EGH 423 CFD Assignment 2 - Aerofoil

Student	ID number	Signature	Date	Contribution
Finbar Delbridge	N9717854		15/10/21	50%
Jacob Garcia-Pavy	N10012478		15/10/21	50%

Introduction:

This report will run various 2D and 3D numerical simulations on ANSYS to determine results for a NACA 0012 Aerofoil model with steady and transient turbulent air flow attacking at various angles. The results include calculating drag and lift coefficients, pressure difference, pressure drag force and skin friction drag force. Analysing these answers will not only help to develop a better understanding of the relationship between results such as lift and drag. But will establish the similarities and differences between 2D and 3D simulations and answers questions to real world applications of aerofoils.

Results:

1. Calculating and validating drag and lift coefficient for 2D steady case at $\alpha=0°$:

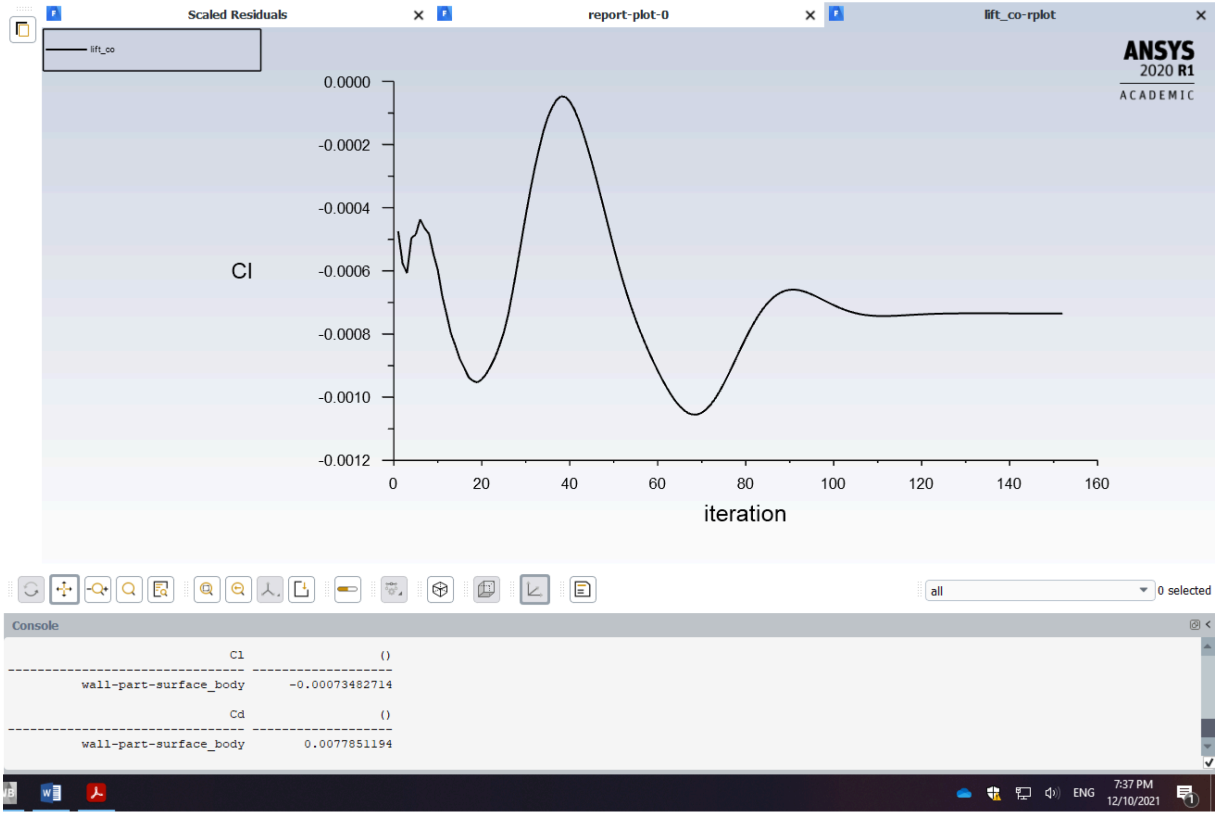

Figure 1: 2D steady state case at 0 degrees.

A) The calculated drag coefficient and lift coefficient are seen in the table 1 below and are validated by the reference values.

	Cd	Cl
Simulated Values	0.0077851194	-0.00073482714
Reference Values	**0.008**	~**0**
Difference	-2.7%	-0.00073482714≈**0**

Table 1: $0°$ simulation drag and lift coefficients .

B) Calculated and tabulated Pressure Difference, Pressure Drag Force and the Skin-Friction (i.e. viscous) Drag Force:

Pressure Difference (PA)	Pressure Drag Force (N)	Skin-Friction (N)
6426	10.472647	26.155567

Table 2: $0°$ simulation values

C) Plot the pressure contour and velocity streamline.

