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RESEARCH ARTICLE OPEN

Airfoil Design and Optimization for tailless aircrafts.

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ABSTRACT

Tailless airplanes are significant in the present and future days as they diminish the general load of the airplane contrasted with traditional airplanes. Henceforth, picking a best airfoil is additionally critical. An airfoil as known assumes an imperative job in producing lift for any airplane. The inverse airfoil configuration process introduced depends on the connection between pressure residuals and the necessary airfoil shape change.This paper focuses principally on the airfoils utilized on tailless airplanes.The reason for this paper is to explore the conduct of obliged improvement arrangements with generally enormous quantities of free structure parameters present. This paper likewise examines the way to deal with assess and pick an airfoil utilizing certain opensource/free programming and furthermore recommend reasonable measures to choose the airfoil. The streamlined qualities of various airfoils utilized on tailless airplanes is analyzed. The techniques talked about in the paper can assist designers of tailless airplanes with choosing a proper airfoil for the tailless airplanes. The airfoils that are introduced here can be changed further for best execution. Inverse designing of the chosen airfoil for tailless aircrafts is done to improvise the aerodynamic parameters and characteristics. Optimization of an airfoil includes improving the plan of the airfoil so as to control the lift and drag coefficients as indicated by the necessities. It is a typical strategy utilized in all fields of designing. MATLAB is a numerical registering condition which underpins interface with other programming. XFOIL is airfoil investigation programming which ascertains the lift and drag qualities for various Reynolds numbers, Mach numbers and approaches. MATLAB is interfaced with XFOIL and the enhancement of NACA 23010 airfoil is done and the outcomes are resulted in this paper.

Keywords-Airfoil, Inverse Design, MATLAB, Optimization, XFOIL.

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I. INTRODUCTION

A flying wing is an airplane that has no fuselage. It is additionally named as tailless fixed-wing. As found in a hypothetical way, the generally discovered proficient airplane arrangements are the flying wings. The fundamental bit of leeway of the flying wing airplanes is that it brings about high lift to drag proportion. An inconvenience of the tailless airplanes is the absence of steadiness. This can be improved by the wing configuration by utilizing more plan limitations. Subsequently picking a fitting airfoil is significant for tailless airplanes.Aerofoil profiles were planned dependent on some significant needs. One was to meet the necessities of flight and the other was to grow new ideas of slim, smooth and proficient shapes. In the 1800's, the takes a shot at aerofoil began with headways proceeding till today. Remembering winged creatures' flight, the level plate was kept at an edge of frequency to the approaching airstreams and the lift powers were inferred.Streamlined inverse design strategies are extremely amazing in their productivity. They are significantly more computationally effectiveness than an immediate improvement approach on the grounds that the ideal execution is as of now indicated by a weight or speed dissemination. It doesn't need to be found by an inquiry procedure. In any case, this is likewise a drawback to the strategy.

The originator is left with the errand of making pressure conveyances that mirror the structure objectives. It very well may be hard to guarantee that the chose pressure circulation has insignificant drag for the ideal execution. Opposite structure strategies don't locate the ideal execution, they basically get as near the ideal execution as could reasonably be expected. Target pressure improvement strategies have been made to help diminish the originator of this assignment.The MATLAB Genetic Algorithm interfaced with XFOIL was utilized for advancement. The point of the advancement is to amplify the lift and limit the drag powers. Three control focuses were utilized for the examination These focuses are the ones that are controlled by the streamlining agent to accomplish advancement objectives. An oblige locale is additionally characterized to restrain the control of the control focuses.

1.1. AIRFOIL GEOMETRY

Airfoil geometry can be described by the directions of the upper and lower surface. It is frequently condensed by a couple of parameters, for example, greatest thickness, most extreme camber, position of max thickness, position of max camber, and nose range. One can create a sensible airfoil area given these parameters. This was finished by Eastman Jacobs in the mid 1930's to make a group of airfoils known as the NACA Sections.

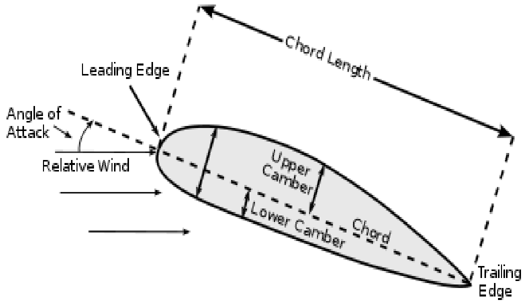

Fig-1: Airfoil Nomenclature

Table-1: NACA 5-Digit Series: NACA 23010

2	30	10
Approx. max camber in % chord	Position of max camber in 2/100 of c	Max thickness in % of chord

1.2. AIRFOIL SELECTION CRITERIA

A lot of models for best execution of tailless airplanes must be set to pick a suitable airfoil.
The majorly chosen parameters are:

- Maximum Lift to Drag Ratio.
- Pitching Moment near zero.
- Drag coefficient to minimum value.
- Maximum Thickness to Chord Ratio up to 12%.
- Stall angle(α stall).

