

Design of Aero Experiments Project: Airfoil Design

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Table of Contents:

Table of Contents:	2
Methods:	2
Discussion:	6
References:	7
Appendices:	8
Appendix A: Aerodynamic performance results from XFLR5 for NACA0006 to NACA00026	8
-Table 1: NACA 00XX Re3e06 Cl vsAlpha	8
-Table 2: NACA 00XX Re3e06 Cl/Cd vsAlpha	11
Appendix B: Python Code for Analysis of the Aerodynamic Performance to airfoil area	15
Figure 4: NACA 00XX Airfoil Analysis Code	15

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.

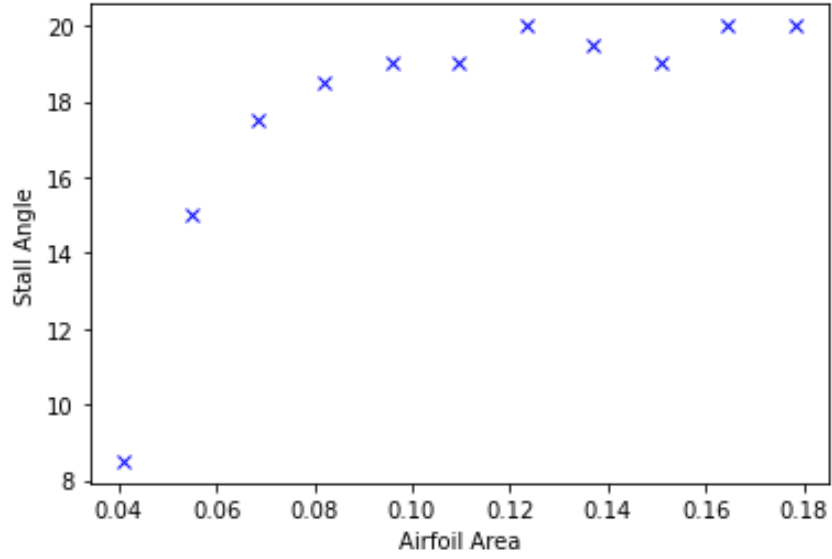


Figure 1: Stall Angle vs Airfoil Area

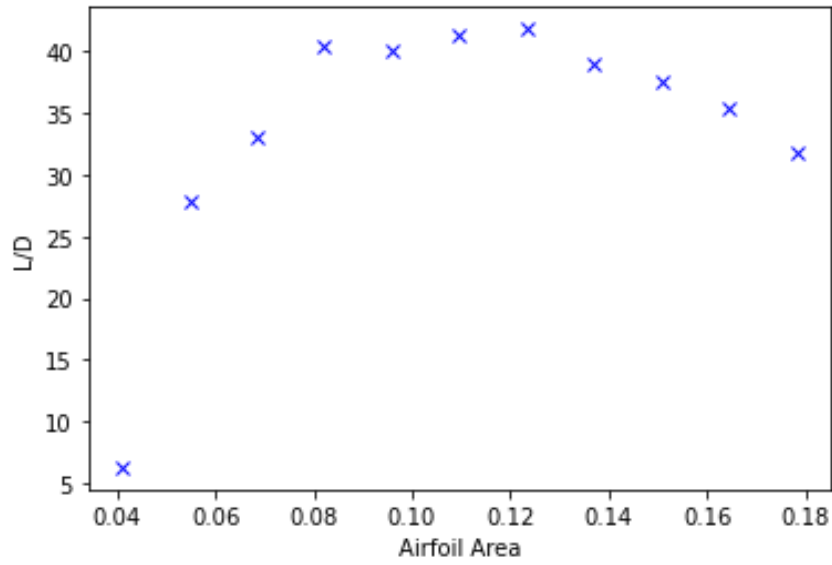


Figure 2: Lift to Drag ratio vs Airfoil Area

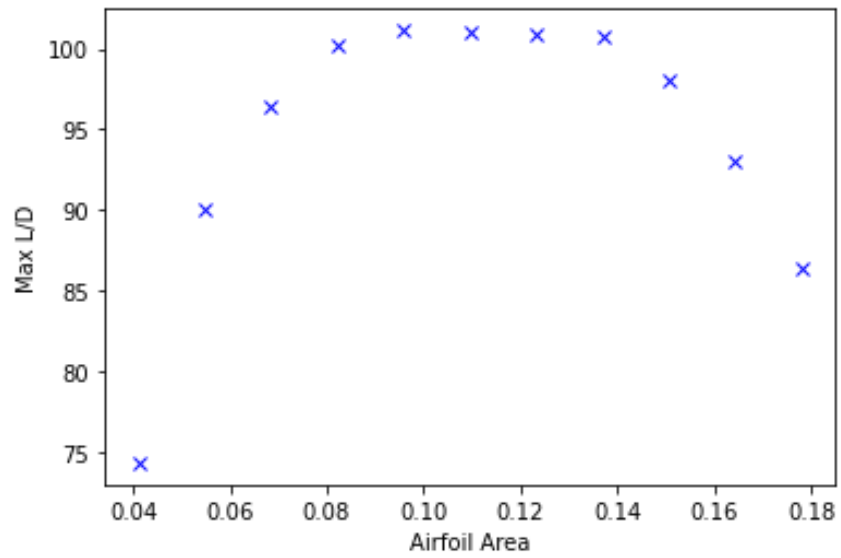


Figure 3: Max Lift to Drag ratio vs Airfoil Area

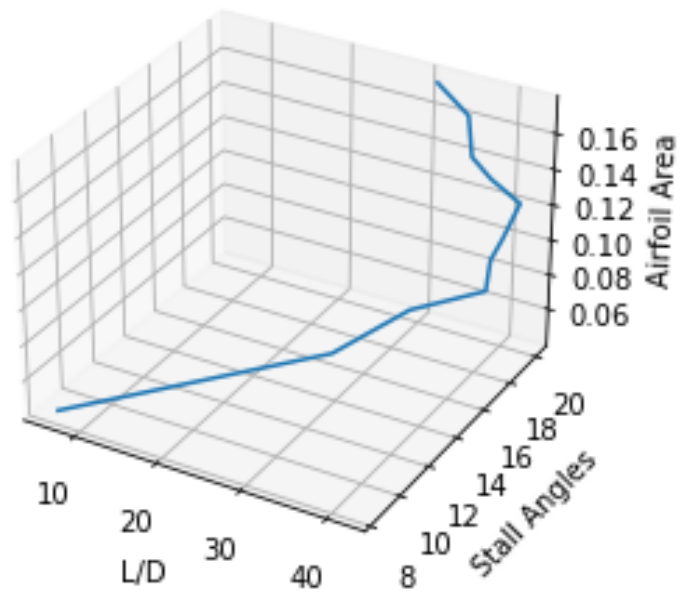


Figure 4: Lift to Drag ratio vs Airfoil Area vs Stall Angle

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

Alph a	NA CA0 006	Alph a	NA CA0 008	Alph a	NA CA0 010	Alph a	NA CA0 012	Alph a	NA CA0 014	Alph a	NA CA0 016	Alph a	NA CA0 018	Alph a	NA CA0 020	Alph a	NA CA0 022	Alph a	NA CA0 024	Alph a	NA CA0 026
-5	-0.5 531 348	-4.5	-0.5 011 708	-5	-0.5 427 622	-5	-0.5 500 568	-5	-0.5 551 196	-5	-0.5 579 766	-5	-0.5 584 043	-5	-0.5 566 441	-5	-0.5 515 867	-5	-0.5 417 782	-5	-0.5 238 444
-4.5	-0.5 004 706	-4	-0.4 371 111	-4.5	-0.4 883 145	-3.5	-0.3 882 028	-4.5	-0.5 008 387	-4.5	-0.5 033 605	-4.5	-0.5 038 059	-4.5	-0.5 021 332	-4.5	-0.4 975 725	-4.5	-0.4 892 073	-4.5	-0.4 731 022
-4	-0.4 478 947	-3.5	-0.3 752 516	-4	-0.4 357 749	-3	-0.3 334 751	-4	-0.4 461 673	-4	-0.4 482 557	-4	-0.4 486 789	-4	-0.4 471 715	-4	-0.4 432 779	-4	-0.4 357 852	-4	-0.4 227 892
