AE705 INTRODUCTION TO FLIGHT ASSIGNMENT-02

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This report deals with modifying the 'geometry of a baseline airfoil (LRN 1015)in five stages to obtain the best Airfoil Score, subject to a set of specified constraints, which can further improve HALE UAV endurance at 190m/s at 55000ft altitude and provide better aerodynamic efficiency. The analysis of the airfoil is performed using XFLR5 software with Direct Foil Design and XFOIL Direct Analysis modules. Data points of the original Airfoil NASA LRN 1015 were downloaded from airfoiltools.com as a .dat file and plotted in the Direct Foil Design Module.

I. Introduction

An airfoil is a cross-section of the wing that generates lift due to the curvature in the streamlines. There are different kinds of airfoils. One of them is the low Reynolds number of airfoils. The LRN 1015 airfoil features a fairly thick, cambered profile and is used in such long-endurance aircraft.
High Altitude Long Endurance (HALE) Unmanned Aerial Vehicles (UAV) have the ability to gather reconnaissance data over large areas over periods of 24+ hours. They require a high aspect-ratio swept wing, with the airfoil optimized for efficient long-endurance flight. The airfoil should also achieve good stability and minimum drag at the low Reynolds numbers occurring at high altitudes.

II. Parameters and Constraints

A. Parameters

Sr.no	Parameter	Values
1	Weight @ Cruise	12,100 kg
2	Cruise Speed	190 m/s
3	Cruise Altitude	55000 ft
4	Wing reference area	50 m^2
5	chord length	1.58m
6	Air density	0.14664 kg/m^3
7	sonic speed	295.07m/s
8	viscosity μ	1.432*10^{-5} Pa.s

$$Reynolds\ \ number = \frac{\rho LV}{\mu} = \frac{0.14664 * 1.58 * 190}{1.432 * 10^{-5}} = 3.0741 * 10^6 \tag{1}$$

$$Mach\ \ number = \frac{Velocity}{sonicspeed} = \frac{190}{295.07} = 0.644 \tag{2}$$

$$C_{L_{wing@cruise}} = \frac{2W}{\rho V^2 S} = \frac{2 * 12100 * 9.81}{0.14664 * 190^2 * 50} = 0.8969 \tag{3}$$

$$C_{l_{airfoil@cruise}} = \frac{100}{90} C_{L_{wing@cruise}} = 0.9966 \tag{4}$$

$$Airfoil \;\; score = \frac{\frac{C_l}{C_d}|_{max}}{C_{m_{@2^\circ}}} \tag{5}$$

B. constraints

- $\frac{C_l}{C_d}|_{max}$ should occur at a Lift Coefficient corresponding to level flight cruise (L = W).
- Angle of Attack at which $\frac{C_l}{C_d}|_{max}$ should occur should be $\leq$ 5 degree
- $10\% \leq t/c \leq 25\%$
- Location of maximum camberis 20 to 40%
- Camber between -10 to 10%of chord
- Location of maximum camber: 20 to 40 %
- External high-lift devices like Flaps or Slats are not permitted

