	78.3726
11	6.45426	8	89.0292	8	96.3696	9	99.4231	8	96.7257	8	97.8680	7.5	96.2157	8	96.9263	7.5	92.0082	8	89.8031	7.5	80.8887
11.5	6.01760	8.5	89.4867	8.5	95.2344	9.5	100.2697	8.5	98.2041	8.5	99.1009	8	98.0776	8.5	98.6074	8	94.2620	8.5	90.9567	8	82.6530
12	5.14416	9	89.2836	9	95.7436	10	99.2255	9	99.4732	9	99.7724	8.5	99.3883	9	99.4701	8.5	95.9336	9	92.0581	8.5	84.7062
12.5	4.67145	9.5	87.6376	9.5	95.9046	10.5	97.8523	9.5	99.8004	9.5	99.9858	9	100.5321	9.5	100.2867	9	97.5678	9.5	93.0466	9.5	85.7403
13	4.45502	10	79.7019	10	95.2056	11	97.6533	10	101.1387	10	100.269	9.5	100.9667	10	100.753	9.5	98.0125	10	92.6897	10	86.3645
13.5	4.27930	10.5	78.2628	10.5	91.1714	11.5	96.7258	10.5	100.5182	10.5	100.9734	10	100.5909	10.5	99.9112	10	97.6696	10.5	91.8755	10.5	85.1605
14	4.13144	11	76.3903	11	90.6216	12	94.5903	11	100.8106	11	100.2711	10.5	100.1801	11	98.1969	10.5	96.8662	11	91.2512	11	84.3414
14.5	4.00518	11.5	74.0885	11.5	89.5634	12.5	91.8091	11.5	99.3651	11.5	100.5497	11	100.1706	11.5	97.2241	11.5	93.6316	11.5	88.6997	11.5	82.5506

15	3.89706	12	71.4579	12	88.2429	13	90.6212	12	97.0272	12	98.9370	11.5	99.0077	12	95.2422	12	91.5944	12	86.8933	12	80.4391
15.5	3.80515	12.5	68.6682	12.5	86.6744	13.5	88.9993	12.5	96.3299	12.5	97.7686	12	98.5968	13	91.5439	12.5	89.1917	12.5	83.4373	12.5	77.6268
16	3.72497	13	65.8915	13	84.5189	14	86.9461	13	95.0076	13	96.1068	12.5	96.8652	13.5	88.6265	13	86.4665	13	80.8464	13	74.4603
16.5	3.65417	13.5	63.1997	13.5	81.9209	14.5	84.4133	13.5	92.7958	13.5	93.1825	13	94.7109	14	84.4849	13.5	84.0456	13.5	77.2622	13.5	70.6773
17	3.59266	14	60.5089	14	78.0935	15	81.2623	14	89.4698	14	89.9227	13.5	91.7471	14.5	80.9100	14	80.0805	14	74.4453	14	67.6511
17.5	3.54017	14.5	57.3654	14.5	70.9987	15.5	76.9319	14.5	86.4215	14.5	87.5139	14	87.8426	15	77.0263	14.5	75.5429	14.5	69.9406	15	60.8981
18	3.49678	15	51.1575	15	68.5797	16	70.1778	15	83.7741	15	84.2202	14.5	85.1726	15.5	71.7135	15	72.0121	15	66.4991	15.5	56.2743
18.5	3.45214	15.5	39.9199	15.5	65.6409	16.5	65.2383	15.5	80.5153	15.5	79.7057	15	81.2145	16	67.3395	15.5	67.0419	15.5	61.9110	16	52.7003
19	3.41129	16	28.3786	16	61.7989	17	60.3500	16	76.5745	16	74.2320	15.5	76.0348	16.5	63.0804	16	62.4409	16	57.5676	16.5	49.0067
19.5	3.37466	16.5	20.4689	16.5	56.9826	17.5	54.8512	16.5	71.7608	16.5	69.1976	16	71.4023	17	58.0469	16.5	58.4353	16.5	53.696	17	44.6715
20	3.34400	17	14.6901	17	51.1394	18	48.8610	17	66.0636	17	64.6695	16.5	67.1727	17.5	52.5232	17	53.5128	17	49.0648	17.5	41.5551
20.5	3.32723			17.5	44.3420	18.5	42.5460	17.5	59.49	17.5	59.7416	17	62.3381	18	47.8525	17.5	48.5905	17.5	45.0885	18	38.2737
21	3.31396			18	36.8009	19	36.2591	18	51.9945	18	54.4271	17.5	56.8609	18.5	43.9217	18	44.8912	18	41.6346	18.5	34.7435
21.5	3.29925			18.5	28.7628	19.5	30.0926	18.5	46.1852	18.5	48.8306	18	51.0474	19	39.7268	18.5	41.1439	18.5	38.0407	19	31.6332
22	3.28537			19	20.3602	20	24.1395	19	40.7348	19	43.186	18.5	45.4527	19.5	35.4845	19	36.9700	19	34.0592	19.5	29.1992
				19.5	10.5657	20.5	18.5265	19.5	35.4182	19.5	37.4935	19	41.2217	20	31.2497	19.5	32.8492	19.5	31.0482	20	26.5932
				20	6.42408	21	13.3522	20	30.3064	20	32.0894	19.5	37.0431	20.5	27.3327	20	29.6740	20	28.3100	20.5	23.71111