-3.5	-0.3 960 54	-3	-0.3 207 56	-3.5	-0.3 829 567	-2.5	-0.2 785 093	-3.5	-0.3 913 234	-3.5	-0.3 928 709	-3.5	-0.3 934 698	-3.5	-0.3 919 75	-3.5	-0.3 887 982	-3.5	-0.3 819 314	-3.5	-0.3 713 951
-3	-0.3 348 68	-2.5	-0.2 691 265	-3	-0.3 293 95	-2	-0.2 232 131	-3	-0.3 360 756	-3	-0.3 374 092	-3	-0.3 377 342	-3	-0.3 366 368	-3	-0.3 338 505	-3	-0.3 278 832	-3	-0.3 191 241
-2.5	-0.2 691 023	-2	-0.2 165 427	-2.5	-0.2 753 817	-1.5	-0.1 675 934	-2.5	-0.2 804 441	-2.5	-0.2 817 712	-2.5	-0.2 818 855	-2.5	-0.2 811 032	-2.5	-0.2 784 62	-2.5	-0.2 735 973	-2.5	-0.2 660 227
-2	-0.2 080 158	-1.5	-0.1 630 868	-2	-0.2 208 807	-1	-0.1 118 575	-2	-0.2 246 6	-2	-0.2 256 8	-2	-0.2 257 664	-2	-0.2 250 168	-2	-0.2 228 991	-2	-0.2 192 543	-2	-0.2 133 053
-0.5	-0.0 531 657 3	-1	-0.1 090 822	-1.5	-0.1 659 971	-0.5	-0.0 559 641 7	-1.5	-0.1 687 396	-1.5	-0.1 693 434	-1.5	-0.1 694 602	-1.5	-0.1 686 466	-1.5	-0.1 672 062	-1.5	-0.1 646 661	-1.5	-0.1 605 716
0	-9.7 1E- 11	-0.5	-0.0 546 090 3	-1	-0.1 108 701	0	-1.3 8E- 12	-1	-0.1 125 996	-1	-0.1 129 177	-1	-0.1 130 765	-1	-0.1 126 812	-1	-0.1 114 243	-1	-0.1 098 812	-1	-0.1 074 588
0.5	0.05 316 602	0	-8.5 8E- 10	-0.5	554 901 5	0.5	0.05 596 449	-0.5	563 295 6	-0.5	565 953 9	-0.5	565 348 8	-0.5	566 140 4	-0.5	557 001 7	-0.5	549 672 1	-0.5	540 459 1
1	0.10 542 31	0.5	0.05 460 934	0	-3.1 1E- 14	1	0.11 185 88	0	1.14 E-11	0	3.41 E-11	0	8.12 E-11	0	-1.5 7E- 10	0	-5.3 3E- 10	0	3.87 E-0 9	0	3.17 E-0 9
2	0.20 801 82	1	0.10 908 35	0.5	0.05 549 044	1.5	0.16 759 63	0.5	0.05 632 991	0.5	0.05 659 578	0.5	0.05 653 533	1	0.11 268 33	0.5	0.05 570 078	0.5	0.05 496 802	0.5	0.05 404 698