III. iterations

A. Base Airfoil

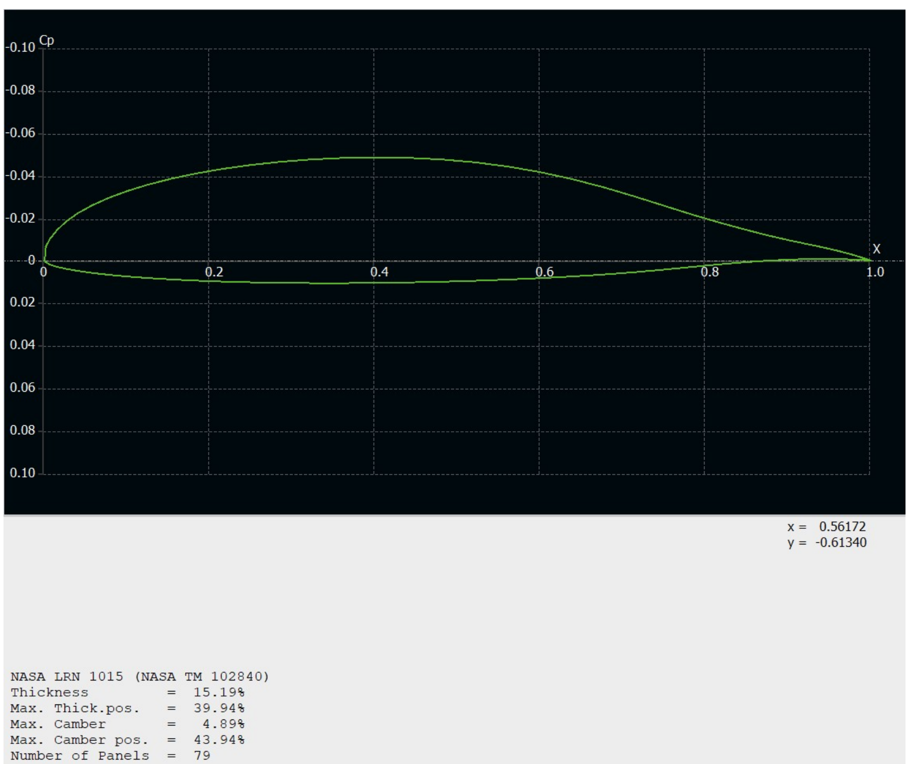

Figure 1. base airfoil LRN1015

Trip location	0.5
Angle of attack	$-3°$ to $10°$
Angle of attack increment	$0.5°$

Table 1. Inputs for the base airfoil

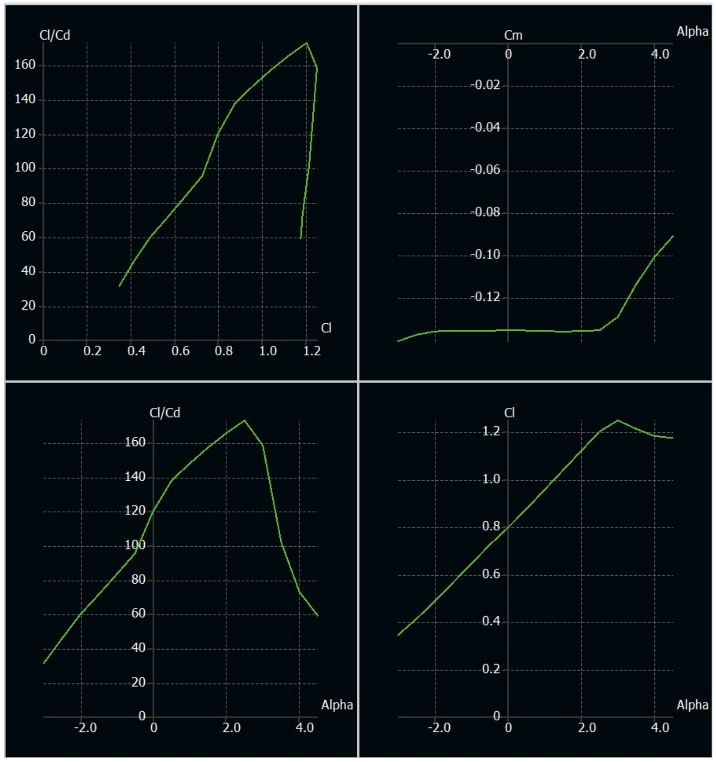

Figure 2. Graphs of base airfoil LRN1015

$\frac{C_l}{C_d}\|_{max}$ @ $C_{l_{airfoil@cruise}}$	157.198
C_m @ $2°$ AOA	-0.135
Score	**1164.42**

