AER325 Aerodynamic Design Project Report

Reg No. 190135223

1. Project brief and aim:

To understand the effect of air foil design (specifically- aspect ratio and air foil section) on aircraft performance. The project requires selection of aspect ratio, air foil section (NACA 4-digit profile with maximum camber at 40%c) for a rectangular wing while analysing the effects of these values on aerodynamics.

2. Aspect Ratio Choice:

Aspect ratio from 1 to 15 was considered and plotted against respective varying Reynolds number and induced drag coefficient. For a rectangular wing:

AR = b/ c -i

S= b x c -ii

From i and ii c= (S/AR) $^{(1/2)}$ -iii

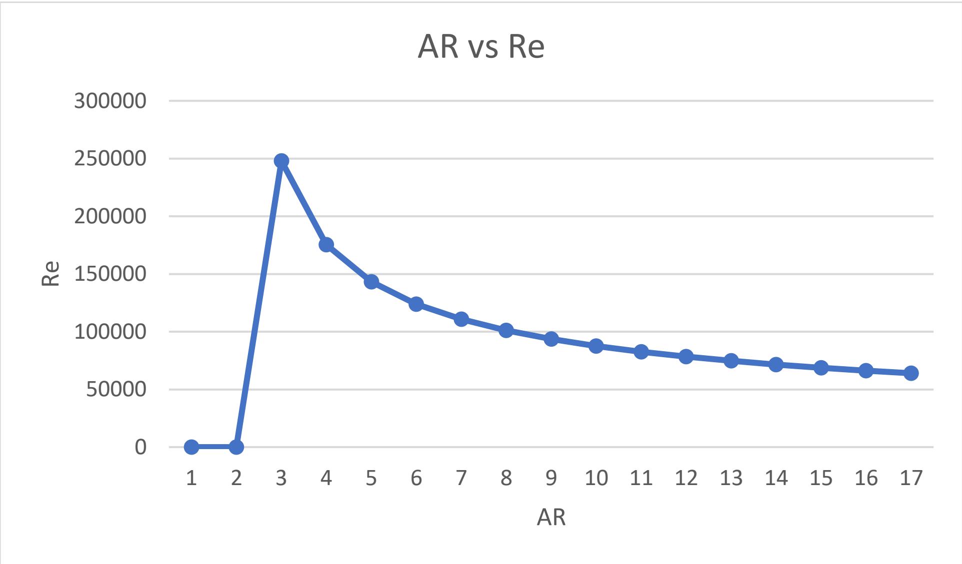
Re= (V*c)/kinematic viscosity -iv

CDi= CL^2/(pi*e*AR) -v

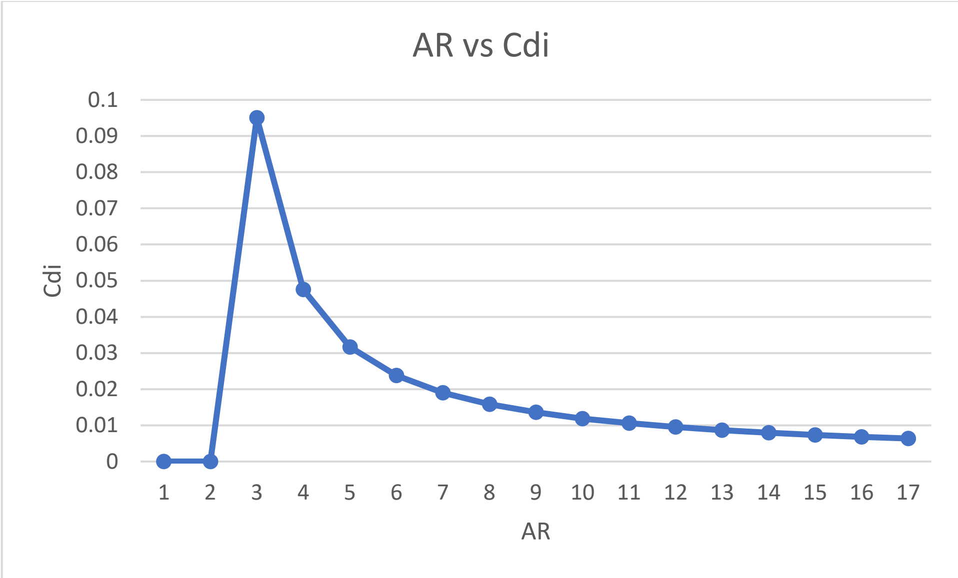
CL= L/(0.5*rho*V^2*S) -vi

CL= 0.9*cl -vii

From equations vi and vii, CL= 0.5185 and cl= 0.576 and from equations i to v, a range of values were obtained for Re and CDi for varying AR. The graph obtained from the calculations are presented in the following graph 1 and graph 2.