Table-2: Airfoil Parameter Study

AIRFOILS	$(L/D)_{Max}$	α_{stall}	C_{Lmax}	C_{Dmin}	C_m	$(t/c)_{max}$ (%)
EH 2.0	158.8181	10.7	1.4070	0.00492	0	10.07
SC20010	142.2207	11	1.3213	0.00550	0	10
SC20012	148.1652	11.1	1.4216	0.00576	0	12
SC2110	156.986	11.8	1.7096	0.0056	-0.0114	9.925
C141A	151.510	12	1.5446	0.00566	-0.0426	12.99
NACA 63015A	130.2799	12.1	1.3286	0.00569	0	14.99
NACA 641212	153.187	10.5	1.5126	0.00484	-0.0435	11.96
SC1095	151.8936	11.5	1.5748	0.00532	-0.0152	9.49
LA2573A	156.5353	12.8	1.7194	0.0047	0.022	13.71
NACA 23010	170.1	12.7	1.7885	0.00463	-0.0113	10
E334	218.7773	14.4	1.7702	0.00451	0.0081	11.95

There are number of airfoils which can be selected for based on criteria's like lift to drag ratio, moment coefficient etc. Reynolds number chosen is 4e+07 and Mach 0.4 few of them are discussed below.

1.3. FLOW SOLVER

The assignment of the stream solver is to investigate and decide the airfoil attributes. Since the enhancement procedure requires numerous assessments and alterations of the airfoil profile, the computational expenses of the stream solver need to remain generally little. These are the reasons why XFOIL is utilized as stream solver in the current work.

For a given approach a, Reynolds number and Mach number, XFOIL gives the weight dispersion, CP(x), lift coefficientCl, and drag coefficient, Cd. Essentially, XFOIL finds the stream around the airfoil for the given approach and a window springs up indicating the weight conveyance, the segment lift coefficient, the segment second coefficient and the approach.

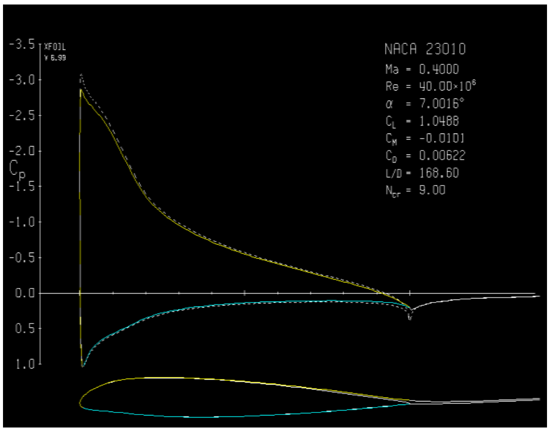

Fig-2: Pressure Distribution in XFOIL

The table below shows an example of input file that directs XFOIL to compute the characteristics of a given airfoil at Re=4e7, Mach=0.4 for a sequence of angles of attack. The results are stored in a data file. An example of XFOIL output file is shown is the table below. The output file can be either a text or a data file depending on the user's needs. In this example, the characteristics of a given airfoil are computed for a sequence of angles of attack (from 0 to 10 with an increment of 1) at Re=4e7 and Mach=0.4.

Table-3: Input file example

Example of Input file	Meaning
NORM LOAD NACA23010.dat OPER VISC 4e+7 MACH 0.4 ITER 200 PACC OUTPUTS/NACA23010.dat ASEQ 0 10 0.1 PACC QUIT	Normalize the airfoil to be loaded. Load the airfoil coordinates Toggle the operational mode Toggle the viscous mode and set Re=4e7 Set Mach Number = 0.4 Change viscous-solution iteration limit Toggle auto point accumulation to active polar. Store the output in the file named output.dat Prescribe a sequence of alphas and launch the flow analysis Quit XFOIL

II. OBJECTIVE

- To study the different airfoils for tailless aircrafts and to compare the airfoil characteristics and choose an appropriate airfoil that meets the requirement of tailless aircrafts.
- To inverse design an airfoil and to improvise the aerodynamic parameters such as Lift to drag ratio to attain a maximum value and pitching moment near zero.
- To optimize an airfoil using optimization process and improving the airfoil characteristics compared to the original airfoil and maintain the pitching moment near zero. To compare the results generated by the inverse designed airfoil with the optimized airfoil which leads to improvement in required airfoil characteristics.

III. INVERSE DESIGN

There are numerous streamlined opposite plan techniques accessible for either airfoil or wing structure. The leftover revision techniques, for example, Takanashi and NASA's streamline ebb and flow strategy are famous opposite plan strategies. Both utilize an iterative revision of either weight or speed contrasts along the objective and planned airfoil surfaces. Fig 3 shows a case of beginning and target airfoils. The original airfoil is a NACA 23010 and the target airfoil is an E334. To arrive at the target airfoil, the main edge and lower toward the back area of the underlying airfoil must be annoyed with a negative outward confronting ordinary and the upper rearward district must be bothered with a positive outward confronting typical.

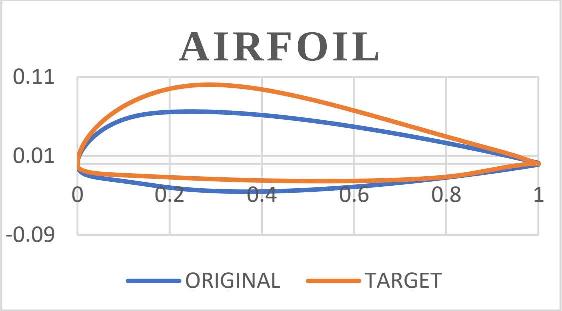

Fig-3: Original and Target Airfoils

Fig 4 shows beginning and target pressure dispersions for various Mach numbers and approaches. The original and target airfoils are again a NACA 23010 and E334 individually. The weights at the main edge and lower toward the back district of the underlying airfoil are on the whole not exactly those of the objective airfoil. Likewise, the weights at the upper toward the back area of the underlying airfoil are more prominent than those of the objective airfoil. In this manner, any place the weight is more noteworthy than the objective weight ($Cp−Cpo > 0$), the airfoil surface must be annoyed with a positive outward confronting ordinary vector. Alternately, any place the weight is lower than the objective weight ($Cp − Cpo < 0$), the airfoil must be irritated with a negative outward confronting ordinary.