Table 2. Analysed results of base airfoil

B. iteration-1

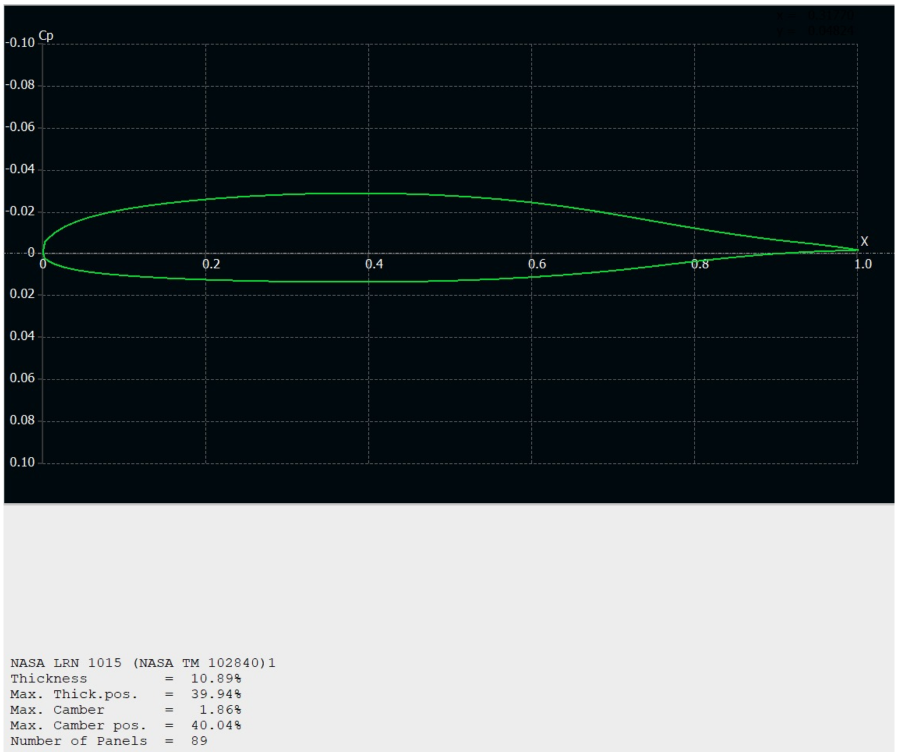

Figure 3. Iteration-1

- Location of max camber is shifted below 40% of the chord
- The leading edge of the original airfoil is smoothened to reduce drag.

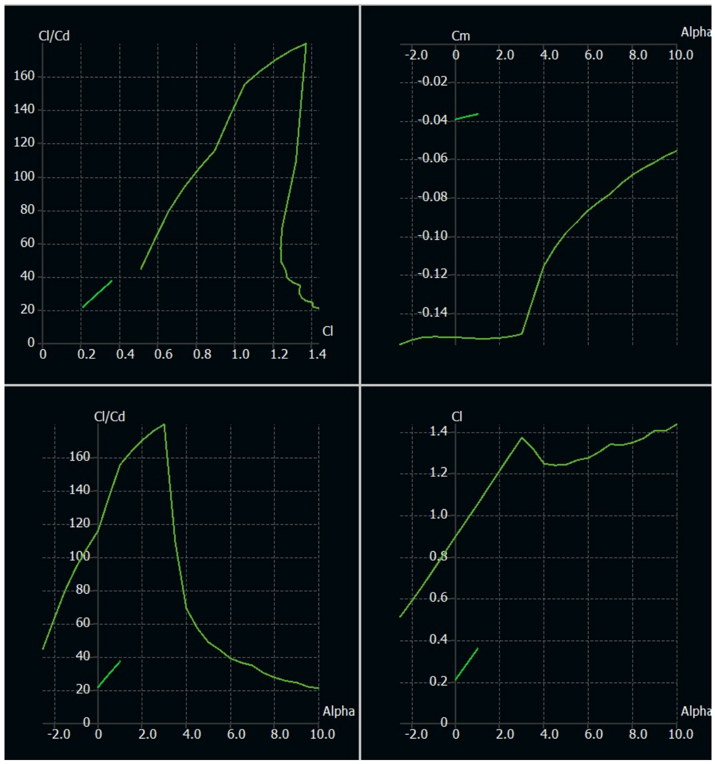

Figure 4. Graphs of Iteration-1

$\frac{C_l}{C_d}\vert_{max}$ @ $C_{l_{airfoil@cruise}}$	109.12
C_m @ 2° AOA	-0.108
Score	**1011**

