Exploring Innovative Wing Designs to Enhance Aerodynamic Efficiency

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IA Project Showcase

Problem Statement: The demand for travel is increasing and prioritizing faster and more sufficient travel is crucial for efficiency.

Research Question: How can innovative wing designs enhance aerodynamic efficiency in modern aircraft?

Abstract

This project proposes to design, 3D print and test a 1/40th scale airplane wing model inspired by the Boeing 777x. This model will include folding wing tips, and an additional innovative feature based on feasibility such as morphing. These additions will help improve aerodynamic efficiency by simultaneously reducing drag and increasing lift, decreasing economic costs, and overall improving individual's flight experience whilst maintaining structural integrity.

This project will explore how modern wing technologies can improve flight performance through require data analysis, simulations, CAD-based modeling, and performance testing.

Background

This study aims to discover the multitude of factors that define functionality and aerodynamic efficiency in an aircraft wing, this would include methods to increase higher lift-to-drag ratio, the creation of adaptive wing technology, and the use of higher aspect ratio, allowing for less drag and contributing to better aerodynamic performance overall. This project focuses on measuring pressure, velocity, density, and temperature data to evaluate lift and drag forces on a range. The long-term goal is to design, simulate, and eventually test a wing prototype optimized for aerodynamic efficiency. Once initial models are validated, a physical prototype will be created using SolidWorks, tested with ANSYS, and 3D printed with PLA-CF and metal reinforcements, then tested using our school's wind tunnel to verify simulation results.

Materials

XFoil v6.99 – Software used to analyze airfoils, calculating lift, drag, and moment coefficients under various flow conditions.
NeuralFoil (https://github.com/peterdsharpe/NeuralFoil?tab=readme-ov-file) – Similar but more powerful machine learning based prediction tool than XFoil used to analyze airfoil flight performance under various flow conditions.
MATLAB R2024b – Used for calculating and plotting aerodynamic curves.
SolidWorks 2024 – CAD software for creating 3D models of the wing.
ANSYS 2025 R1 (in progress) – Software used for analyzing pressure, velocity, and temperature distributions around the wing.
UIUC Airfoil Coordinates Data Base – (https://m-selig.ae.illinois.edu/ads/coord_database.html)
Visual Studio Code – Used to run NeuralFoil
Aerospace Engineering Textbooks and Websites

Method and Process Steps

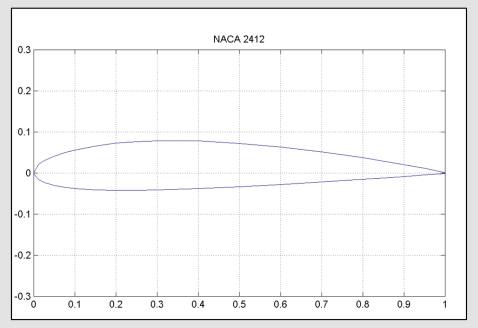
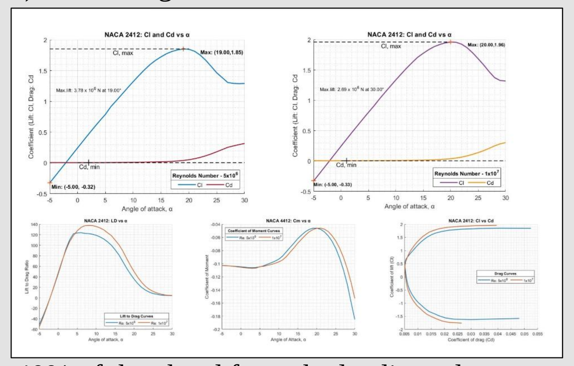
- Researched multiple airfoils such as the NACA 2412, NACA 4412, and one supercritical airfoil known as NASA SC(2) – 0714.
- Analyzed their lift, drag, and moment coefficient using XFoil and MATLAB to compare aerodynamic performance with lower Reynolds numbers. Then calculated realistic values for Reynolds numbers, velocity, and Mach numbers under certain conditions using MATLAB.
- XFoil struggled with handling high Reynolds and Mach numbers, leading me to switch to NeuralFoil for more advanced simulations.
- After completing several simulations with NeuralFoil, I created several .dat files including the airfoils performance in different flight phases such as takeoff, climb, and cruise and ran it through MATLAB to create curve plots and a table of data to compare each airfoil's performance. I selected the airfoil that demonstrated the most promising results (NASA SC(2)-0714), focusing on mostly the lift-to-drag ratio and lift curves.