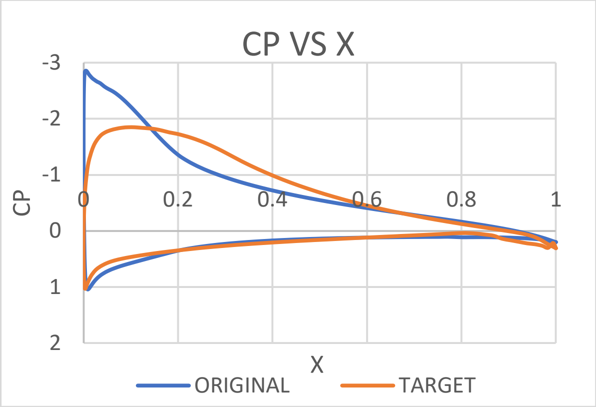

Fig-4: Original and Target pressure distributions

IV. OPTIMIZATION

Improvement issues require a target capacity to limit and are regularly dependent upon limitations. For airfoil drag streamlining the target work is characterized as the standardized drag esteem appeared in equation 3.1. The airfoil enhancement is performed by setting the lift coefficient (Cl) to a particular worth and the solver ascertains the approach (AOA). Two requirements are utilized for this streamlining issue. Just the target work and the pitching minute imperative require a high-loyalty solver. The main requirement is the thickness limitation appeared in equation 3.2, the enhanced airfoil ought to have not have alittler most extreme thickness because of fuel space. The subsequent requirement is the contributing minute imperative indicated equation 3.3. The advanced airfoil ought not have a bigger pitching minute than the underlying airfoil. The pitching minute ought to stay beneath 0 for security reasons, yet not get a bigger negative worth. Drag minimization improvements for the most part have a functioning pitching minute limitation along these lines the security rule doesn't need to be constrained.

$$J=\frac{Cd}{Cdi} \text{ ....(1).}$$

$$C_1=\frac{(\frac{t}{cmax_i}-\frac{t}{cmax})}{t/cmax\_i} \text{ ....(2).}$$

$$C_2=\frac{cm_i-cm}{|cm_i|} \text{ ....(3).}$$

V. RESULTS AND DISCUSSIONS

5.1. AIRFOIL STUDY RESULTS

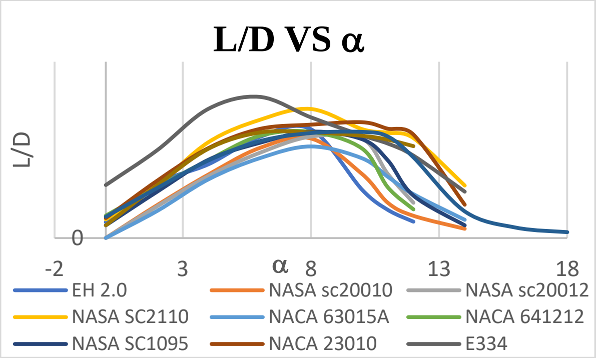

Fig-5: Variation of lift to drag ratio with angle of attack

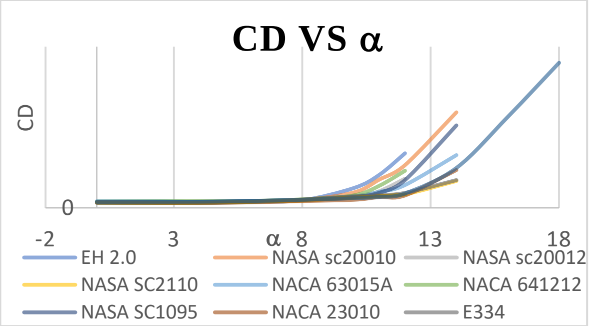

Fig-6: Variation of drag coefficient with angle of attack

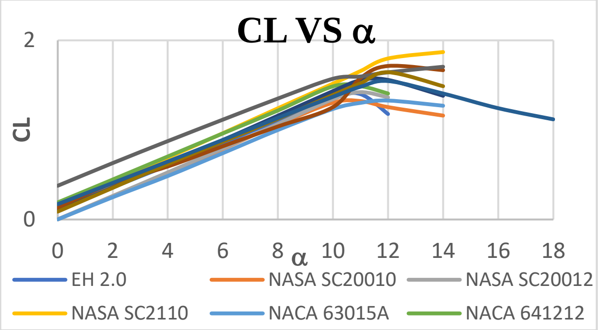

Fig-7: Variation of lift coefficient with angle of attack

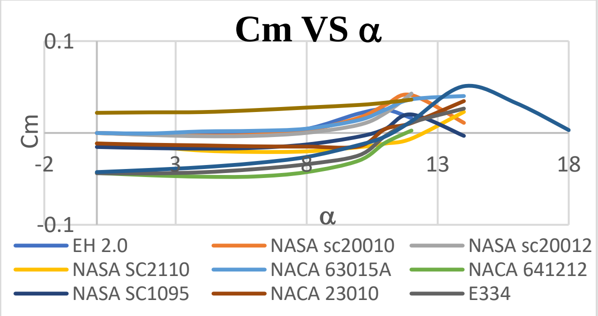

Fig-8: Variation of moment coefficient with angle of attack.