Table 3. Analysed results of iteration-1

C. iteration-2

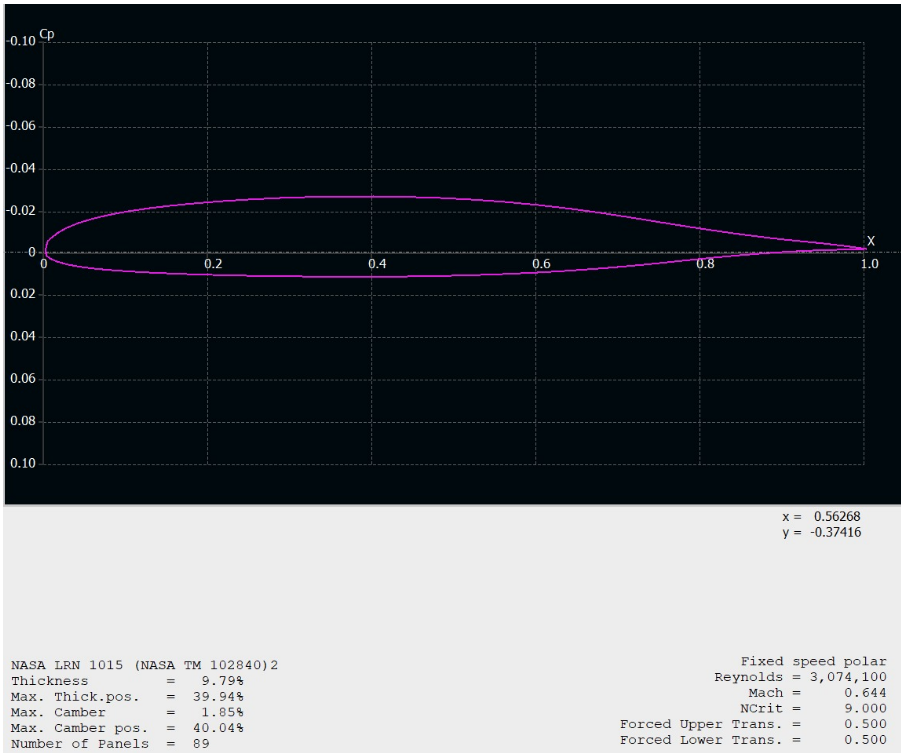

Figure 5. Iteration-2

- Reduction of score in iteration indicates the requirement to increase $\frac{C_l}{C_d}|_{max}$. and decrease the C_m
- $\frac{C_l}{C_d}$ max is increased by reducing the camber 1.85%
- slight adjustments to other parameters to ensure a smooth shape to maintain a smooth favourable pressure gradient.

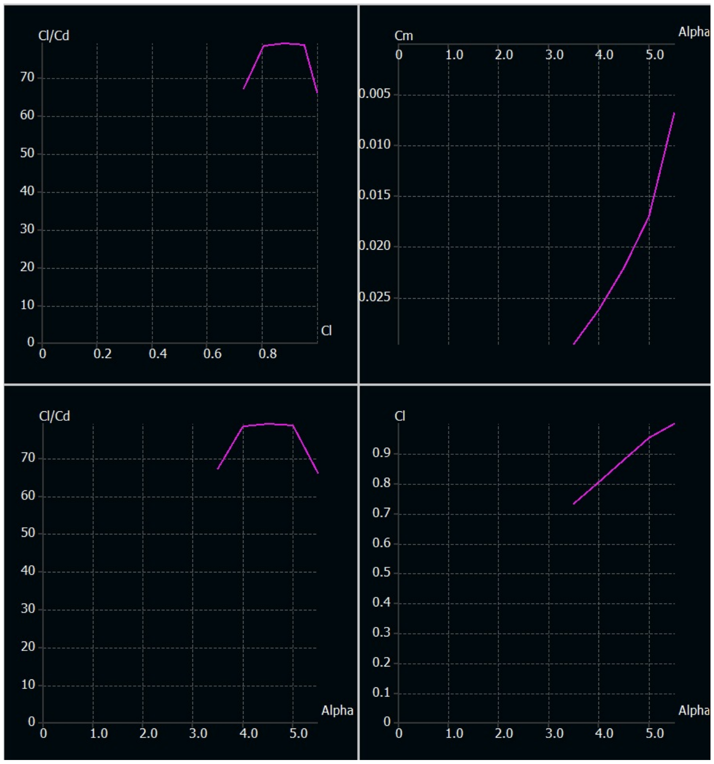

Figure 6. Graphs of Iteration-2

$\frac{C_l}{C_d}$ max @ $C_{l_{airfoil@cruise}}$ C_m @ 2° AOA	66.36 -
Score	**-**