In progress:

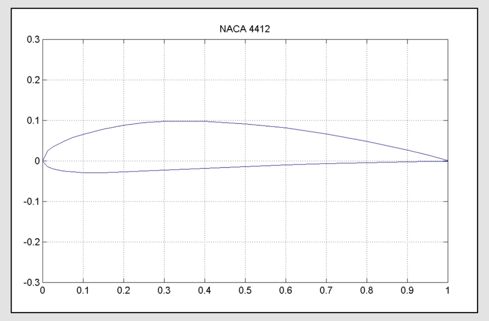
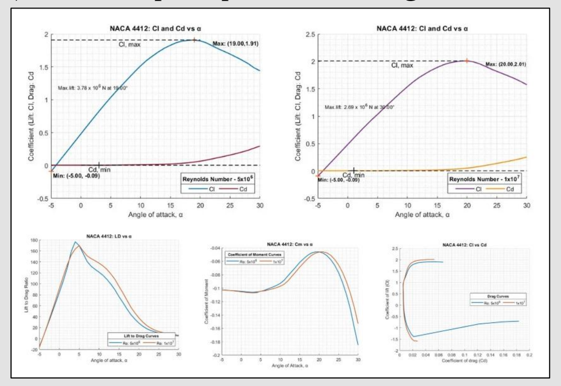
- These tests allowed me to understand what I should look for in an airfoil, allowing me to create my own airfoil data and import it into SolidWorks. Once imported, I sketched a rough wing design with little refinements for CFD testing.
- Constructed CFD simulations in ANSYS to observe flow patterns, pressure distribution, and aerodynamic behavior using the rough wing design.

Early Data

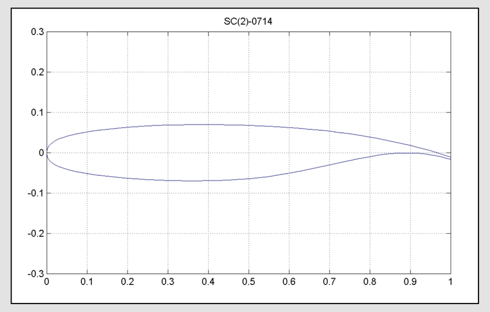
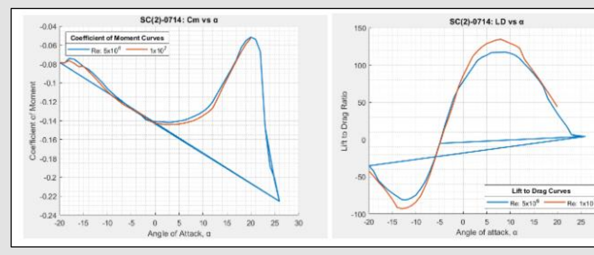
NACA 2412 – (Maximum camber 2% at 40% of the chord from the leading edge. Maximum thickness of 12% of the chord.) Good for general aviation due to LD ratio.

NACA 4412 – (Maximum camber 4% at 40% of the chord from the leading edge. Maximum thickness of 12% of the chord.) Used for sports planes, has a higher coefficient of lift.

NASA SC(2)-0714 – (Maximum thickness of 0.14, blunt trailing edge, camber of 1.5%) Supercritical airfoil – Designed to reduce wave drag in aircrafts that operate close to or above the speed of sound.

This airfoil is similar to the supercritical airfoil the B777x uses.

Hypothesis

If modern wing designs are optimized using advanced airfoils and features, they should demonstrate increase aerodynamic efficiency, specifically higher lift to drag ratios, under realistic flow conditions. Compared to traditional designs, these profiles will allow for smoother airflow and lower fuel consumption.

BOEING. (n.d.). *777X*. Www.boeing.com. https://www.boeing.com/commercial/777x

Results

Completed initial simulations using XFoil, NeuralFoil, and MATLAB focused on airfoils NACA 2412, NACA 4412, and NASA SC(2)-0714. Data revealed that the NASA SC(2)-0714 airfoil demonstrated the most favorable aerodynamic characteristics, with a life-to-drag ratio of 182.74 at Mach 0.84 and Reynolds number 2.2x10^7. MATLAB was used to generate curve plots comparing lift, drag, and moment coefficients as a function of angle of attack. In comparison to the other airfoils, NASA SC(2)-0714 was proven to both minimize drag while maintain a strong lift performance.