2.5	0.26 910 36	1.5	0.16 308 97	1	0.11 087 13	2	0.22 321 83	1	0.11 260 1	1	0.11 291 93	1	0.11 307 83	1.5	0.16 865 14	1	0.11 142 69	1	0.10 988 44	1	0.10 746 31
3	0.33 487 43	2	0.21 654 8	1.5	0.16 599 99	2.5	0.27 851 77	1.5	0.16 874 27	1.5	0.16 934 69	1.5	0.16 946 43	2	0.22 502 55	1.5	0.16 721 21	1.5	0.16 467 37	1.5	0.16 058 18
3.5	0.39 602 45	2.5	0.26 913 44	2	0.22 088 57	3	0.33 348 74	2	0.22 466 57	2	0.22 568 64	2	0.22 577 37	2.5	0.28 111 67	2	0.22 290 98	2	0.21 926 79	2	0.21 332 38
4	0.44 786 86	3	0.32 076 55	2.5	0.27 538 95	3.5	0.38 821 98	2.5	0.28 045 33	3	0.33 742 42	2.5	0.28 189 7	3	0.33 665 66	2.5	0.27 847 89	2.5	0.27 361 9	2.5	0.26 605 21
4.5	0.50 045 29	3.5	0.37 525 95	3	0.32 940 63	4	0.44 258 26	3	0.33 608 9	3.5	0.39 289 14	3	0.33 775 12	3.5	0.39 200 26	3	0.33 387 52	3	0.32 791 49	3	0.31 916 74
5	0.55 312 57	4	0.43 711 76	3.5	0.38 297 19	5	0.55 009 12	3.5	0.39 134 17	4	0.44 828 28	3.5	0.39 349 31	4	0.44 720 89	3.5	0.38 883 23	3.5	0.38 197 56	3.5	0.37 145 7
5.5	0.60 554 67	4.5	0.50 118 77	4	0.43 579 38	5.5	0.60 291 93	4	0.44 619 18	4.5	0.50 339 58	4	0.44 871 04	4.5	0.50 218 16	4	0.44 332 38	4	0.43 584 45	4	0.42 287 48
6	0.65 684 3	5	0.56 657 47	4.5	0.48 833 51	6	0.65 549 35	4.5	0.50 087 06	5	0.55 802 14	4.5	0.50 384 6	5	0.55 670 5	4.5	0.49 763 24	4.5	0.48 928 55	4.5	0.47 321 66
6.5	0.70 331 84	5.5	0.62 807 31	5	0.54 278 14	6.5	0.70 954 77	5	0.55 515 94	5.5	0.61 199 36	5	0.55 845 61	5.5	0.61 057 21	5	0.55 166 32	5	0.54 187 93	5	0.52 399 29
7.5	0.76 201 48	6	0.67 768 95	5.5	0.60 252 58	7	0.76 772 63	5.5	0.60 918 35	6	0.66 620 76	5.5	0.61 282 23	6	0.66 394 58	5.5	0.60 487 05	5.5	0.59 370 38	5.5	0.57 217 61
8	0.80 131 78	6.5	0.72 805 37	6	0.66 629 09	7.5	0.83 121 39	6.5	0.71 585 83	6.5	0.71 965 06	6	0.66 651 18	6.5	0.71 696 53	6	0.65 768 28	6	0.64 458 37	6	0.61 478 02
8.5	0.85 985 22	7	0.77 938 3	6.5	0.73 050 9	8	0.89 395 01	7	0.76 808 47	7	0.77 280 07	6.5	0.72 019 81	7	0.76 972 87	6.5	0.71 001 5	6.5	0.69 453 1	6.5	0.66 127 74
10.5	0.76 011 79	7.5	0.83 036 01	7	0.79 541 42	8.5	0.95 864 28	7.5	0.81 964 81	7.5	0.82 532 88	7	0.77 327 04	7.5	0.82 157 59	7	0.76 124 98	7.5	0.78 813 43	7	0.70 993 04
11	0.76 346 07	8	0.88 237 01	8	0.90 379 93	9	1.02 168 8	8	0.87 327 6	8	0.87 672 79	7.5	0.82 569 31	8	0.87 285 25	7.5	0.81 186 88	8	0.83 380 73	7.5	0.75 734 27
11.5	0.76 603 35	8.5	0.93 463 62	8.5	0.95 067 24	9.5	1.07 504 9	8.5	0.93 057 93	8.5	0.92 718 04	8	0.87 756 03	8.5	0.92 292 91	8	0.86 122 43	8.5	0.87 969 38	8	0.80 345 92
12	0.74 466 23	9	0.98 651 29	9	0.99 964 64	10	1.11 769 9	9	0.99 331 4	9	0.97 706 5	8.5	0.92 818 46	9	0.97 187 03	8.5	0.90 935 67	9	0.92 557 32	8.5	0.85 098 52
12.5	0.73 641 05	9.5	1.03 733 9	9.5	1.04 957	10.5	1.16 159	9.5	1.05 467 5	9.5	1.02 929 2	9	0.97 833 08	9.5	1.01 981 3	9	0.95 353 1	9.5	0.97 209	9.5	0.94 010 94