Graph 1: Curve representation between aspect ratio and corresponding Reynolds number.



Graph 2: Curve representation between the aspect ratio and induced drag coefficient.

Reynolds number below 10^5 shows significant reduction in the lift to drag ratio as well as maximum coefficient of lift. Due to this reason, any AR (from 8.5 onwards) below Re 10^5 as seen in graph 1 was not considered for the analysis.

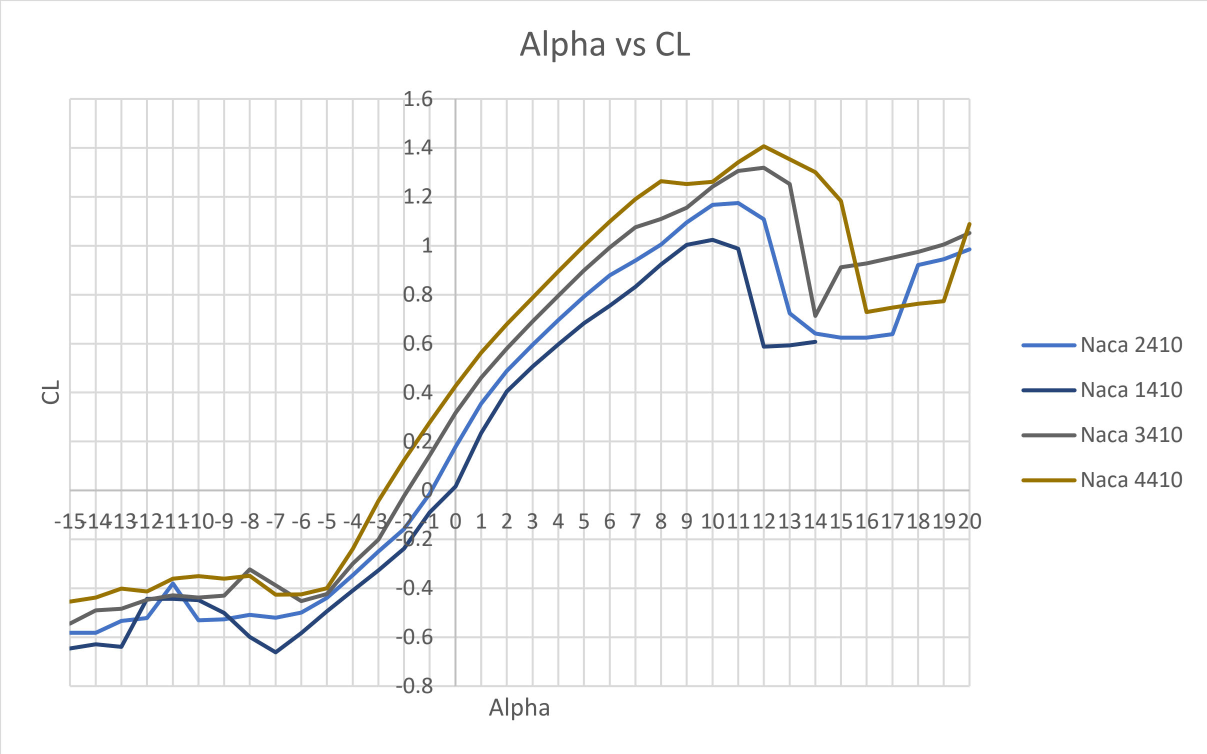
Similarly for efficiency, the darg must be kept to minimum as much as possible. As seen on graph 2, CDi is high for AR of 3 & 4 compared to the CDi values for AR between to 8. This brings to selection of AR between 5 to 8. For the purpose of this project, I selected AR of 6 as Re is above 10^5 and CDi is at a reasonable point. At AR= 6 (c= 0.1472), the CDi= 0.01584, Re= 101197.