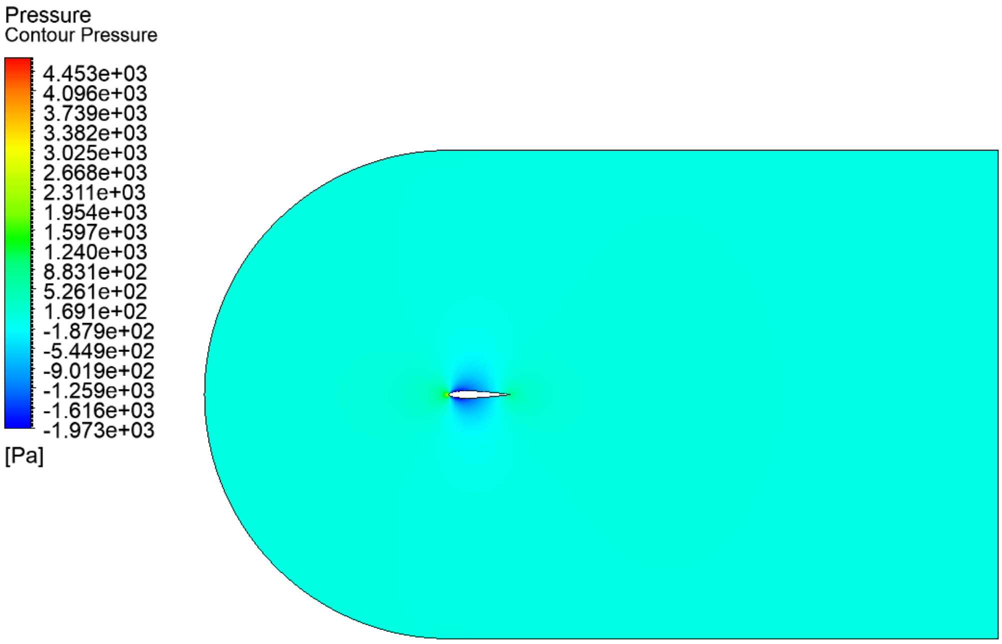

Figure 2: 2D pressure contour for 0 degrees.

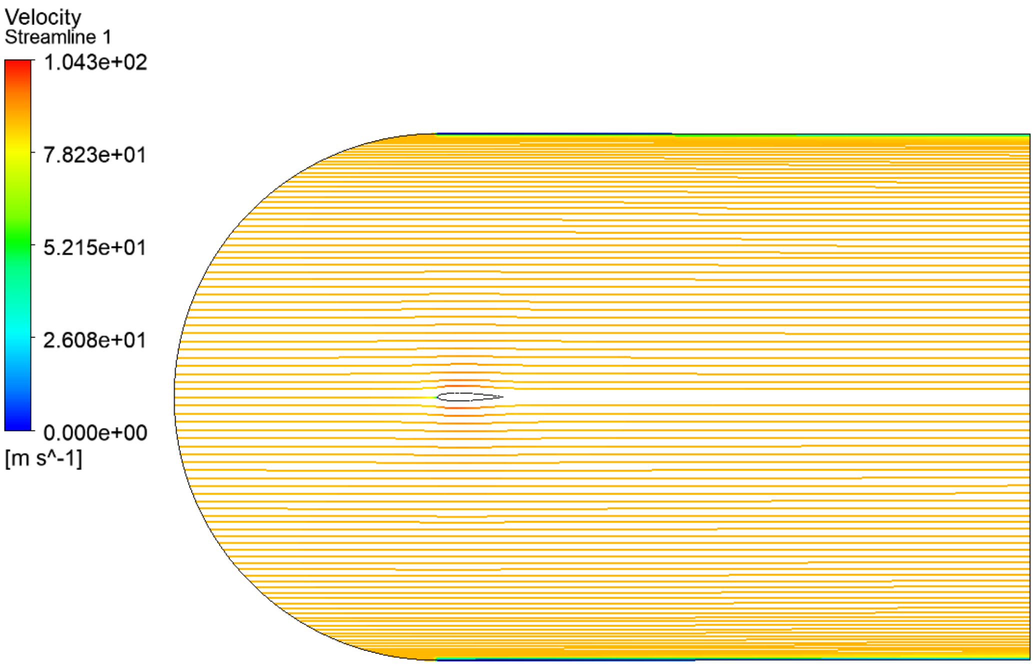

Figure 3: 2D Velocity streamline for 0 degrees

D) Explain why there is no lift being produced based on the results above:

There is no lift being produced when the angle of attack to the aerofoil is in parallel with the Chord line (ie. $\alpha = 0°$). This is because the aerofoil is symmetrical which means the air attacking at 0° has equal forces acting on the top and bottom of the aerofoil (Lift = downwards force = 0).

2. Run 2D steady cases at α=5°,10°, and 15°:

A) Calculate and tabulate the drag coefficient (C_D) and the lift coefficient (C_L) results.

	Cd	Cl
α=5°	0.010710396	0.50150181
α=10°	0.023326831	0.96924212
α=15°	0.0397988	1.3067358

*Table 3: **5°**,**10°**, and **15** drag and lift coefficients.*

B) Calculate and tabulate the Pressure Difference, Pressure Drag Force and the Skin-Friction (i.e. viscous) Drag Force.

	Pressure Difference (PA)	Pressure Drag Force (N)	Skin-Friction (N)
α=5°	12506	25.476397	24.914956
α=10°	26881	88.984831	20.765594
α=15°	45407	168.46407	18.78533

*Table 4: **5°**,**10°**, and **15** values.*

C) Plot the pressure contour and velocity streamline for all cases.