13	0.74 181 21	10	1.08 294 6	10	1.09 949 6	11	1.20 826 8	10	1.11 857 3	10	1.08 727 4	9.5	1.02 680 3	10	1.06 611 2	9.5	0.99 768 01	10	1.01 523 5	10	0.98 585 63
13.5	0.74 955 45	10.5	1.13 244 8	10.5	1.14 672 9	11.5	1.25 541 10.5	10.5	1.17 995 3	10.5	1.14 902 4	10	1.07 262 9	10.5	1.10 515 9	10	1.04 136 3	10.5	1.05 784 3	10.5	1.02 699 5
14	0.75 871 95	11	1.18 087 5	11	1.19 659 12	12	1.30 131 9	11	1.23 131 11	11	1.20 931 1	10.5	1.12 033 6	11	1.14 254 3	10.5	1.08 341 8	11	1.10 036 9	11	1.06 928 8
14.5	0.76 896 11	11.5	1.22 796 1	11.5	1.24 561 2	12.5	1.34 585 6	11.5	1.26 829 7	11.5	1.27 087 8	11	1.17 442 6	11.5	1.18 652 1	11.5	1.16 101 5	11.5	1.13 814 3	11.5	1.10 900 2
15	0.77 968 62	12	1.27 348 6	12	1.29 383 4	13	1.39 188 6	12	1.30 624 8	12	1.32 446 11.5	11.5	1.23 166 4	12	1.23 869 9	12	1.19 852 3	12	1.17 598 12	12	1.14 759 9
15.5	0.79 145 37	12.5	1.31 732 6	12.5	1.34 105 1	13.5	1.43 633 6	12.5	1.34 975 8	12.5	1.35 309 4	12	1.29 158 4	13	1.34 402 4	12.5	1.24 441 5	12.5	1.20 781 6	12.5	1.18 267 2
16	0.80 416 86	13	1.35 943 1	13	1.38 657 3	14	1.47 874 6	13	1.39 310 3	13	1.38 580 5	12.5	1.34 688 9	13.5	1.36 512 5	13	1.29 592 4	13	1.24 518 6	13	1.21 522 5
16.5	0.81 759 96	13.5	1.39 965 5	13.5	1.43 016 14.5	14.5	1.51 839 8	13.5	1.43 422 2	13.5	1.41 505 4	13	1.35 897 9	14	1.39 392 5	13.5	1.34 872 2	13.5	1.29 027 5	13.5	1.24 316 9
17	0.83 170 03	14	1.43 746 3	14	1.46 971 2	15	1.55 377 7	14	1.47 109 5	14	1.44 672 9	13.5	1.38 916 6	14.5	1.42 640 7	14	1.36 906 2	14	1.34 099 14	14	1.28 146 5
17.5	0.84 657 02	14.5	1.47 078 2	14.5	1.49 783 9	15.5	1.57 783 4	14.5	1.50 258 1	14.5	1.48 196 14	14	1.42 026 8	15	1.45 808 6	14.5	1.39 541 14.5	14.5	1.36 788 6	15	1.36 972 3
18	0.86 239 44	15	1.48 533 6	15	1.53 360 7	16	1.59 121 2	15	1.53 500 9	15	1.51 467 5	14.5	1.45 57 15.5	15.5	1.48 389 6	15	1.42 702 6	15	1.39 454 1	15.5	1.38 271 1
18.5	0.87 739 96	15.5	1.44 277 4	15.5	1.56 196 6	16.5	1.61 042 8	15.5	1.56 561 15.5	15.5	1.54 297 5	15	1.48 722 8	16	1.51 179 7	15.5	1.45 253 6	15.5	1.41 869 1	16	1.40 611 7
19	0.89 231 29	16	1.39 454 2	16	1.58 044 4	17	1.62 896 16	16	1.59 353 3	16	1.56 705 4	15.5	1.51 385 4	16.5	1.53 884 6	16	1.47 810 8	16	1.44 259 3	16.5	1.42 821 6
19.5	0.90 732 53	16.5	1.35 609 9	16.5	1.59 389 4	17.5	1.64 317 7	16.5	1.61 761 5	16.5	1.59 156 9	16	1.54 148 1	17	1.55 976 9	16.5	1.50 418 8	16.5	1.46 721 9	17	1.44 270 3
20	0.92 266 91	17	1.29 198 3	17	1.60 140 2	18	1.65 226 3	17	1.63 709 8	17	1.61 643 2	16.5	1.56 920 6	17.5	1.57 496 5	17	1.52 345 4	17	1.48 493 5	17.5	1.46 276 2
20.5	0.93 903 66			17.5	1.60 165 7	18.5	1.65 479 1	17.5	1.65 044 1	17.5	1.63 809 7	17	1.59 304 9	18	1.59 094 2	17.5	1.53 889 6	17.5	1.50 194 5	18	1.47 799 6
21	0.95 540 85			18	1.59 151 7	19	1.64 874 6	18	1.65 516 1	18	1.65 482 1	17.5	1.61 092 7	18.5	1.60 728 1	18	1.55 797 5	18	1.52 030 2	18.5	1.48 560 2