High aspect ratio will provide high lift but high induced drag, less manoeuvrability, and more bending moment on the wing. Low aspect ratio will give better manoeuvrability but lesser lift compared to a high aspect ratio wing and lesser drag.

3. Aerofoil selection:

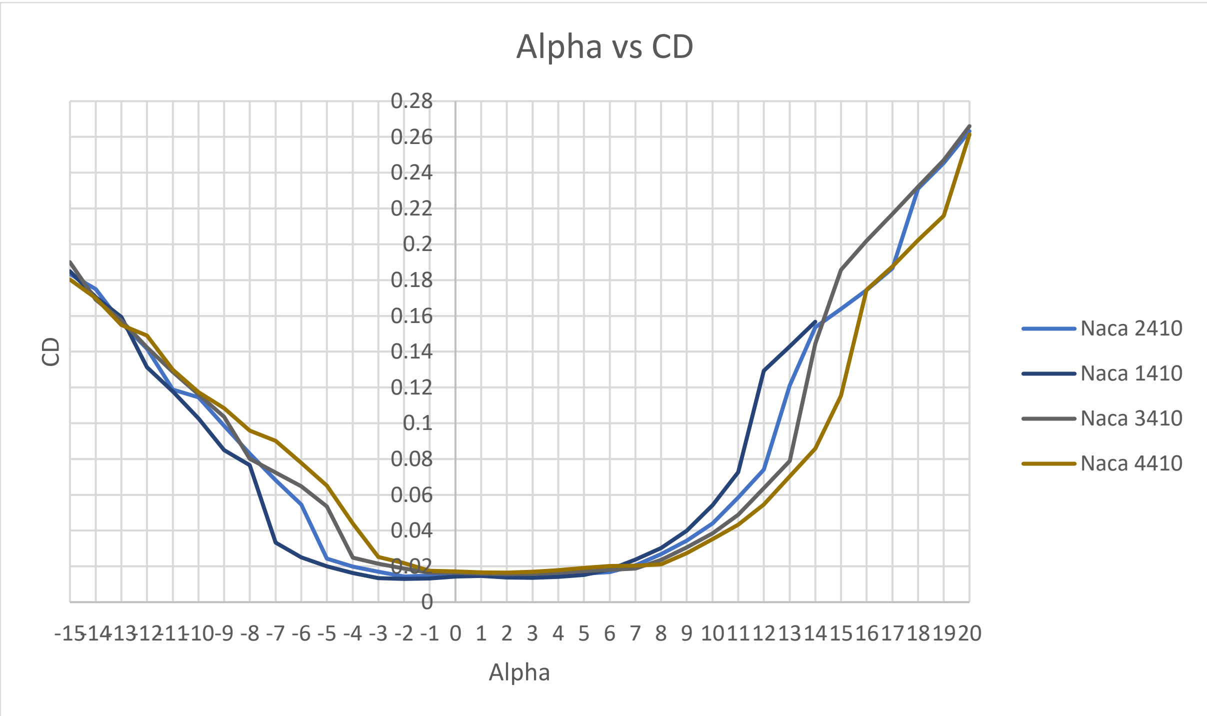
The aerofoil was selected after comparison of various thickness, series, and the boundary layer plot as well. I selected NACA 2410.

First, I tested with thickness (last two digits of the NACA 4 series code) ranging from 10% to 15%. Low thickness (below 9%) would have negative impact on the structure and the same applies for high thickness unless required. From analysis of thickness, 10% to 12% showed increase in lift and lesser drag compared to thickness between 13% to 15% which showed increase in lift but increase in drag as well. Hence, I decided to select a thickness of 10% which had less drag and although not higher but similar lift of 11% and 12%. Additionally, at cl of around 0.576, the cd was the least for 10% with the highest lift to drag ratio. High lift to drag ratio shows better efficiency and range.