α=5°

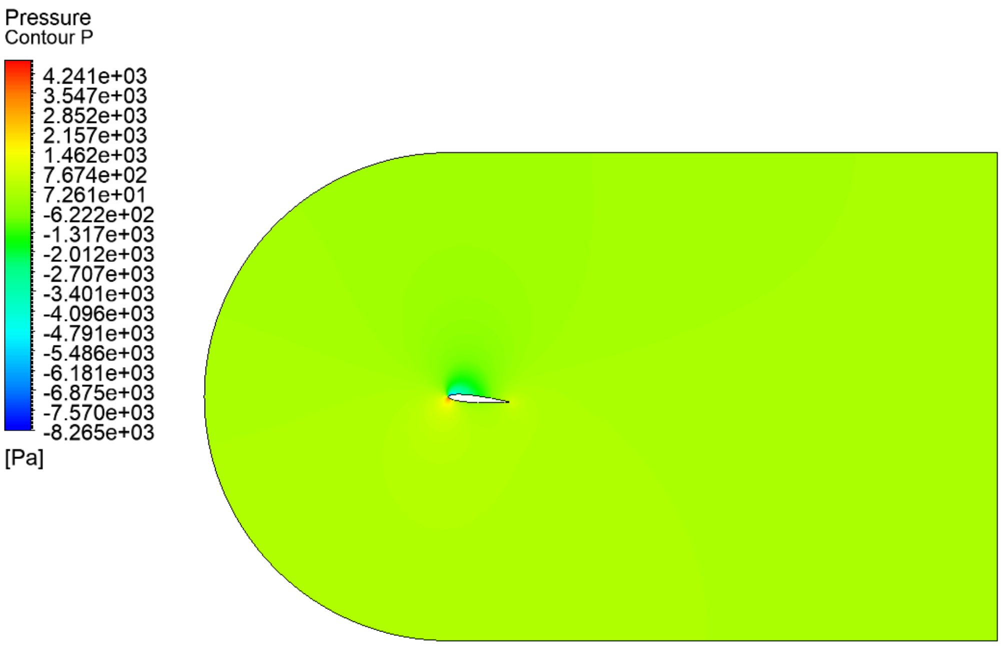

Figure 4: 2D pressure contour for 5 degrees.

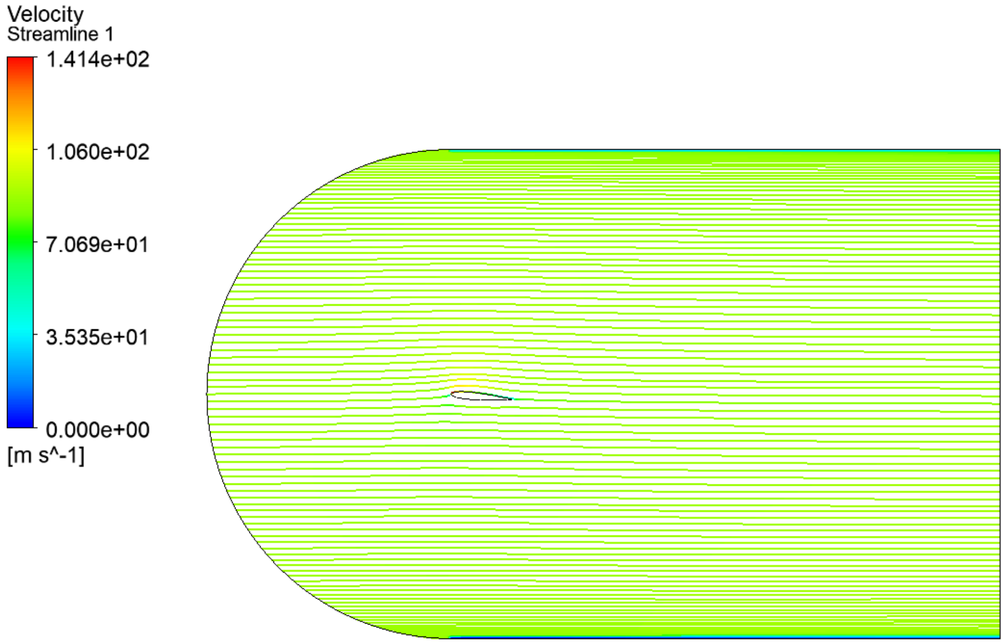

Figure 5: 2D Velocity streamline for 5 degrees.

α=10°

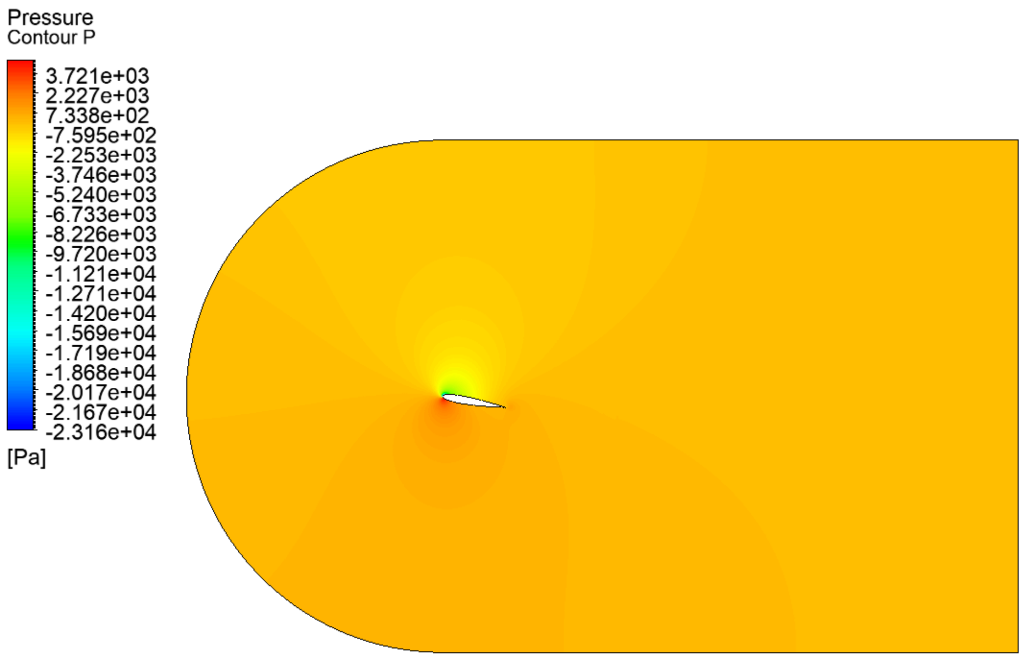

Figure 6: 2D Pressure contour for 10 degrees.