Comparing all these airfoils the chosen airfoil is NACA 23010 as this airfoil is used on military aircraft that is Northrop Grumman B2 bomber and Boeing X58. This airfoil meets the requirements like the pitching moment to be near zero and better Lift to Drag ratio suitable for the commercial and conventional aircrafts. Thus, the pitching moment is around -0.0119. The other airfoils with pitching moment near zero are not chosen because they are not used on the commercial aircrafts rather used on RC tailless aircrafts.

5.2. INVERSE DESIGN RESULTS

5.2.1. CASE-1

SEED AIRFOIL	TARGET AIRFOIL
NACA23010	EPPLER334

Table-4: Comparison of inversely designed NACA23010 airfoils.

PARAMETERS	CL	CD	Cm	L/D	t/c
ORIGINAL	1.0488	0.00619	-0.0102	169.4346	10
TARGET	1.0488	0.00503	-0.0405	208.4	11.95
ITER-1	1.0488	0.00554	-0.0171	189.32	11.56
ITER-2	1.0488	0.00504	-0.0031	208.18	10.68
ITER-3	1.0488	0.0052	-0.0091	201.69	11.61
DESIGNED	1.0488	0.0053	-0.0095	198.03	11.58

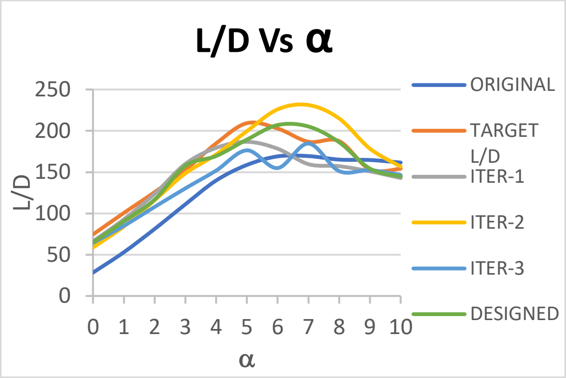

Fig-9: Lift to Drag ratio Vs Angle of attack

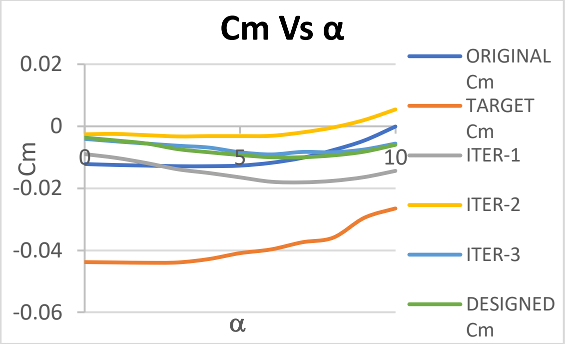

Fig-10: Pitching Moment Vs Angle of attack

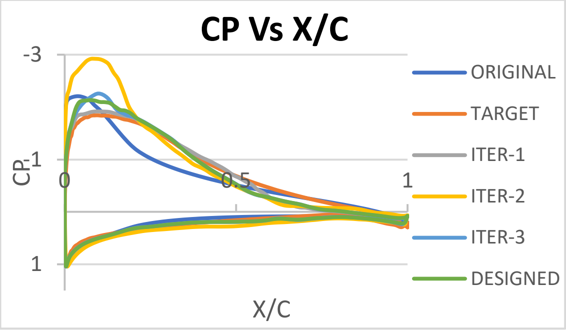

Fig-11: Coefficient of pressure Vs X/C.

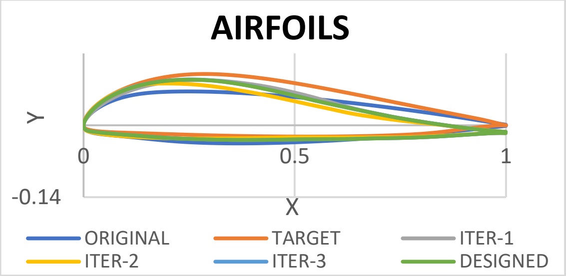

Fig-12: Airfoils

As seen from the table 4, we can infer that the seed airfoil is NACA 23010 and the target airfoil chosen is E334. The reason behind choosing this airfoil as target is that it has really a high Lift to Drag ratio of 208.4 with moment coefficient around -0.0405. The main reason behind this inverse design is that the airfoil characteristics such as L/D ratio, moment coefficient to reach the requirements of tailless aircrafts.

5.2.2. CASE-2

SEED AIRFOIL	TARGET AIRFOIL
EPPLER334	NACA23010

Table-5: Comparison of inversely designed E334 airfoils.