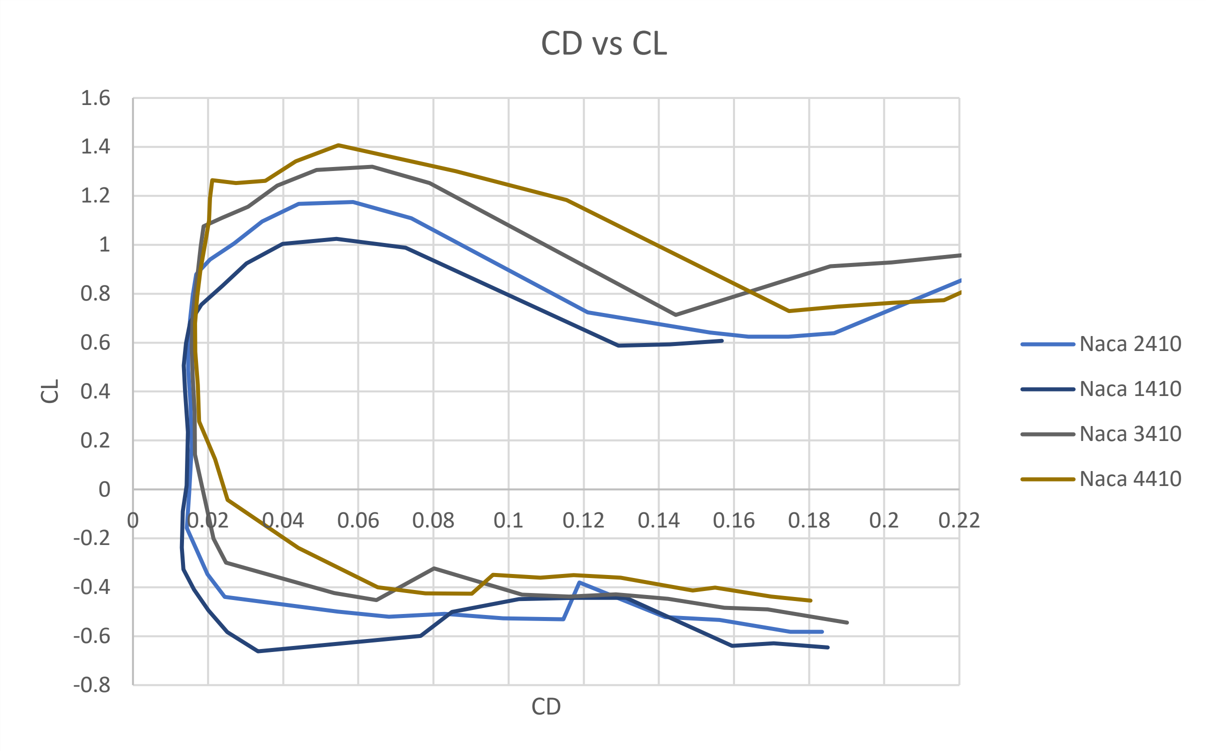


Graph 3: CL versus alpha graph for various NACA aerofoils.

As depicted on graph 3, series 3 and 4 has the highest lift and delayed stalls. Series 3 has a steep stall slope and 4 shows instability or reduce and then increase in the lift without a constant gradual increase. Series 1 and 2 has gradual increase in the lift but series 1 has low lift compared to series 2. Series 1 has less camber which will show low pressure difference and hence low lift.



Graph 4: CD versus alpha graph for various NACA aerofoils.



Graph 5: CL versus CD graph for NACA aerofoils with varying series.