Filename	AoA ClMax	ClMax	AoA CdMin	CdMin	Max L/D
AirfoilData(NACA2412).dat	8	1.17764561	4	0.00571814	167.093907
AirfoilData(NACA2412_CLIMB).dat	6	1.03603261	3	0.00554699	162.422128
AirfoilData(NACA2412_CRUISE).dat	3	0.45519971	1	0.07955682	3.62630365
AirfoilData(NACA2412_CRUISE2).da	3	0.45519971	1	0.07955682	3.62630365
AirfoilData(NACA4412).dat	8	1.41117637	4	0.00621683	179.34797
AirfoilData(NACA4412_CLIMB).dat	6	1.29707667	3	0.00584904	183.1457
AirfoilData(NACA4412_CRUISE).dat	3	0.64232262	1	0.10837975	4.76898071
AirfoilData(NACA4412_CRUISE2).da	3	0.64232262	1	0.10837975	4.76898071
AirfoilData(SC20714).dat	8	1.57232034	4	0.00671355	182.744777
AirfoilData(SC20714_CLIMB).dat	8	1.57232034	4	0.00671355	182.744777
AirfoilData(SC20714_CRUISE).dat	8	1.57232034	4	0.00671355	182.744777
AirfoilData(SC20714_CRUISE2).dat	8	1.57232034	4	0.00671355	53883

AoA – Angle of Attack | Cl – Lift Coefficient | Cd – Drag Coefficient L/D – Lift-to-drag ratio

1	Altitudes	Velocity	Reynolds Numnber	Phase	Mach
2	312.7248	74.8633081	60031810.91	Takeoff	0.220788338
3	459.237144	91.6312433	71607592.98	Climb	0.27069153
4	605.749489	92.7891886	70660948.04	Climb	0.274571122
5	752.261833	93.9696337	69726759.78	Climb	0.278531198
6	898.774177	95.1732057	68804929.28	Climb	0.282574063
7	1045.28652	96.4005556	67895359.11	Climb	0.286702112
8	1191.79887	97.6523593	66997953.38	Climb	0.290917831
9	1338.31121	98.9293189	66112617.81	Climb	0.295223802
10	1484.82355	100.232164	65239259.7	Climb	0.299622711
11	1631.3359	101.561654	64377788.06	Climb	0.304117349
12	1777.84824	102.918577	63528113.58	Climb	0.308710621
13	1924.36059	104.303754	62690148.72	Climb	0.31340555
14	2070.87293	105.718042	61863807.76	Climb	0.318205282
15	2217.38528	107.162329	61049006.84	Climb	0.323113098
16	2363.89762	108.637545	60245664.04	Climb	0.328132414
17	2510.40996	110.144657	59453699.42	Climb	0.333266793
18	2656.92231	111.684674	58673035.12	Climb	0.338519954
19	2803.43465	113.25865	57903595.42	Climb	0.343895775
20	2949.947	114.867685	57145306.83	Climb	0.349398309
21	3096.45934	116.512929	56398098.17	Climb	0.35503179
22	3242.97169	118.195583	55661900.66	Climb	0.360800646
23	3389.48403	119.916906	54936648.04	Climb	0.366709506
24	3535.99637	121.678213	54222276.67	Climb	0.372763218
25	3682.50872	123.480883	53518725.66	Climb	0.37896686
26	3829.02106	125.326361	52825937	Climb	0.385325751
27	3975.53341	127.216162	52143855.69	Climb	0.391845471
28	4122.04575	129.151876	51472429.9	Climb	0.398531876
29	4268.5581	131.135174	50811611.14	Climb	0.405391115
30	4415.07044	133.16781	50161354.45	Climb	0.412429649