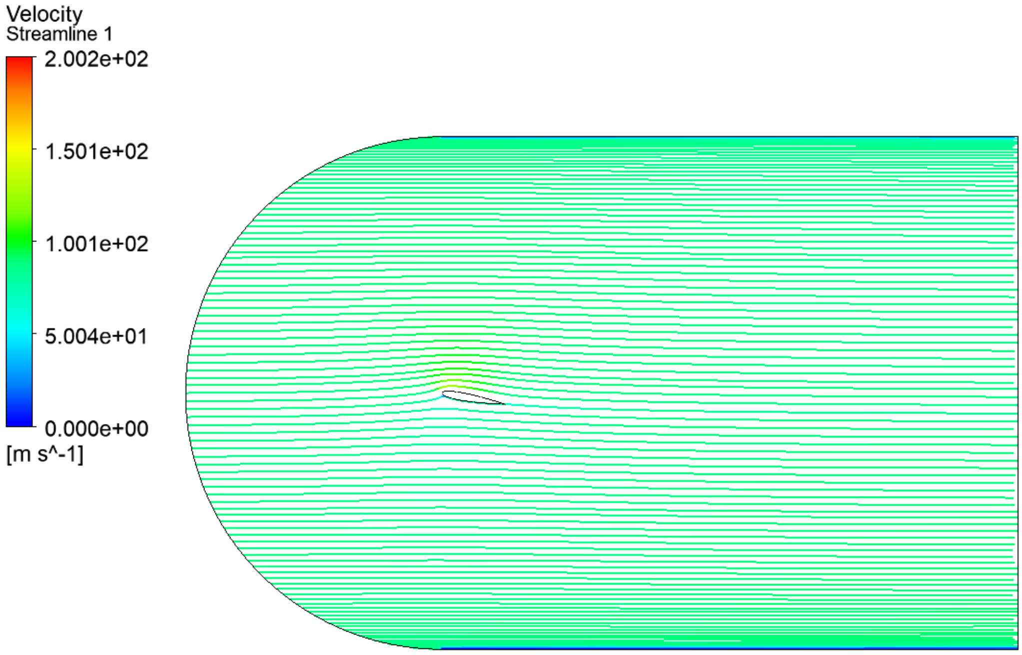

Figure 7: 2D velocity streamline for 10 degrees.

α=15°

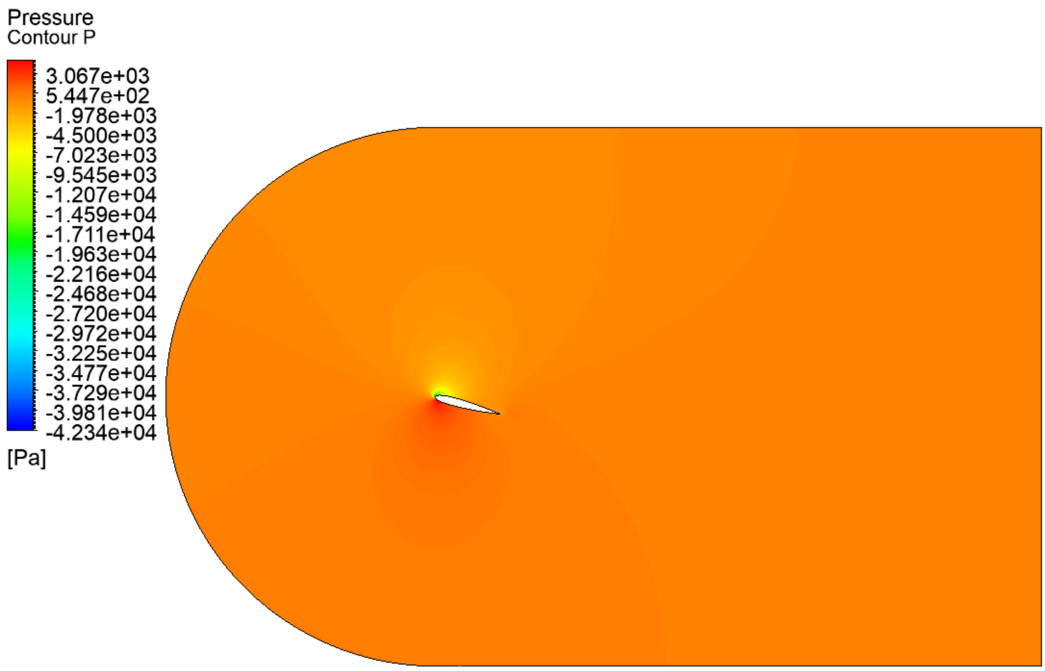

Figure 8: 2D pressure contour for 15 degrees.