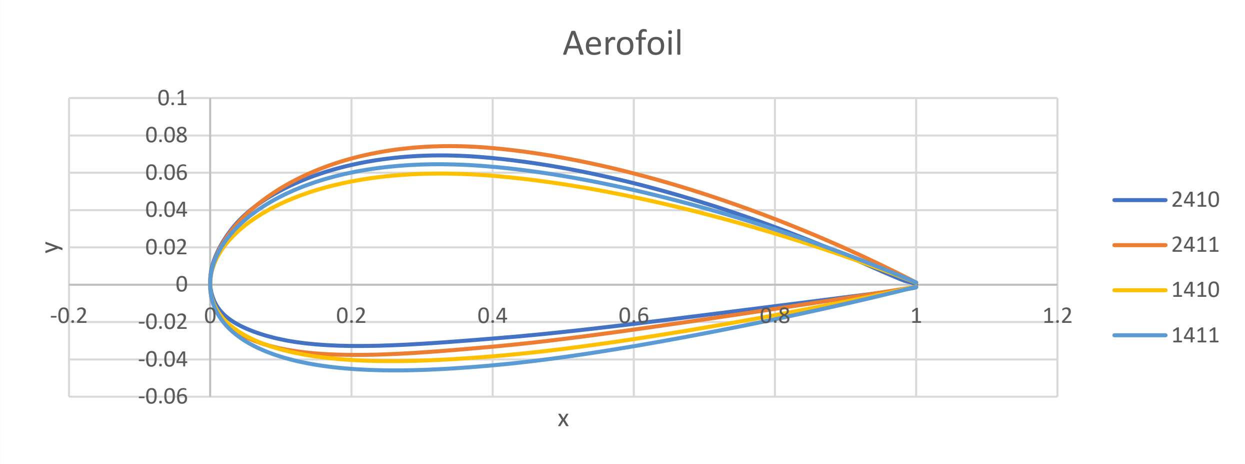
From graph 3, a cl of 0.576 was achieved around an angle of attack of 3 degrees for NACA 2410. While considering this angle of attack on graph 4, the 2 and 1 series has the least drag compared to series 3 and 4 which has bigger drag bucket. Similarly on graph 5, at cl of 0.576, the drag was less for 1 and 2 series with a nominal operating range. These graphs made me select series 2.

On individual comparison of the aerofoils at cl= 0.576, the results from table 1 were found. This was used for a quick comparison where the cd is least for 1410 and 2410.

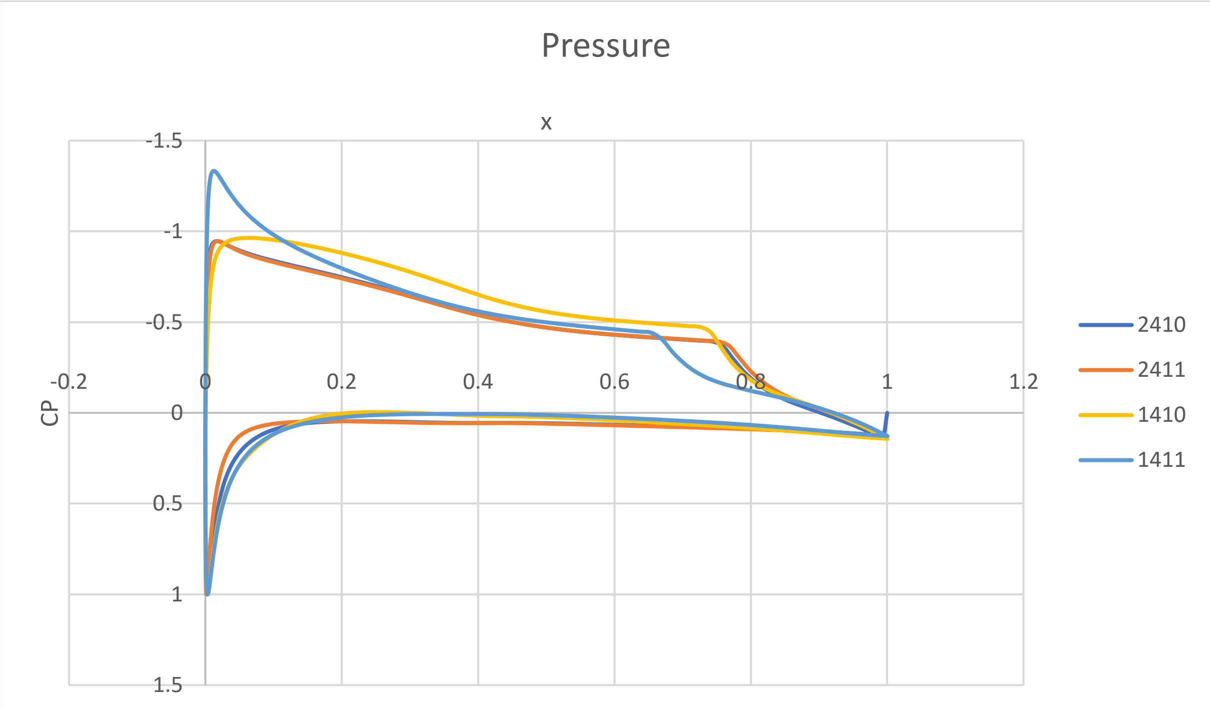
NACA SERIES	cd	Angle of attack	l/d
NACA 1410	0.01392	3.7701	41.38
NACA 2410	0.01464	2.8137	39.33
NACA 3410	0.01566	1.9673	36.79
NACA 4410	0.01672	1.1560	34.44