31	4561.58278	135.251633	49521618.57	Climb	0.419654275
32	4708.09513	137.388584	48892366.2	Climb	0.427072144
33	4854.60747	139.580712	48273564.19	Climb	0.434690789
34	5001.11982	141.830175	47665183.84	Climb	0.442518152
35	5147.63216	144.139252	47067201.14	Climb	0.45056261
36	5294.14451	146.510347	46479597.12	Climb	0.45883301
37	5440.65685	148.946005	45902358.16	Climb	0.467338701
38	5587.16919	151.448916	45335476.36	Climb	0.476089574
39	5733.68154	154.021932	44778949.99	Climb	0.485096103
40	5880.19388	156.668074	44232783.89	Climb	0.494369389
41	6026.70623	159.390551	43696990	Climb	0.50392121
42	6173.21857	162.192771	43171587.9	Climb	0.513764078
43	6319.73092	165.078359	42656605.43	Climb	0.523911299
44	6466.24326	168.051178	42152079.36	Climb	0.534377036
45	6612.75561	171.115345	41658056.13	Climb	0.545176388

63	9249.9778	242.678587	33826466.56	Cruise	0.801713607
64	9396.49015	244.849483	33048823.19	Cruise	0.810579819
65	9543.00249	247.049045	32286026.51	Cruise	0.819581966
66	9689.51484	249.277776	31537851.09	Cruise	0.828722718
67	9836.02718	251.536187	30804074.04	Cruise	0.83800481
68	9982.53952	253.824803	30084475.01	Cruise	0.84743104
69	10129.0519	256.144159	29378836.14	Cruise	0.857004276
70	10275.5642	258.494803	28686942.05	Cruise	0.866727457
71	10422.0766	260.877293	28008579.82	Cruise	0.876603589
72	10568.5889	263.292202	27343539.01	Cruise	0.886635757
73	10715.1012	265.740114	26691611.57	Cruise	0.896827118
74	10861.6136	268.221627	26052591.88	Cruise	0.907180909
75	11008.1259	270.77034	25411794.67	Cruise	0.917700376
76	11154.6383	273.916319	24546234.91	Cruise	0.928362794
77	11301.1506	277.09885	23710157.26	Cruise	0.939149094
78	11447.663	280.318358	22902557.55	Cruise	0.950060717
79	11594.1753	283.575273	22122465.76	Cruise	0.961099117
80	11740.6877	286.870028	21368944.94	Cruise	0.972265769
81	11887.2	290.203064	20641090.05	Cruise	0.983562161

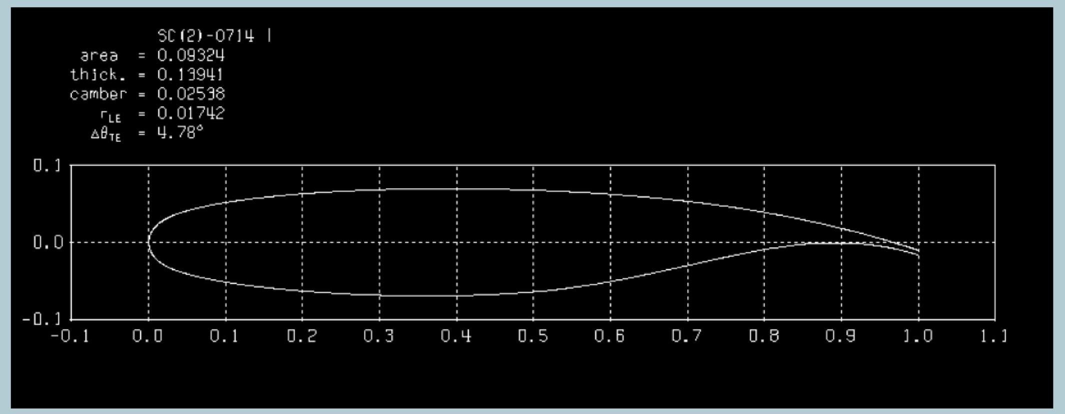
Using MATLAB, I generated realistic parameters for velocity, Reynolds number, and Mach number based on the altitude (starting at 312.7248m – Hartsfield Jackson altitude above sea-level)

Conclusion

Among the tested airfoils, the NASA SC(2)-0714 demonstrated the highest lift-to-drag ratio and consistent performance across different flight phases and Reynolds numbers over traditional airfoils. Since the SC(2)-0714 is a supercritical airfoil, this was expected. XFoil, NeuralFoil, and MATLAB provided aerodynamic coefficient analysis and data visualization to compare the performance.