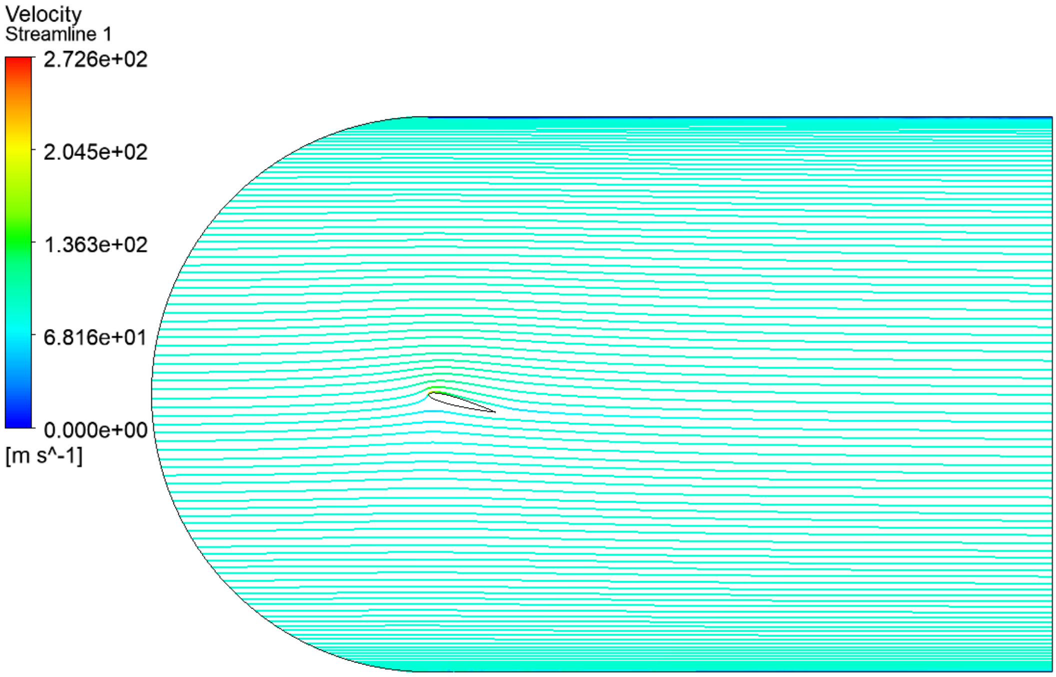

Figure 9: 2D velocity streamline for 15 degrees.

3. Run 2D transient case at $\alpha = 20°$:

A) Calculate and tabulate the average drag coefficient (C_D) and the average lift coefficient (C_L) results.

The average values were calculated from 1.5-2 seconds in excel being steadier.

	Cd	**Cl**
α=20°	0.261489	0.867772

Table 5: **20°** drag and lift coefficients.