Table 4. Analysed results of iteration-2

D. iteration-3

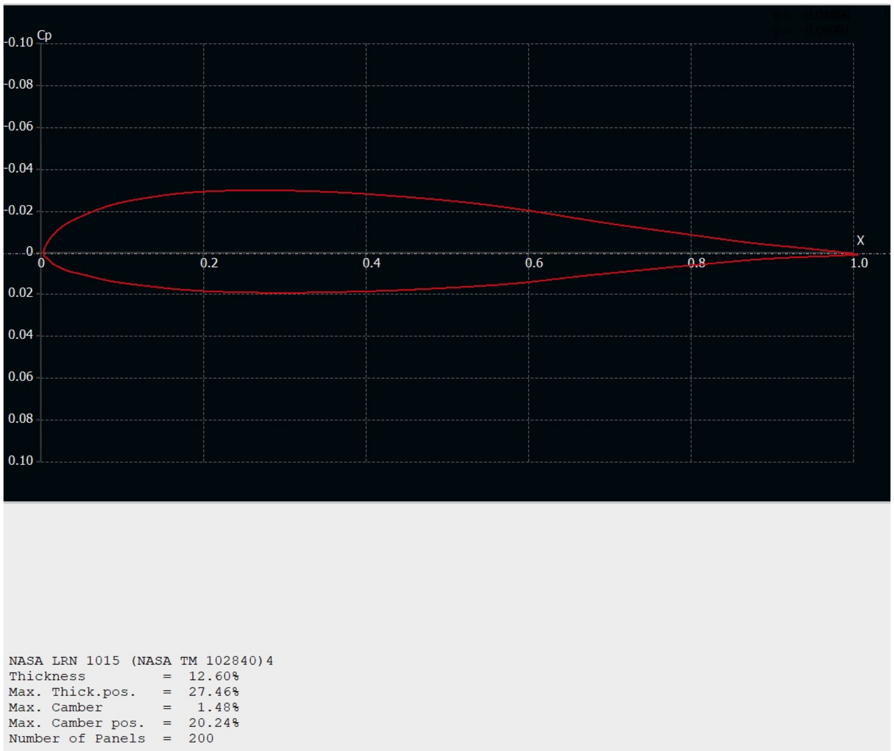

Figure 7. Iteration-3

- camber is further reduced to 1.56% of the chord to verify improvements in $\frac{C_l}{C_d}$ and Cm values.
- There is a trade-off of $\frac{C_l}{C_d}|_{max}$. However, C_m has improved drastically.
- The airfoil is also given a gradual curvature throughout its chord length to maintain a smooth pressure gradient.