Table 1: Data of cd, angle of attack, and L/D at cl of 0.576 for various NACA series on XFOIL.

From XFOIL, the drag at 0 degree of angle of attack, was lower for 1410 than 2410. The same applied for the skin friction drag of 2410 due to a higher viscosity than 1410. The pressure drag was also lesser for 1410 than 2410.

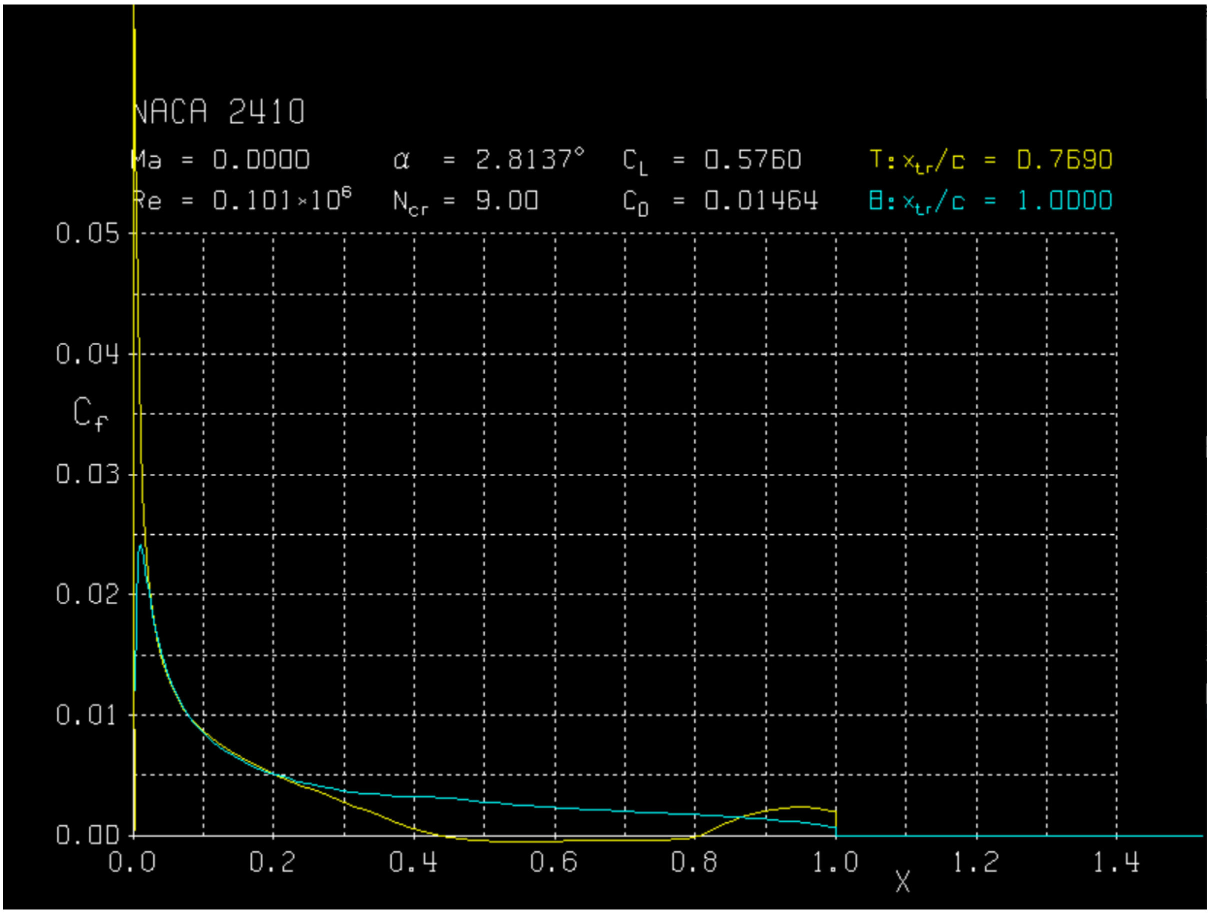


Graph 6: Aerofoil for NACA 2410, 2411, 1410, 1411 to indicate the thickness differences.



Graph 7: Coefficient of pressure graph for NACA 1410, 1411, 2410, 2411 (x ais is the chord).

From graph 7, the plateau towards the end of the flow indicates a separation bubble. There is a disturbance in the laminar flow due to the separation bubble where the flow is detached and then reattached to the surface before it finally faces turbulent flow (due to separation from the wing surface). The dip in the graph after the plateau shows the reattachment of the flow. For NACA 1411, the graph peaks initially and drops quickly to reach the plateau. This would not be efficient as we require a gradual lift difference. Out of the other aerofoils, 2411 and 2410 has the delayed separation bubble and a gradual lift difference which shows more laminar flow than the other aerofoils. Because of which the skin friction drag is lower and hence the overall drag is lower (NACA 2411, 2410).



Graph 8: Skin friction drag plot of NACA 2410

As evident on graph 8, the negative skin friction drag around 4.5 chord is due to the separation bubble when the flow is detached. Skin friction seems to become positive after chord point of 8. This shows the reattachment of the flow and existence of a separation bubble.

Further, on analysis it was found that side 1 had free transition at x/c= 0.6642 as the flow was transitioned from laminar to turbulent and side 2 had a forced transition at x/c= 1.000 indicating the flow stayed laminar for the whole of side 2 until the end where it forced to turbulent flow. The skin friction and pressure drags are high for 2410 than 1410.