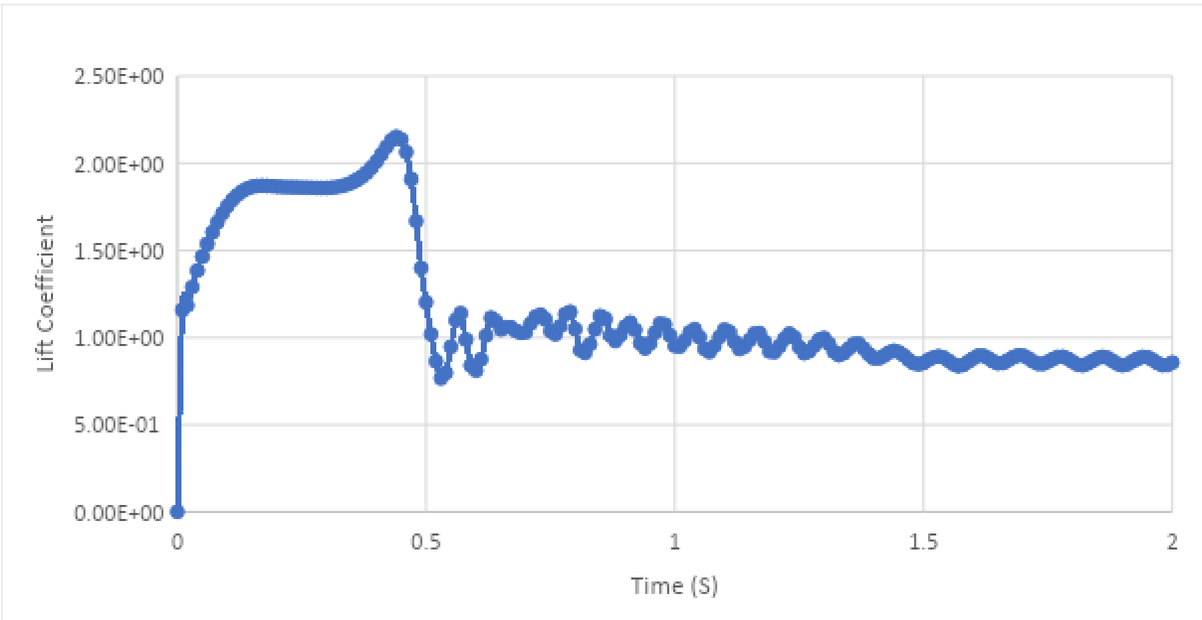

Figure 10: Lift VS Time

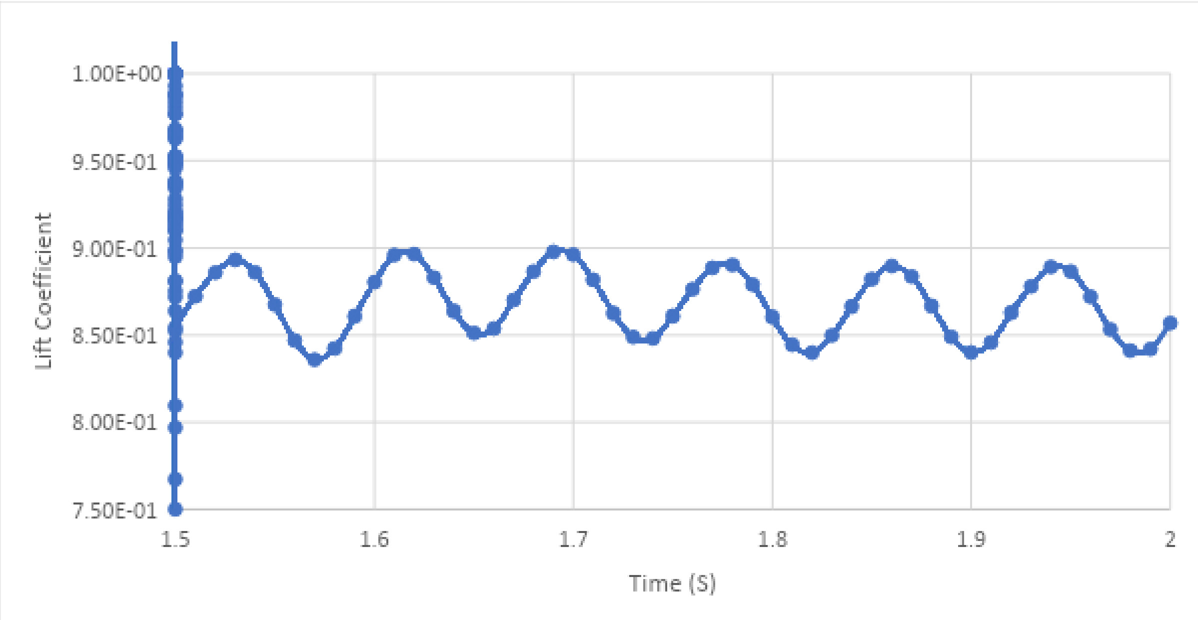

Figure 11: Lift VS Time from 1.5-2 seconds

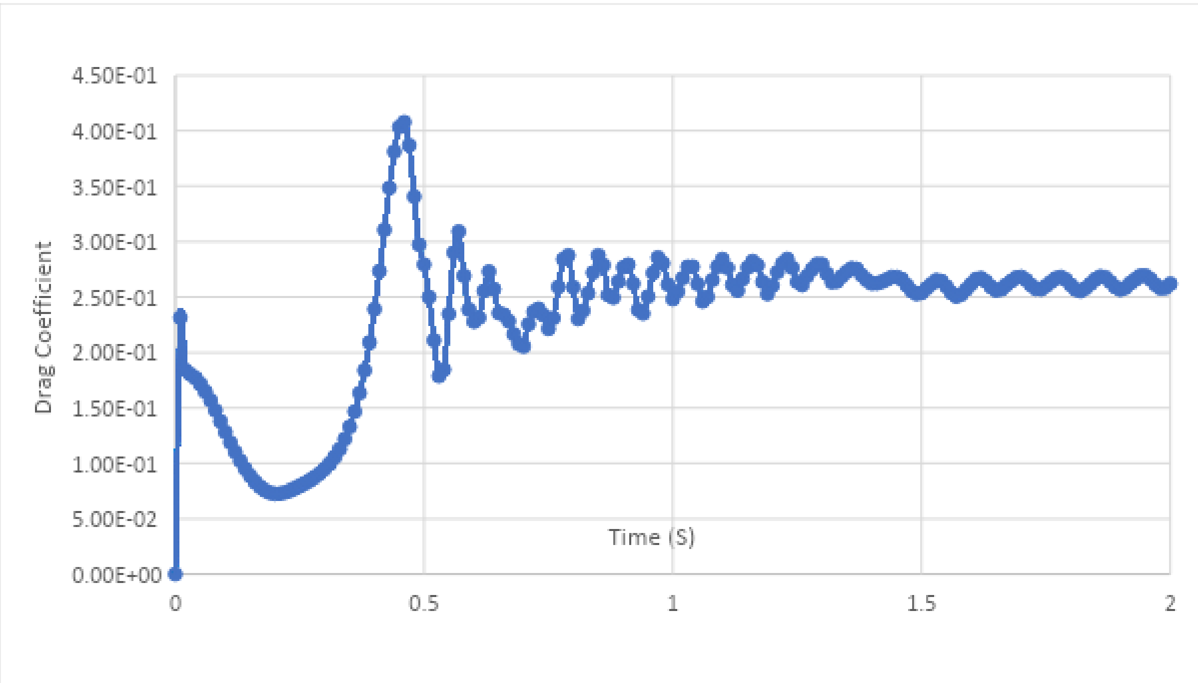

Figure 12: Drag VS Time

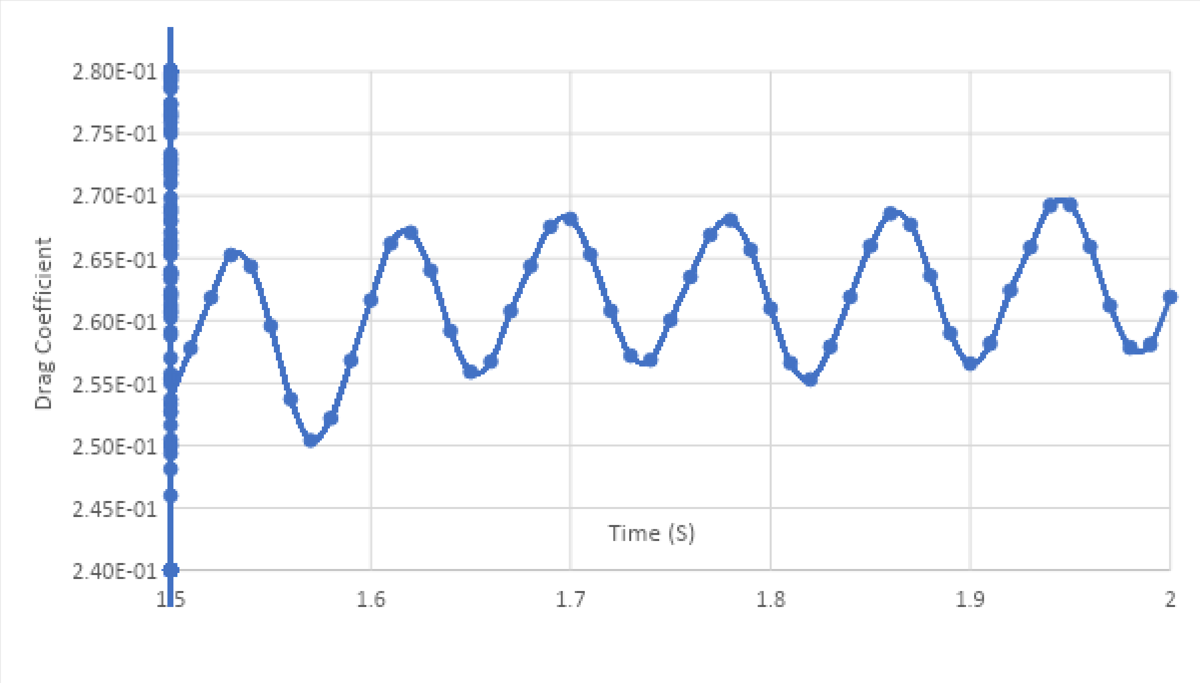

Figure 13: Drag VS Time from 1.5-2 seconds

B) Calculated and tabulated Pressure Difference, Pressure Drag Force and the Skin-Friction (i.e. viscous) Drag Force.