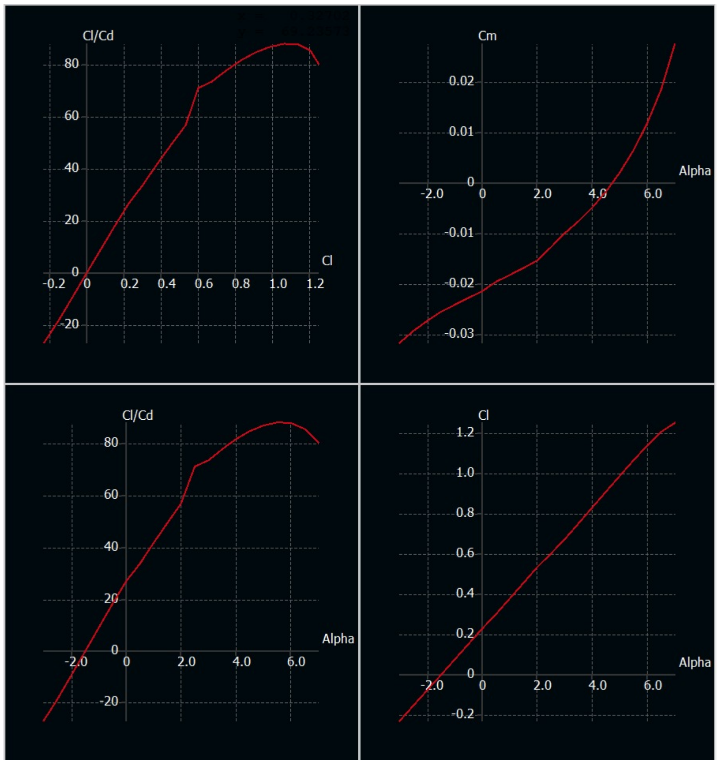

Figure 8. Graphs of Iteration-3

$\frac{C_l}{C_d}\|_{max}$ @ $C_{l_{airfoil@cruise}}$	90.236
C_m @ 2° AOA	-0.016
Score	**5639.75**

Table 5. Analysed results of iteration-3

E. iteration-4

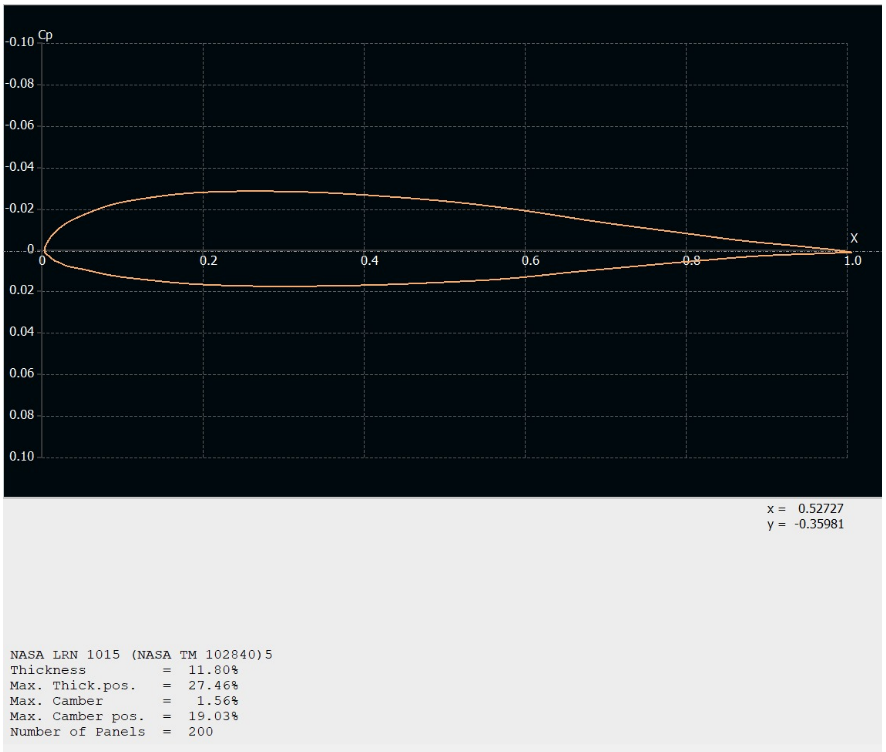

Figure 9. Iteration-4

- To reduce the values of Cm, The airfoil is slightly refined by adjusting the camber to 1.48%
- the position of max camber shifted to 20.24%.