						21.5	9.371925	20.5	25.50377	20.5	27.04258	20	32.98584	21	24.36505	20.5	26.85494	20.5	25.64032	21	21.66923
						22	7.298755	21	21.1414	21	23.06782	20.5	29.09105	21.5	21.87402	21	24.28428	21	22.83301	21.5	19.99306
						22.5	6.278262	21.5	17.21185	21.5	19.70492	21	25.40337	22	19.45546	21.5	21.6044	21.5	20.45667	22	18.23558
						23	5.598014	22	13.89004	22	16.84143	21.5	21.8962	22.5	17.25139	22	19.09768	22	18.56869	22.5	16.37867
						23.5	5.062718	22.5	11.13186	22.5	14.24524	22	18.82431	23	15.33428	22.5	16.9357	22.5	16.98206	23	14.81057
						24	4.642152	23	9.146794	23	12.22745	22.5	16.16852	23.5	13.60019	23	15.07217	23	15.50853	23.5	13.74155
								23.5	7.72698	23.5	10.4365	23	13.77302	24	12.01083	23.5	13.81887	23.5	13.93805	24	12.78531
								24	6.784601	24	9.117507	23.5	11.8947	24.5	10.63911	24	12.53048	24	12.58544	24.5	11.79963
								24.5	6.172327	24.5	8.078442	24	10.60356	25	9.469652	24.5	11.48364	24.5	11.38925	25	10.71877
								25	5.631716	25	7.303313	24.5	9.586397			25	10.54286	25	10.70015		
												25	8.65264								

Appendix B: Python Code for Analysis of the Aerodynamic Performance to airfoil area

Figure 4: NACA 00XX Airfoil Analysis Code

```
"""
EAS3810C Project 1
04/25/21
Group 1

@author: Lucas
"""

"""
assuming chord length of 1 meter
"""
```

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits import mplot3d


data1 = pd.read_csv('C:/Users/Lucas/Desktop/School/EAS3810/NACA00XX Re3e6 Cl v alpha.csv')
data1.replace('', np.nan)
data_array1 = data1.values

stallAngles = np.zeros((1,0), dtype = float, order = 'C')
rows, columns = np.shape(data_array1)
columns = columns -2
for i in range(0, columns):
    if(i%2 == 1):
        for j in range(0, rows):
            if(data_array1[j,i] > data_array1[j+1,i]):
                stallAngles = np.append(stallAngles, data_array1[j,i-1])
                break

NACA_thickness = [6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26]
NACA_area = np.zeros((0,0), dtype = float, order = 'C')
length = len(NACA_thickness)
for i in range(0, length):
    x_i = 0;
    x_f = 1;
    delx = 0.001;
    num_steps = (x_f - x_i)/delx;
    area = 0;
    for j in range(1, int(num_steps)):
        x_1 = x_i + (j-1)*delx;
        x_2 = x_i + (j)*delx;
        y_1 = 5*(NACA_thickness[i]/100)*((0.2969*np.sqrt(x_1))-(0.1260*x_1)-(0.3516*x_1**2)+(0.2843*x_1**3)-(0.1015*x_1**4));
        y_2 = 5*(NACA_thickness[i]/100)*((0.2969*np.sqrt(x_2))-(0.1260*x_2)-(0.3516*x_2**2)+(0.2843*x_2**3)-(0.1015*x_2**4));
        y_mp = (y_1+y_2)
        area = area + y_mp*delx
    NACA_area = np.append(NACA_area, area)


r_stallAngles_NACAAreas = np.corrcoef(stallAngles, NACA_area)

fig = plt.figure
plt.plot(NACA_area, stallAngles, "xb")
plt.xlabel('Airfoil Area')
plt.ylabel('Stall Angle')


data2 = pd.read_csv('C:/Users/Lucas/Desktop/School/EAS3810/NACA00XX Re3e6 Cl-Cd v alpha.csv')
data2.replace('', np.nan)
data_array2 = data2.values

L_D_Airfoils = np.zeros((1,0), dtype = float, order = 'C')
rows, columns = np.shape(data_array2)
for i in range(0, columns-2):
    if(i%2 == 1):
        placeholder = 0;
        for j in range(0, rows):
            if(np.isnan(data_array2[j, i])):
                continue
            placeholder = placeholder + data_array2[j, i]
```

```
        mean_L_D = placeholder/rows
        L_D_Airfoils = np.append(L_D_Airfoils, mean_L_D)

r_LD_NACAAreas = np.corrcoef(L_D_Airfoils, NACA_area)

fig = plt.figure()
plt.plot(NACA_area, L_D_Airfoils, "xb")
plt.xlabel('Airfoil Area')
plt.ylabel('L/D')

fig = plt.figure()
ax = plt.axes(projection = '3d')
ax.plot3D(L_D_Airfoils, stallAngles, NACA_area)
ax.set_xlabel('L/D')
ax.set_ylabel('Stall Angles')
ax.set_zlabel('Airfoil Area')
```