21.5	0.97 135 76			18.5	1.56 25	19.5	1.63 065 3	18.5	1.66 350 8	18.5	1.66 622 6	18	1.62 315 8	19	1.61 743	18.5	1.57 288 1	18.5	1.53 253 6	19	1.49 17
22	0.98 669 5			19	1.49 196 2	20	1.59 424 3	19	1.66 758 1	19	1.67 095 4	18.5	1.63 108 6	19.5	1.62 058 4	19	1.57 911 9	19	1.53 493 1	19.5	1.50 095
				19.5	1.27 184 3	20.5	1.53 086 5	19.5	1.66 477	19.5	1.66 778 7	19	1.64 281 4	20	1.61 496 9	19.5	1.57 772	19.5	1.54 088 2	20	1.50 211 1
				20	1.08 377 8	21	1.42 652 5	20	1.65 262 4	20	1.65 558 1	19.5	1.64 958 5	20.5	1.60 305 9	20	1.57 946 2	20	1.54 485 2	20.5	1.49 076 8
						21.5	1.29 352 4	20.5	1.62 977 3	20.5	1.63 300 7	20	1.64 988 2	21	1.59 398 4	20.5	1.57 927 5	20.5	1.54 263 8	21	1.48 742 5
						22	1.20 036 6	21	1.59 375 1	21	1.60 840 5	20.5	1.64 344 4	21.5	1.58 439 9	21	1.57 470 7	21	1.52 978 9	21.5	1.48 592 6
							1.15 234 1	21.5	1.54 243 2	21.5	1.57 874 7	21	1.62 876 5	22	1.56 719 8	21.5	1.56 023 2	21.5	1.51 582	22	1.47 585
						23	1.12 060 1	22	1.47 771 9	22	1.54 249 3	21.5	1.60 375 4	22.5	1.54 381 5	22	1.53 861 1	22	1.50 504 2	22.5	1.45 546 8
							1.09 461	22.5	1.40 089 8	22.5	1.49 591 3	22	1.57 205 5	23	1.51 805 4	22.5	1.51 392 8	22.5	1.49 461 4	23	1.43 54
							1.07 540 9	23	1.33 034 6	23	1.44 938 7	22.5	1.53 376 3	23.5	1.48 696 1	23	1.48 776 9	23	1.48 094 4	23.5	1.42 602 8
								23.5	1.26 938 6	23.5	1.39 723 7	23	1.48 651 6	24	1.45 026 8	23.5	1.47 315 9	23.5	1.45 582 8	24	1.41 626 1
								24	1.22 674 4	24	1.35 233 8	23.5	1.44 045	24.5	1.41 217 5	24	1.45 027 7	24	1.43 003 1	24.5	1.40 026 9
								24.5	1.20 086 7	24.5	1.31 269 1	24	1.40 764 3	25	1.37 339 4	24.5	1.43 079 9	24.5	1.40 325 1	25	1.37 324 7
								25	1.17 534 1	25	1.28 233 7	24.5	1.37 921 1			25	1.41 007 6	25	1.39 529 9		
												25	1.34 809 3								