PARAMETERS	CL	CD	Cm	L/D	t/c
ORIGINAL	1.0004	0.00474	-0.0399	211.0549	11.95
TARGET	1.0004	0.00589	-0.0111	169.96	10
ITER-1	1.0004	0.00651	-0.0351	153.64	10.58
ITER-2	1.0004	0.00652	-0.0336	153.42	9.45

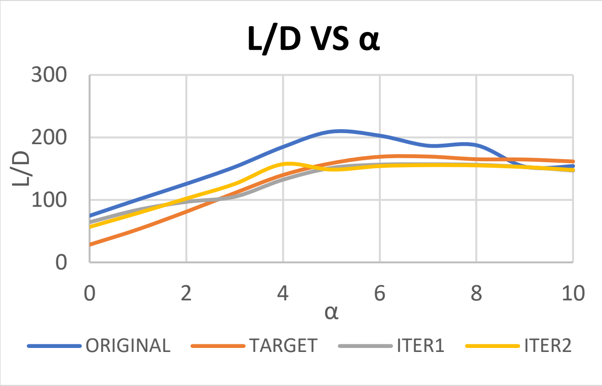

Fig-13: Lift to Drag ratio Vs Angle of attack

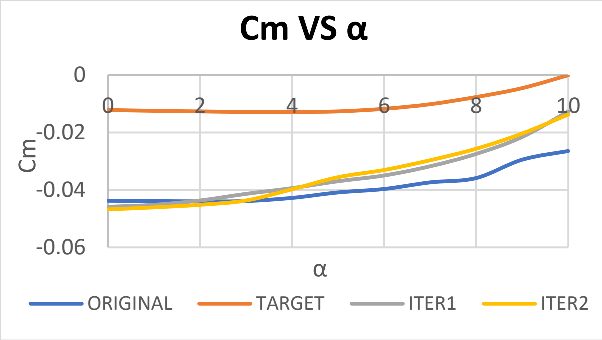

Fig-14: Pitching Moment Vs Angle of attack

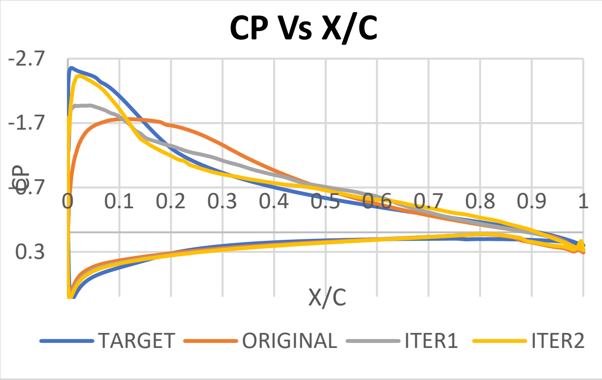

Fig-15: Coefficient of pressure Vs X/C.

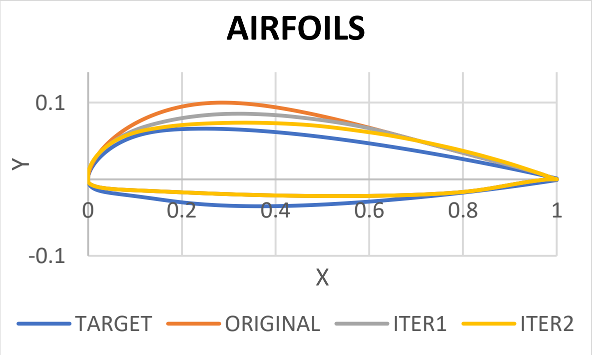

Fig-16: Airfoils.

As seen from the table 4.3, we can infer that the target airfoil is NACA 23010 and the seed airfoil chosen is E334. The reason behind choosing this airfoil as seed is that it has really a high Lift to Drag ratio of 208.4 with moment coefficient around0.0405. The main reason behind this inverse design is to check whether the inverse design using XFOIL is accurate or the correct way of designing better airfoils such that the airfoil characteristics such as L/D ratio, moment coefficient to reach the requirements of tailless aircrafts.

5.2.3. CASE-3

SEED AIRFOIL	TARGET AIRFOIL
S5020	EPPLER334

Table-6: Comparison of inversely designed S5020 airfoils.

PARAMETERS	CL	CD	L/D	Cm	t/c
ORIGINAL	0.909	0.00554	164.0794	0.0059	8.4
TARGET	0.909	0.00454	200.4	-0.042	11.95
ITER1	0.909	0.0052	174.76	-0.0022	10.769
ITER2	0.909	0.00499	182.06	-0.0044	9.72
ITER3	0.909	0.00469	193.88	-0.0071	10.34

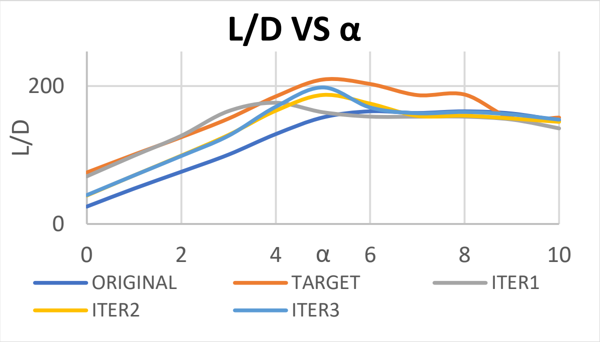

Fig-17: Lift to Drag ratio Vs Angle of attack

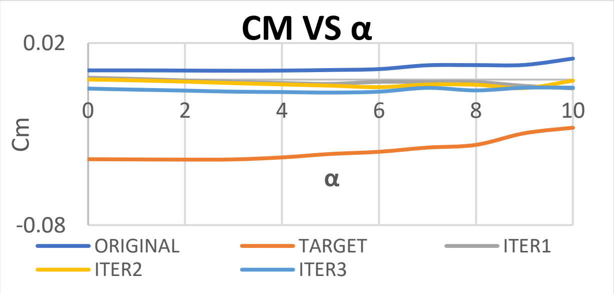

Fig-18: Pitching Moment Vs Angle of attack

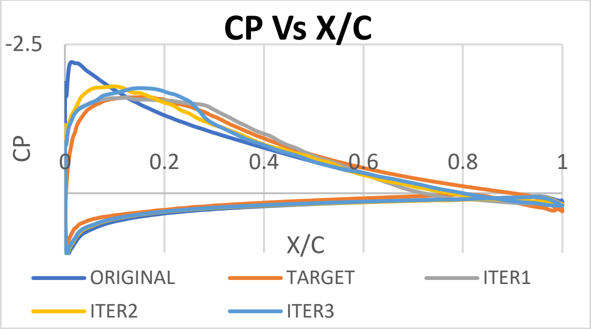

Fig-19: Coefficient of pressure Vs X/C.