4. Effect of aerofoil on thrust:

Given that e= 0.9. CL= 0.5185. The thrust (T)= drag (D) at cruse conditions.

Drag= 0.5*rho*V^2*S*CD -viii

CD (lift of the 3D wing) = cd (drag at zero lift in 2 dimension) + CDi -ix

CDi= CL^2/(pi*e*AR) -x

The cd at zero lift is 0.01502

From equation viii, ix, and x, the CDi= 0.01585, CD= 0.0309, D= 0.2976 N.

When the AR increases, the induced drag decreases. This also decreases the overall drag. Thus, by using a higher aspect ratio, the drag can significantly reduce. Since the drag is equal to thrust at cruise conditions, the decrease in drag, decreases the thrust required for the MAV.

5. Conclusion:

From the analysis above:

a. I selected the NACA 2410 aerofoil- lower drag in comparison to other aerofoils which was the main requirement of this project along with a good lift gradient.
b. Higher the AR, higher the chord and hence higher Re.
c. Higher the camber, higher the viscosity, thus higher the skin friction drag. This increases the overall drag.
d. Higher thickness, higher drag.
e. Higher series gave a higher lift but also a higher drag.
f. Delayed separation bubble provides more laminar flow which is preferred for this project.
g. Higher the aspect ratio, lower the CDi and this reduced the over all drag.
h. CDi increases as CL increases. There is a quadratic dependence.
i. Increase in drag increases the required thrust (here at cruise conditions).

Nomenclature

AR	Aspect ratio= 6
b	Span
c	Chord
S	Wing area= 0.13m^2
Re	Reynolds number= 101200
Kinematic viscosity at 20c	1.6 * 10 $^{-5}$
CDi	Induced drag coefficient
e	Span efficiency factor
pi	3.142
Rho (density at sea level)	1.226kg/ m^3
CL	Coefficient of lift (3D)
cl	Coefficient of lift (2D)
CD	Coefficient of drag (3D)
cd	Coefficient of drag (2D)
l/d	Lift to drag ratio (as shown on XFOIL)
T	Thrust
D	Drag
L	Lift= 5N
W	Weight= 0.51 kg