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

Alph a	NA CA0 006	Alph a	NA CA0 008	Alph a	NA CA0 010	Alph a	NA CA0 012	Alph a	NA CA0 014	Alph a	NA CA0 016	Alph a	NA CA0 018	Alph a	NA CA0 020	Alph a	NA CA0 022	Alph a	NA CA0 024	Alph a	NA CA0 026
-5	-74. 241 74	-4.5	-75. 970 92	-5	-79. 025 3	-5	-80. 595 43	-5	-80. 713 65	-5	-79. 652 02	-5	-77. 626 25	-5	-75. 051 82	-5	-71. 868 69	-5	-68. 033 03	-5	-63. 361 07
-4.5	-74. 317 9	-4	-70. 193 29	-4.5	-75. 070 05	-3.5	-65. 418 62	-4.5	-75. 851 72	-4.5	-74. 463 68	-4.5	-72. 100 74	-4.5	-69. 451 23	-4.5	-66. 298 95	-4.5	-62. 650 74	-4.5	-58. 082 05
-4	-69. 760 76	-3.5	-64. 135 67	-4	-70. 610 9	-3	-58. 546 77	-4	-70. 143 22	-4	-68. 352 27	-4	-65. 936 22	-4	-63. 134 94	-4	-60. 210 95	-4	-56. 745 33	-4	-52. 851 85
-3.5	-65. 041 87	-3	-58. 760 67	-3.5	-65. 826 8	-2.5	-50. 604 83	-3.5	-63. 815 14	-3.5	-61. 507 5	-3.5	-59. 099 92	-3.5	-56. 383 49	-3.5	-53. 669 55	-3.5	-50. 449 6	-3.5	-47. 108 41
-3	-58. 829 55	-2.5	-53. 065 62	-3	-59. 750 92	-2	-41. 727 41	-3	-56. 523 55	-3	-54. 143 55	-3	-51. 859 58	-3	-49. 418 84	-3	-46. 760 27	-3	-43. 878 7	-3	-40. 944 58
-2.5	-51. 118 5	-2	-45. 455 28	-2.5	-52. 482 83	-1.5	-32. 030 69	-2.5	-48. 347 14	-2.5	-46. 181 21	-2.5	-43. 974 41	-2.5	-41. 841 25	-2.5	-39. 524 89	-2.5	-37. 024 95	-2.5	-34. 382 79
-2	-43. 814 19	-1.5	-36. 068 19	-2	-43. 767 16	-1	-21. 665 08	-2	-39. 583 54	-2	-37. 694 58	-2	-35. 783 88	-2	-33. 870 8	-2	-31. 973 36	-2	-29. 975 67	-2	-27. 801 42
-0.5	-14. 475 91	-1	-25. 009 16	-1.5	-33. 967 56	-0.5	-10. 982 18	-1.5	-30. 276 12	-1.5	-28. 657 06	-1.5	-27. 097 62	-1.5	-25. 614 03	-1.5	-24. 172 22	-1.5	-22. 694 33	-1.5	-21. 087 55
0	-2.6 9E- 08	-0.5	-12. 799 42	-1	-23. 251 99	0	-2.7 1E- 10	-1	-20. 459 32	-1	-19. 244 17	-1	-18. 276 48	-1	-17. 252 13	-1	-16. 188 2	-1	-15. 231 65	-1	-14. 169
0.5	14.4 76	0	-2.0 3E- 07	-0.5	-11. 787 09	0.5	10.9 822 5	-0.5	-10. 307 05	-0.5	-9.7 132 92	-0.5	-9.1 446 55	-0.5	-8.6 951 64	-0.5	-8.1 181 66	-0.5	-7.6 446 25	-0.5	-7.1 377 63
1	27.2 582 3	0.5	12.7 995 1	0	-6.6 3E- 12	1	21.6 653 5	0	2.09 E-0 9	0	5.87 E-0 9	0	1.32 E-0 8	0	-2.4 1E- 08	0	-7.7 8E- 08	0	5.39 E-0 7	0	4.20 E-0 7
2	43.8 148 8	1	25.0 094 8	0.5	11.7 871 6	1.5	32.0 312 6	0.5	10.3 071 2	0.5	9.71 336 8	0.5	9.14 473 7	1	17.2 525	0.5	8.11 826 8	0.5	7.64 475 3	0.5	7.13 792 2
2.5	51.1 191 9	1.5	36.0 688 5	1	23.2 522 6	2	41.7 284 2	1	20.4 596	1	19.2 444 7	1	18.2 768 1	1.5	25.6 148 6	1	16.1 886 5	1	15.2 321 6	1	14.1 696 4
3	58.8 312	2	45.4 563 8	1.5	33.9 681 7	2.5	50.6 063 5	1.5	30.2 767 4	1.5	28.6 577 1	1.5	27.0 983 2	2	33.8 722 6	1.5	24.1 732	1.5	22.6 955 1	1.5	21.0 890 3
3.5	65.0 384	2.5	53.0 670 2	2	43.7 680 5	3	58.5 487 9	2	39.5 845 6	2	37.6 957 4	2	35.7 851 8	2.5	41.8 435	2	31.9 750 7	2	29.9 777 6	2	27.8 040 9
4	69.7 587 8	3	58.7 622 1	2.5	52.4 840 7	3.5	65.4 211 8	2.5	48.3 488 1	3	54.1 460 8	2.5	43.9 762 9	3	49.4 219 1	2.5	39.5 275 5	2.5	37.0 282 3	2.5	34.3 868 9