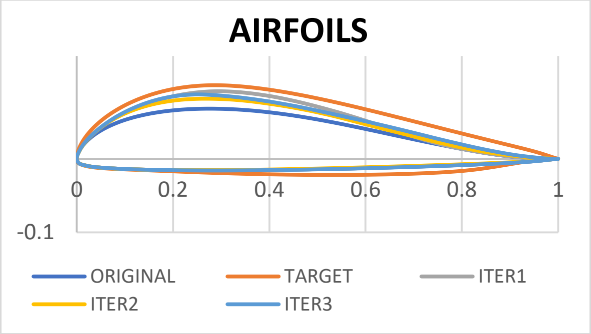

Fig-20: Airfoils.

As seen from the table 4.4, we can infer that the seed airfoil is S5020 and the target airfoil chosen is E334. The reason behind choosing this airfoil as seed is that it has a moderate Lift to Drag ratio of 164.07 with moment coefficient around 0.0059 which is nearly zero. The main reason behind this inverse design is to check whether the inverse design results in such a way that the airfoil reaches the requirements of tailless aircrafts.

5.2.4. CASE-4

SEED AIRFOIL	TARGET AIRFOIL
NACA23010	EPPLER334

Table-7: Comparison of inversely designed NACA 23010 airfoils.

PARAMETERS	ORIGINAL	TARGET	ITER1	ITER2	ITER3
CL	0.6	0.6	0.6	0.6	0.6
CD	0.00464	0.00502	0.00443	0.0044	0.00442
Cm	-0.0135	-0.0436	-0.0197	-0.0172	-0.0087
L/D	129.32	119.46	135.55	136.34	135.71
TRANSITION	0.1313	0.2652	0.2459	0.2341	0.2266
t/c	10	13.5	12.24	11.77	11.73

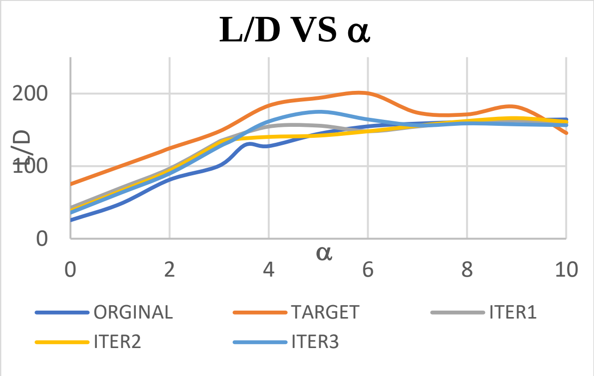

Fig-21: Lift to Drag ratio Vs Angle of attack

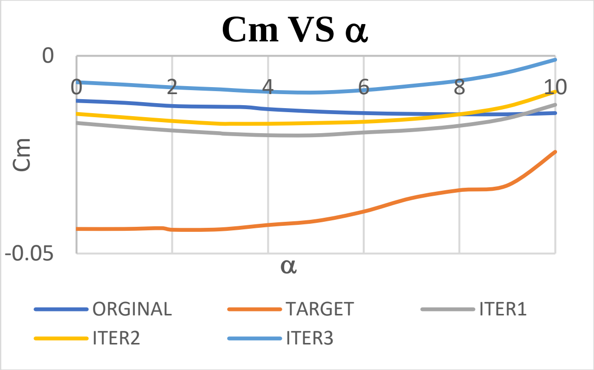

Fig-22: Pitching Moment Vs Angle of attack

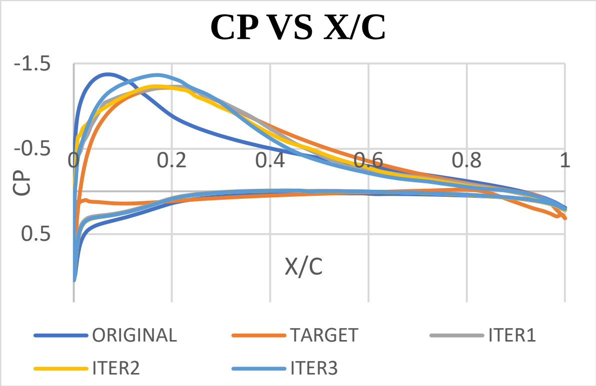

Fig-23: Coefficient of pressure Vs X/C.

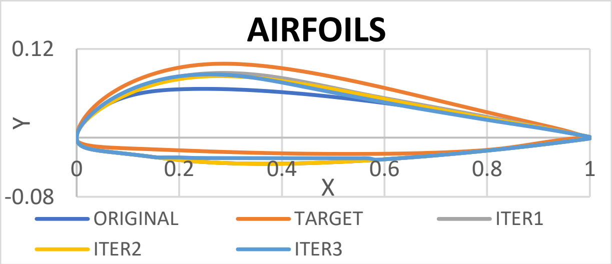

Fig-24: Airfoils.