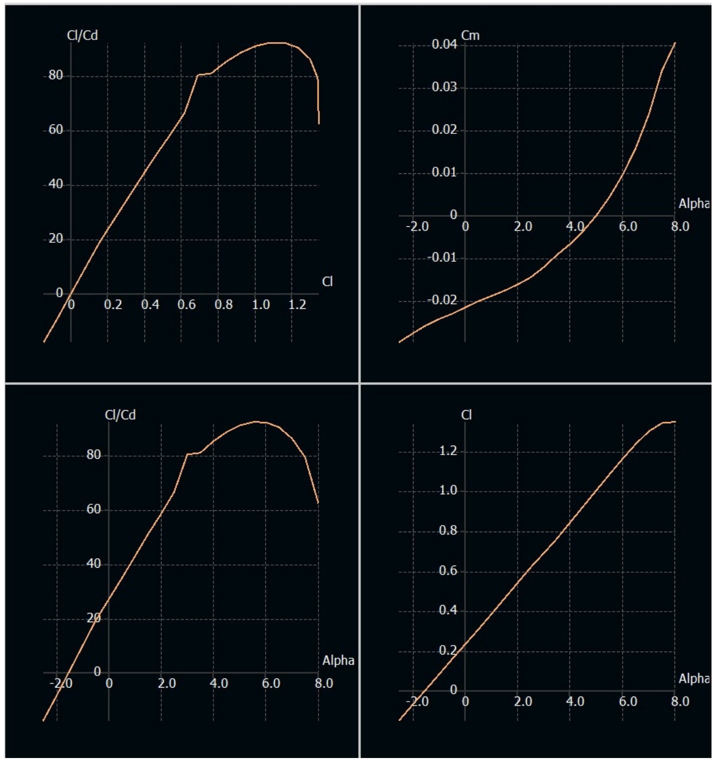

Figure 10. Graphs of Iteration-4

$\frac{C_l}{C_d}\|_{max}$ @ $C_{l_{airfoil@cruise}}$	87.236
C_m @ 2° AOA	-0.015
Score	**5815**

Table 6. Analysed results of iteration-4

F. iteration-5

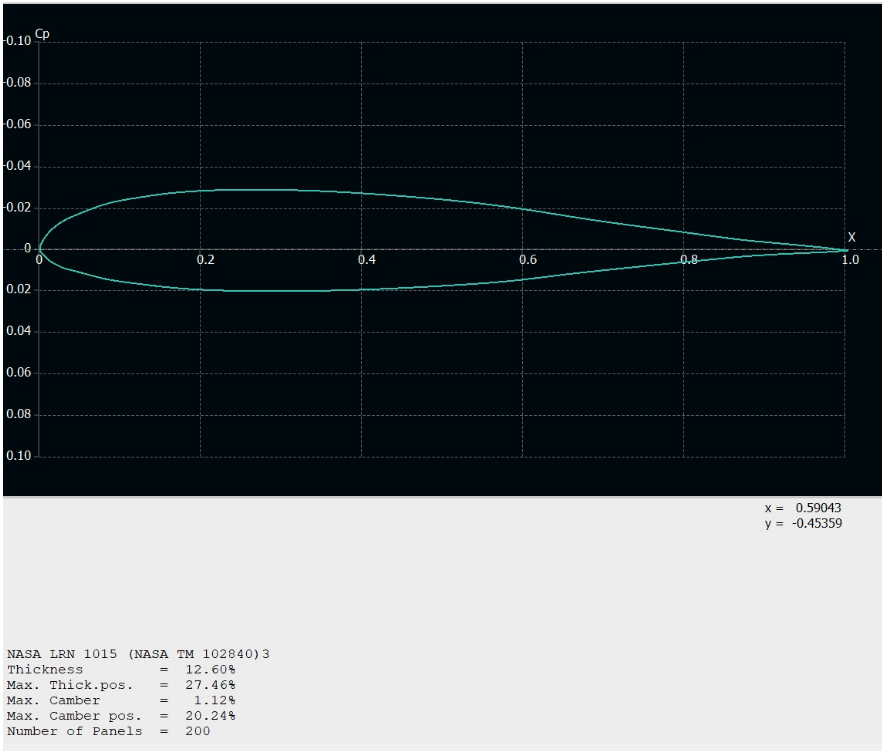

Figure 11. Iteration-5: Best air foil

- The airfoil is slightly refined to improve the values of Cm.
- The camber is adjusted to 1.12%. From the analysis of the output obtained, we see that $\frac{C_l}{C_d}|_{max}$ @ Cl = 0.9968 = 85.236, Cm@ 2 deg = -0.009 (values obtained from data plot). Airfoil Score = 9470.