4.5	74.3 178 4	3.5	64.1 373 7	3	59.7 524 7	4	71.2 730 1	3	56.5 257 8	3.5	61.5 105 5	3	51.8 623 9	3.5	56.3 875 3	3	46.7 640 4	3	43.8 832 6	3	40.9 505
5	74.2 418 4	4	70.1 951 7	3.5	65.8 288 9	5	80.5 996	3.5	63.8 177 9	4	68.3 559 5	3.5	59.1 033 7	4	63.1 405 8	3.5	53.6 747 1	3.5	50.4 556 7	3.5	47.1 168 1
5.5	72.8 283 4	4.5	75.9 742 4	4	70.6 133 7	5.5	84.1 189 4	4	70.1 464 5	4.5	74.4 683 8	4	65.9 409 6	4.5	69.4 580 6	4	60.2 175 9	4	56.7 532 4	4	52.8 632 6
6	68.2 407 5	5	81.2 589 5	4.5	75.0 724 8	6	87.1 917	4.5	75.8 561 5	5	79.6 578 6	4.5	72.1 06 5	5	75.0 596 9	4.5	66.3 072 2	4.5	62.6 609 4	4.5	58.0 965 1
6.5	53.6 263 6	5.5	85.1 456 5	5	79.0 280 4	6.5	89.7 481 9	5	80.7 184 6	5.5	84.0 623 8	5	77.6 332 6	5.5	80.1 510 5	5	71.8 788 1	5	68.0 461 5	5	63.3 789 1
7.5	21.9 519 2	6	87.0 891 8	5.5	83.3 362 4	7	92.4 135 7	5.5	84.9 229 4	6	88.3 639 4	5.5	82.7 193 4	6	84.3 880 4	5.5	76.9 797 1	5.5	73.0 435 9	5.5	68.0 981 6
8	21.3 345 2	6.5	88.4 308 3	6	87.0 413 9	7.5	94.8 619 5	6.5	91.3 118	6.5	91.2 606 7	6	86.6 212	6.5	88.4 163 9	6	81.6 330 8	6	77.4 113 1	6	71.7 007 8
8.5	26.5 389	7	90.0 878 1	6.5	90.5 050 4	8	96.6 634 1	7	93.3 804 6	7	94.3 024 5	6.5	90.6 530 7	7	91.8 676 1	6.5	85.5 963 5	6.5	81.1 446 7	6.5	75.0 669
10.5	6.90 831 3	7.5	88.8 063 8	7	93.7 340 9	8.5	98.8 162 7	7.5	95.0 818 3	7.5	96.3 605 3	7	93.7 210 3	7.5	94.7 378 8	7	89.1 520 5	7.5	87.7 912 6	7	78.3 726 7
11	6.45 426 7	8	89.0 292 5	8	96.3 696	9	99.4 231 7	8	96.7 257	8	97.8 680 9	7.5	96.2 157 6	8	96.9 263 8	7.5	92.0 082 6	8	89.8 031 4	7.5	80.8 887 5
11.5	6.01 760 1	8.5	89.4 867 6	8.5	95.2 344 5	9.5	100. 269 7	8.5	98.2 041	8.5	99.1 009 4	8	98.0 776 3	8.5	98.6 074 7	8	94.2 620 4	8.5	90.9 567 3	8	82.6 530 8
12	5.14 416 1	9	89.2 836 3	9	95.7 436 6	10	99.2 255	9	99.4 732 5	9	99.7 724 3	8.5	99.3 883 9	9	99.4 701 2	8.5	95.9 336 5	9	92.0 581	8.5	84.7 062 9
12.5	4.67 144 5	9.5	87.6 376 1	9.5	95.9 046 5	10.5	97.8 523 5	9.5	99.8 004 7	9.5	99.9 858 5	9	100. 532 1	9.5	100. 286 7	9	97.5 678 5	9.5	93.0 466 4	9.5	85.7 403 6
13	4.45 502 9	10	79.7 019 9	10	95.2 056 6	11	97.6 533 2	10	101. 138 7	10	100. 269	9.5	100. 966 7	10	100. 753	9.5	98.0 125	10	92.6 897 2	10	86.3 645 9
13.5	4.27 930 7	10.5	78.2 628 5	10.5	91.1 714 4	11.5	96.7 258 2	10.5	100. 518 2	10.5	100. 973 4	10	100. 590 9	10.5	99.9 112 1	10	97.6 696	10.5	91.8 755	10.5	85.1 605 2
14	4.13 144 1	11	76.3 903 4	11	90.6 216 3	12	94.5 903 7	11	100. 810 6	11	100. 271 1	10.5	100. 180 1	11	98.1 969 9	10.5	96.8 662 9	11	91.2 512	11	84.3 414 1
14.5	4.00 518 4	11.5	74.0 885 5	11.5	89.5 563 4	12.5	91.8 091 8	11.5	99.3 651 1	11.5	100. 549 7	11	100. 170 6	11.5	97.2 241 3	11.5	93.6 316 2	11.5	88.6 997 6	11.5	82.5 506 8