Next Steps

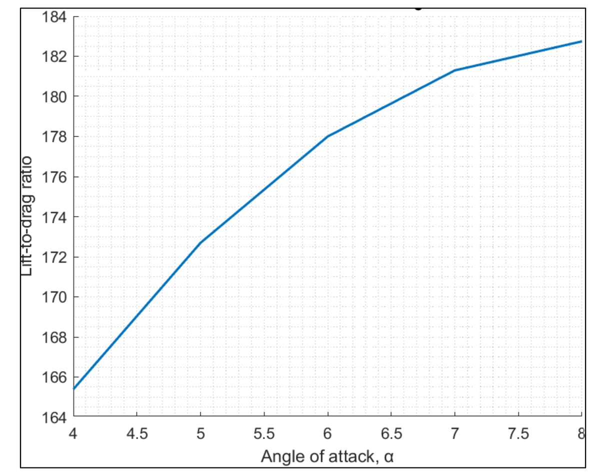
While no SolidWorks model and CFD analysis has been completed yet, these simulations provide a strong foundation for the next phase of my project that will begin this summer. These software will allow me to evaluate real-world flow characteristics such as turbulence, separation zones, and pressure gradience, which will be applied to the physical testing in the future.



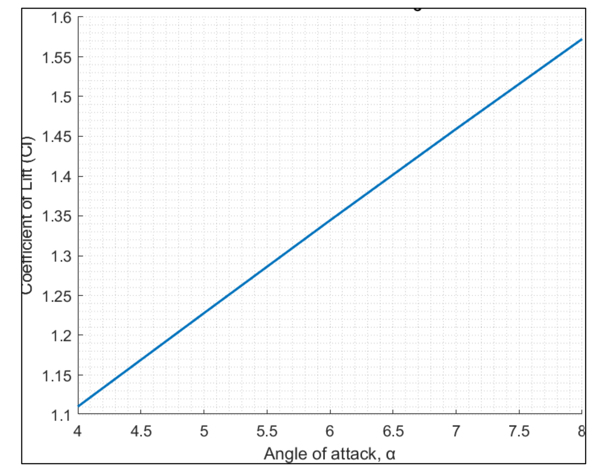
XFoil v6.99 GDES
Goal: NASA Modify SC(2)-0714 to have a thicker leading edge, aft camber (near TE), and flattened upper surface.

Results | Updated Graphs for NASA SC(2)-0714

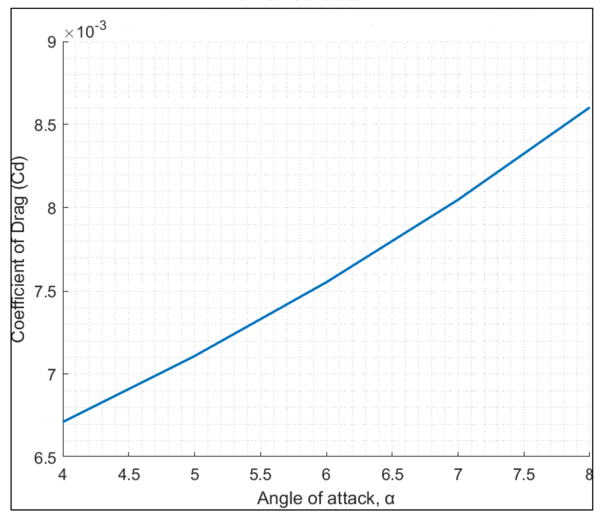
α vs. Ld data:



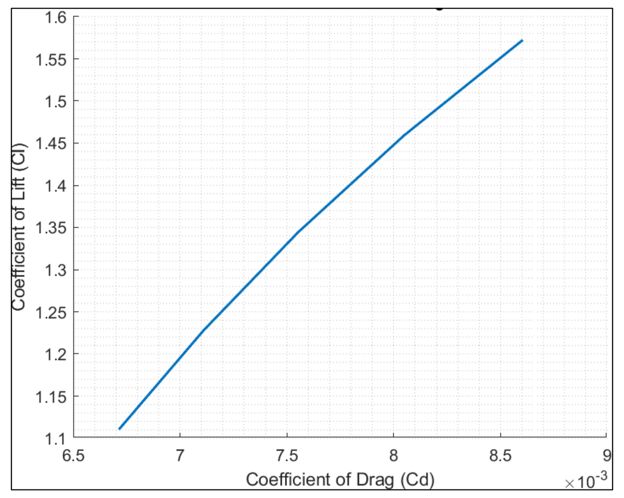
α vs. Cl data:



α vs. Cd data:



Cd vs. Cl data:



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