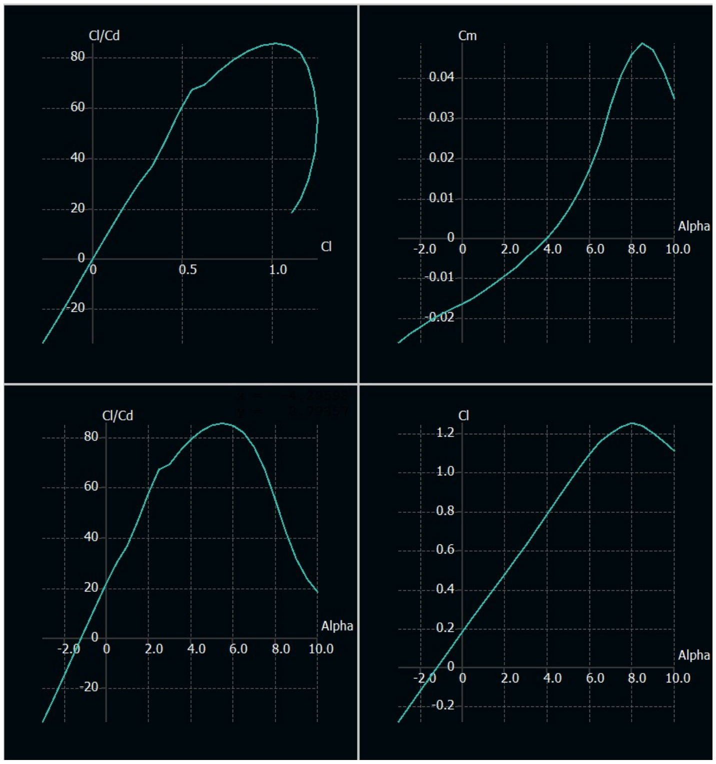

Figure 12. Graphs of Iteration-5

$\frac{C_l}{C_d}$ max @ $Cl_{airfoil@cruise}$	85.2366
C_m @ 2° AOA	-0.009
Score	**9470**

Table 7. Analysed results of iteration-5

IV. Conclusions

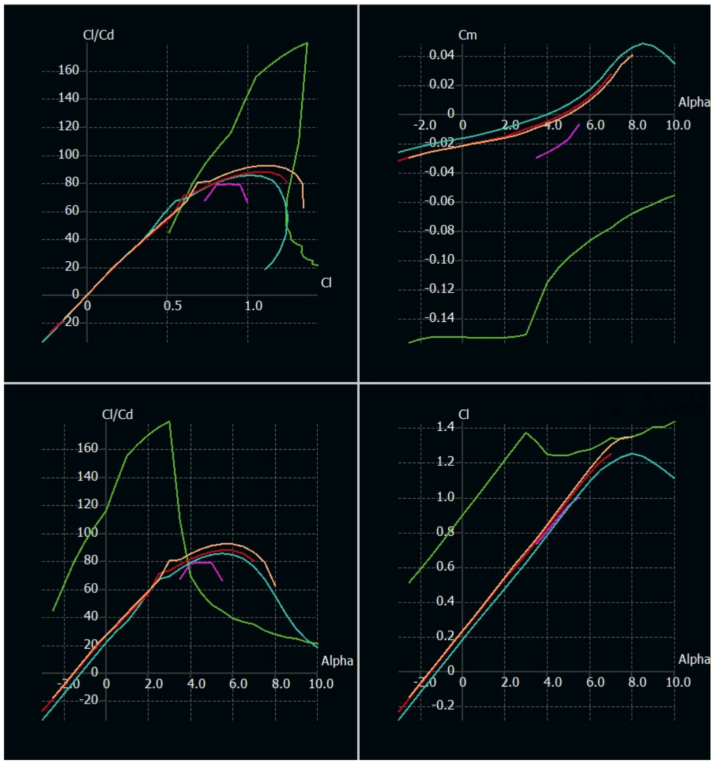

Figure 13. Graphs of all the iterations

The airfoil obtained in Iteration 5 is the most optimized airfoil for given point performance requirement under the given constraints and aircraft operating conditions, with an **Airfoil score of 9470**.