	Pressure Difference (PA)	Pressure Drag Force (N)	Skin-Friction (N)
α= 20°	12506	1220.9325	11.285432

Table 6: ***20°*** *values.*

Plot the pressure contour and velocity streamline at T= 2 sec.

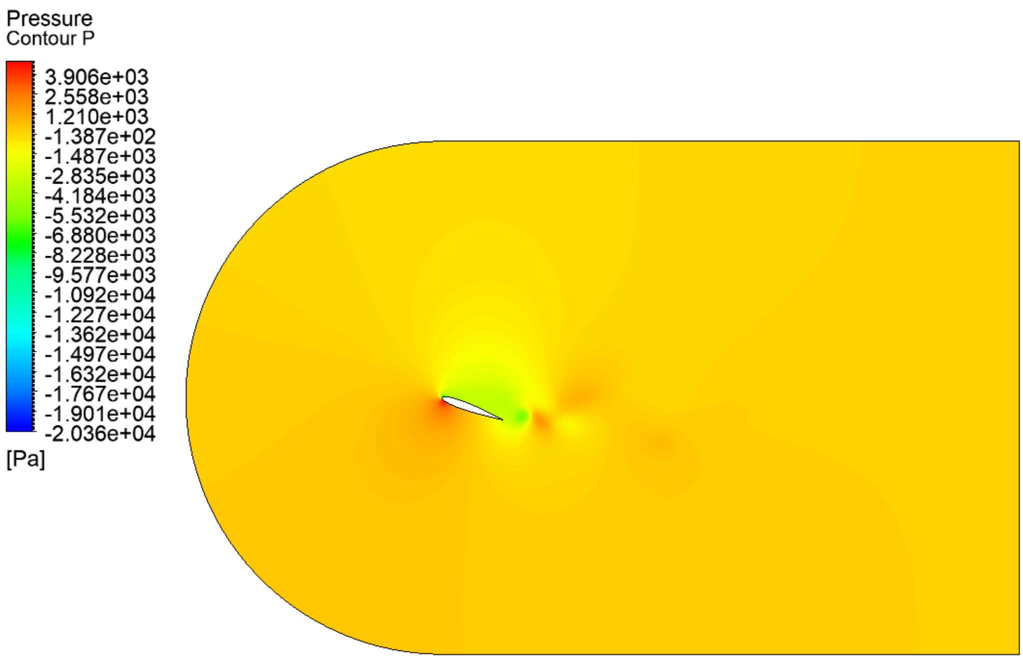

Figure 14: 2D pressure contour for 20 degrees.

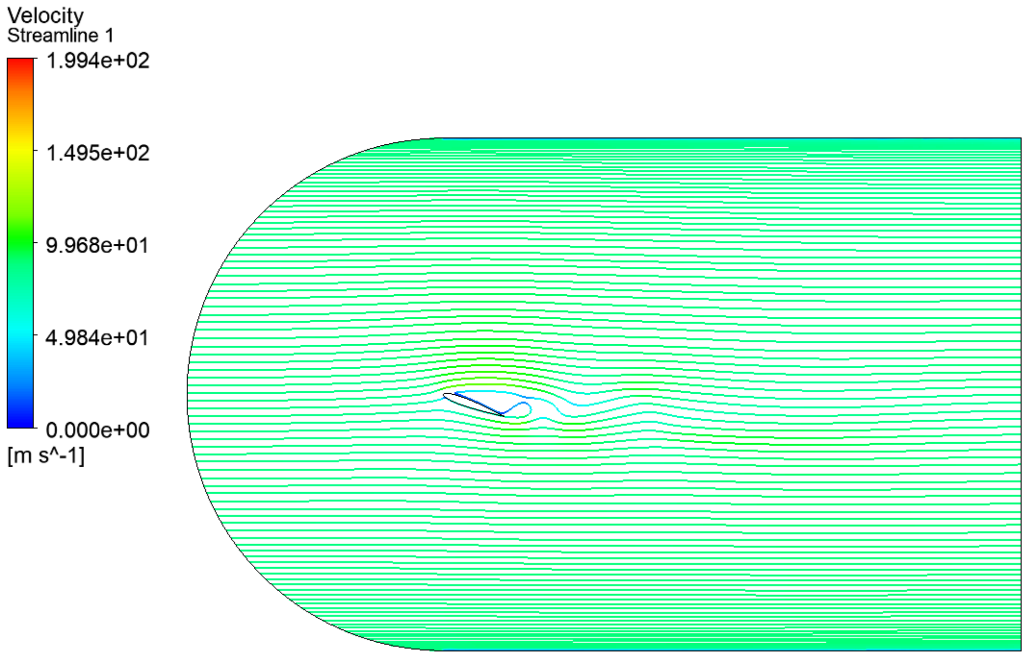

Figure: 15: Velocity streamline for 20 degrees.