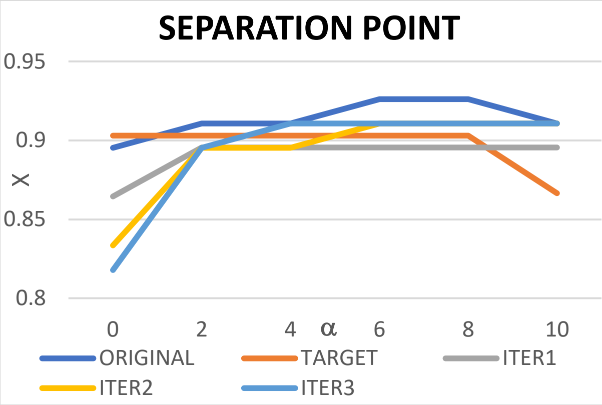

Fig-25: Separation Point

As seen from the table 4.5, we can infer that the seed airfoil is NACA 23010 and the target airfoil chosen is E334. The reason behind choosing this airfoil as seed is that it has a moderate Lift to Drag ratio of 129.32 with moment coefficient around -0.0135 which is nearly good. The main reason behind this inverse design is to check whether the inverse design results in such a way that the airfoil characteristics such as L/D ratio, moment coefficient to reach the requirements of tailless aircrafts.

As observed from the Fig-25 we can infer that separation point for the original airfoil is near 0.9 as sequence of angle of attack between 0 to 10. After inverse design the separation point for inversely designed airfoils comparatively improved to the target airfoil. This point is very much efficient for the boundary layer studies. Hence, improving it would be a better study of tailless aircrafts airfoils.

5.3. OPTIMIZATION RESULTS

In this section the airfoils obtained from the optimization and the performance of these airfoils computed using the XFOIL will be presented. The first strategy for optimization was set so as to find the influences of using specific goals, constraints and weightings in section below. The Second strategy resulted in a final airfoil. These strategies and final airfoil will be presented.

Table-8: Comparison of the three airfoils

PARAMETERS	ORIGINAL	OPTIMIZED
CL	1.0488	1.0488
CD	0.00622	0.00588
Cm	-0.0099	-0.0076
L/D	168.61	178.3673
TRANSITION	0.0373	0.048
T/C	10	10.19

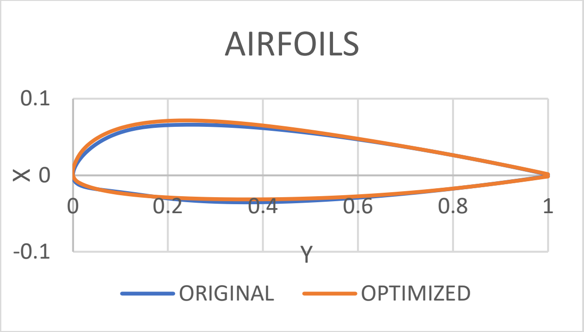

Fig-26: Airfoils

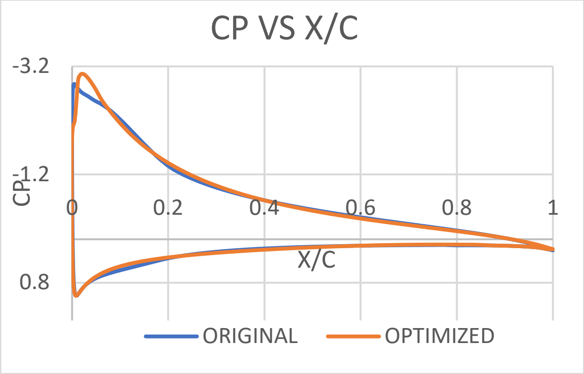

Fig-27: Coefficient of pressure Vs X/C.

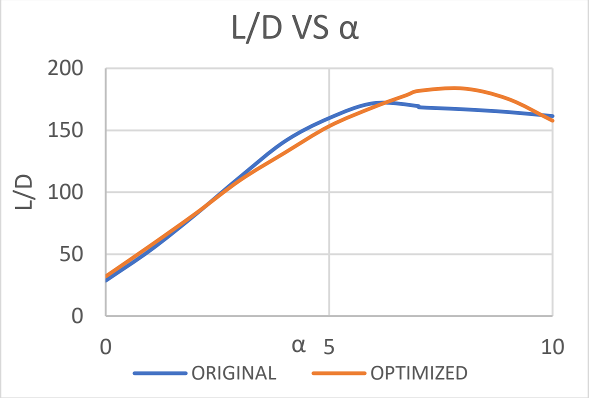

Fig-28: Lift to Drag ratio Vs Angle of attack

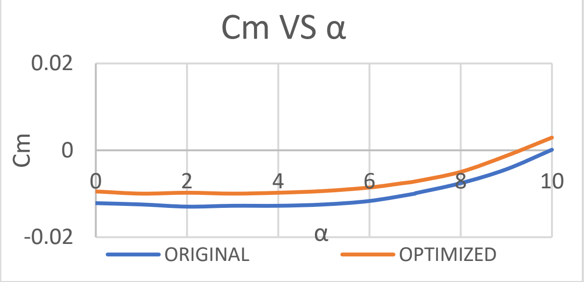

Fig-29: Pitching Moment Vs Angle of attack

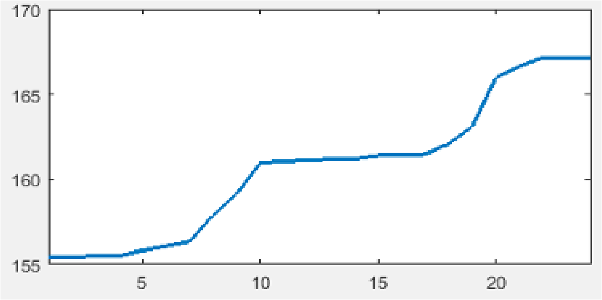

Fig-30:L/D VS Number of Iterations.