15	3.89 706 3	12	71.4 579 8	12	88.2 429 7	13	90.6 212 9	12	97.0 272 3	12	98.9 370 1	11.5	99.0 077 3	12	95.2 422 7	12	91.5 944 8	12	86.8 933 1	12	80.4 391 6
15.5	3.80 515 1	12.5	68.6 682 4	12.5	86.6 744	13.5	88.9 993 7	12.5	96.3 299 4	12.5	97.7 686	12	98.5 968 2	13	91.5 439 6	12.5	89.1 917 4	12.5	83.4 373 5	12.5	77.6 268 6
16	3.72 497 9	13	65.8 915 5	13	84.5 189 2	14	86.9 461 4	13	95.0 076 7	13	96.1 068 1	12.5	96.8 652 2	13.5	88.6 265 3	13	86.4 665 5	13	80.8 464 1	13	74.4 603 7
16.5	3.65 417	13.5	63.1 997 4	13.5	81.9 209 5	14.5	84.4 133	13.5	92.7 958 1	13.5	93.1 825 1	13	94.7 109 1	14	84.4 849 5	13.5	84.0 456 5	13.5	77.2 622 5	13.5	70.6 773 4
17	3.59 266	14	60.5 089 9	14	78.0 935 6	15	81.2 623 8	14	89.4 698 6	14	89.9 227 2	13.5	91.7 471 6	14.5	80.9 100 1	14	80.0 805 6	14	74.4 453 6	14	67.6 511 7
17.5	3.54 017 4	14.5	57.3 654 4	14.5	70.9 987 4	15.5	76.9 319 6	14.5	86.4 215 2	14.5	87.5 139 5	14	87.8 426 4	15	77.0 263	14.5	75.5 429 2	14.5	69.9 406 7	15	60.8 981 4
18	3.49 678 6	15	51.1 575 5	15	68.5 797 8	16	70.1 778 1	15	83.7 741	15	84.2 202 7	14.5	85.1 726 6	15.5	71.7 135 2	15	72.0 121 7	15	66.4 991 4	15.5	56.2 743 4
18.5	3.45 214 5	15.5	39.9 199 2	15.5	65.6 409	16.5	65.2 383 4	15.5	80.5 153 9	15.5	79.7 057 5	15	81.2 145 1	16	67.3 395 2	15.5	67.0 419 1	15.5	61.9 110 1	16	52.7 003 3
19	3.41 129 5	16	28.3 786 3	16	61.7 989 4	17	60.3 500 2	16	76.5 745 6	16	74.2 320 5	15.5	76.0 348 8	16.5	63.0 804	16	62.4 409 3	16	57.5 676 8	16.5	49.0 067 9
19.5	3.37 466 5	16.5	20.4 689 6	16.5	56.9 826 8	17.5	54.8 512 4	16.5	71.7 608 4	16.5	69.1 976 4	16	71.4 023 9	17	58.0 469 9	16.5	58.4 353	16.5	53.6 696	17	44.6 715 9
20	3.34 400 5	17	14.6 901 2	17	51.1 394 1	18	48.8 610 8	17	66.0 636 4	17	64.6 695 5	16.5	67.1 727 6	17.5	52.5 232 6	17	53.5 128 5	17	49.0 648 9	17.5	41.5 551 6
20.5	3.32 723 5			17.5	44.3 420 1	18.5	42.5 460 8	17.5	59.4 59.4 9	17.5	59.7 416 8	17	62.3 381 7	18	47.8 525 3	17.5	48.5 905 6	17.5	45.0 088 5	18	38.2 737 4
21	3.31 396 7			18	36.8 009 8	19	36.2 591	18	51.9 945 4	18	54.4 271 5	17.5	56.8 609 4	18.5	43.9 217 6	18	44.8 912 6	18	41.6 346 6	18.5	34.7 435
21.5	3.29 992 5			18.5	28.7 628 9	19.5	30.0 926 3	18.5	46.1 852 1	18.5	48.8 306 3	18	51.0 474 2	19	39.7 268 5	18.5	41.1 439 5	18.5	38.0 407 2	19	31.6 332 7
22	3.28 537 7			19	20.3 602 1	20	24.1 395 9	19	40.7 348	19	43.1 86	18.5	45.4 527 1	19.5	35.4 845 1	19	36.9 700 9	19	34.0 592	19.5	29.1 992 6
				19.5	10.5 657 6	20.5	18.5 265 8	19.5	35.4 182 2	19.5	37.4 935 4	19	41.2 217 6	20	31.2 497 8	19.5	32.8 492 9	19.5	31.0 482	20	26.5 932
				20	6.42 408 9	21	13.3 522 2	20	30.3 064	20	32.0 894 1	19.5	37.0 431 7	20.5	27.3 327 2	20	29.6 740 8	20	28.3 100 7	20.5	23.7 1111


```

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')
```