As seen from Fig-30, we can infer that as there is significant increase in the number of iterations L/D of the optimized airfoil increases gradually.

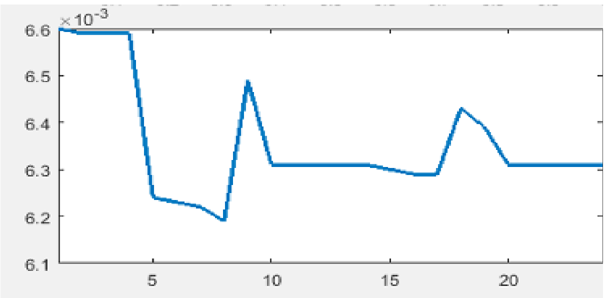

Fig-31: Drag Coefficient (Cd) VS Number of Iterations.

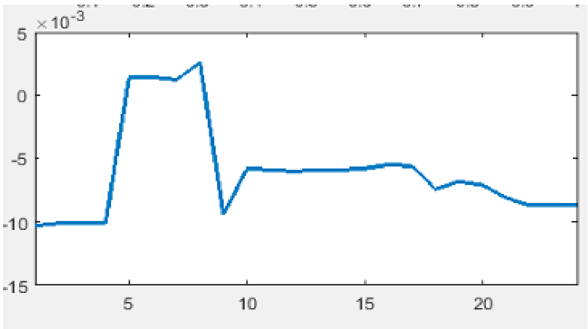

Fig-32: Moment Coefficient (Cd) VS Number of Iterations.

From Fig-31 and Fig-32, it is inferred that moment and drag coefficient are optimized.

5.4. COMPARISON OF INVERSE AND OPTIMIZED AIRFOIL

Table-9: Comparison of inverse and optimized NACA23010 airfoil

PARAMETERS	INVERSE	OPTIMIZED
CL	1.0488	1.0488
CD	0.00528	0.00588
Cm	-0.0096	-0.0076
L/D	198.69	178.3673
TRANSITION	0.0397	0.048
T/C	11.58	10.19

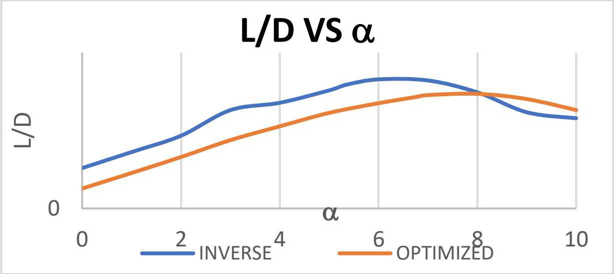

Fig-33: Lift to Drag ratio Vs Angle of attack

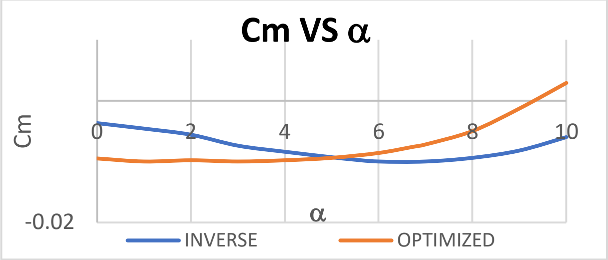

Fig-34: Pitching Moment Vs Angle of attack

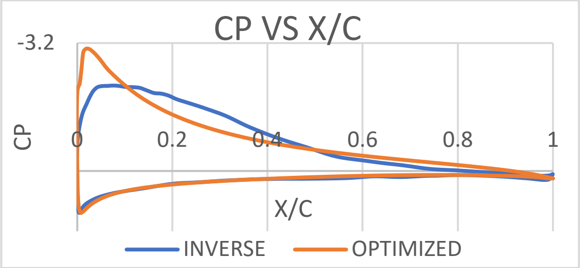

Fig-35: Coefficient of pressure Vs X/C.

As seen from Fig-34 we can infer that the moment is reaching the requirement of tailless aircrafts in case of both inverse and optimized. The Moment of the optimized airfoil is much stable and meets the longitudinal stability criterion.

VI. CONCLUSION

This paper focused on optimizing airfoils for Tailless aircraft applications and designing an efficient optimized airfoil. Recalling the research goals:

- To design an airfoil shape or family of shapes that is suitable for Tailless aircrafts. This will give a general idea on how airfoil for this application should look and what characteristics are advised.
- Inverse designing in this project report explains that the airfoils used on tailless aircrafts needed to meet the requirements that are very important. The literature explains the different types of inverse designing methods out of which the chosen method in the project report is matching the requirements of the tailless aircrafts. Thickness of near 12% is achieved and the required L/D is achieved. The moment

coefficient is nearly zero and it suits the stability criterion.

- The optimization strategy discussed in this project report demonstrates that airfoils can be designed with aerodynamic performance in both clean conditions similar to its predecessors like the NACA 23010. More importantly, the performance of the optimized airfoils is significantly higher.

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