C) Calculate the Strouhal number from the numerical results using the expression below, and discuss why the aerofoil at $\alpha = 20°$ experiences mild vortex shedding.

$$St = f \cdot L\, U\,,$$

Where, f = shedding frequency, L = characteristic length, U = characteristic velocity

The average time interval per oscillation is .08 seconds found through the zoomed in graphs. Therefore, the shedding frequency is

$$f = \frac{1}{t}$$

$$f = \frac{1}{.08}$$

$$f = 12.5hz$$

Utilising the Strouhal formula, $St = \frac{fL}{U}$ the characteristic length is $L = 1m$ and the characteristic velocity is $U = 87.644m/s$. The **Strouhal number is**

$$St = \frac{12.5 \cdot 1}{87.644}$$

$$St = .143$$

4. For the steady and transient 2D cases above:

A) Generate a plot for C_D vs. α (for all the α cases) and discuss.

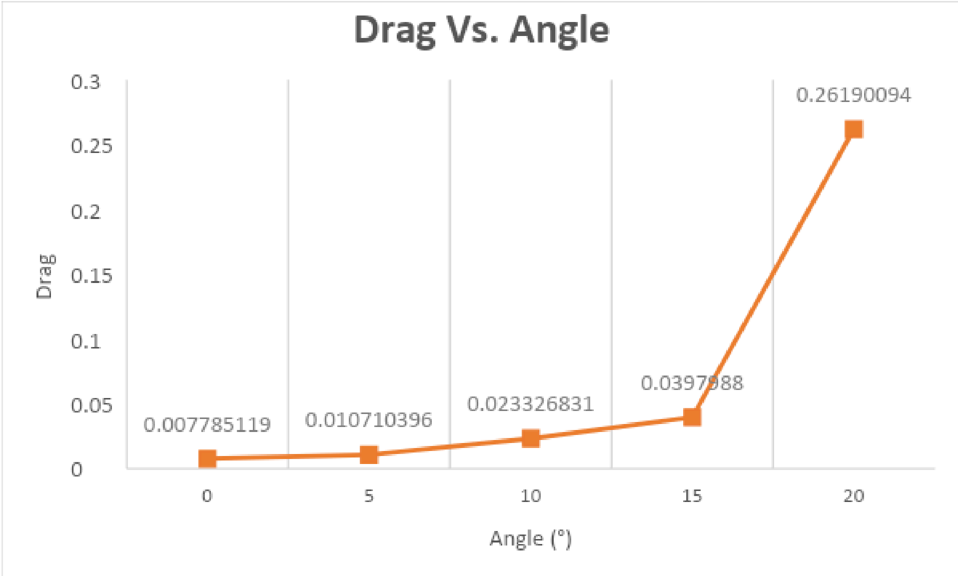

Figure 16: Drag Vs. Angle Graph.

The above graph displays a steady increasing trend in drag coefficient from 0 to 15 degrees. However, there is a very dramatic increase in drag between 15 and 20 degrees. This increase is not only due to the fact that there is a larger surface area of the aerofoil facing the attack angle of air but because this simulation was run with a transient model rather than steady state. This difference allows conditions to change with time rather than assuming all flow conditions and properties remain constant with respect to time. Transient simulations create more drag in the results because it is an oscillating flow that creates vortex shedding because at a 20 degree angle the aerofoil is more of a bluff body rather than streamlined.

B) Generate a plot for C_L vs. α (for all the α cases) and discuss.

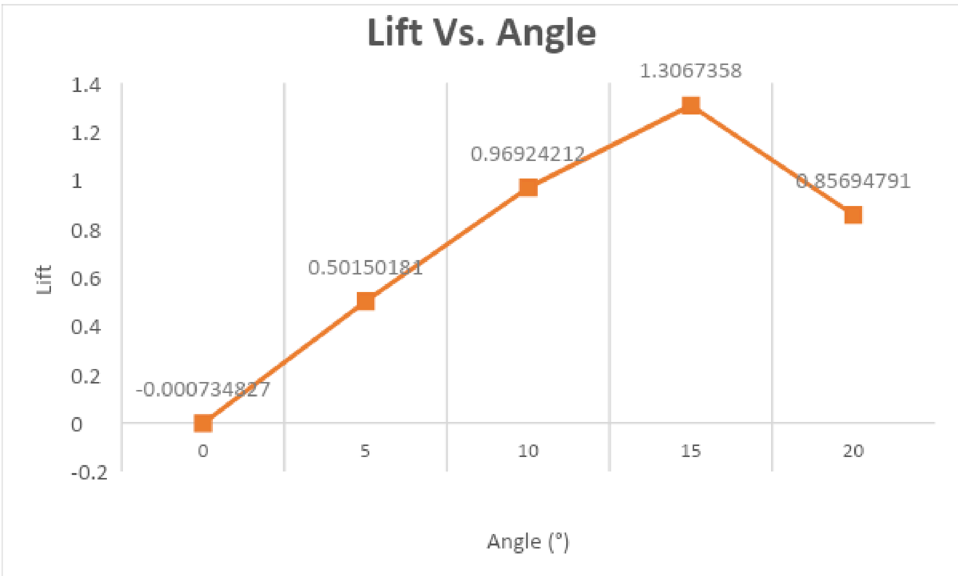

Figure 17: Lift Vs. Angle Graph

Analysing this graph shows that there is a steady increase in lift from 0 degrees (which has approximately no lift) to 15 degrees. However, there is a decrease in lift at the 20 degree angle for the aerofoil. Firstly, this is because of the massive increase in drag mentioned in the previous section.

Generate a plot for C_L / C_D vs. α (for all the α cases) and approximate the intersection point. Discuss the results.

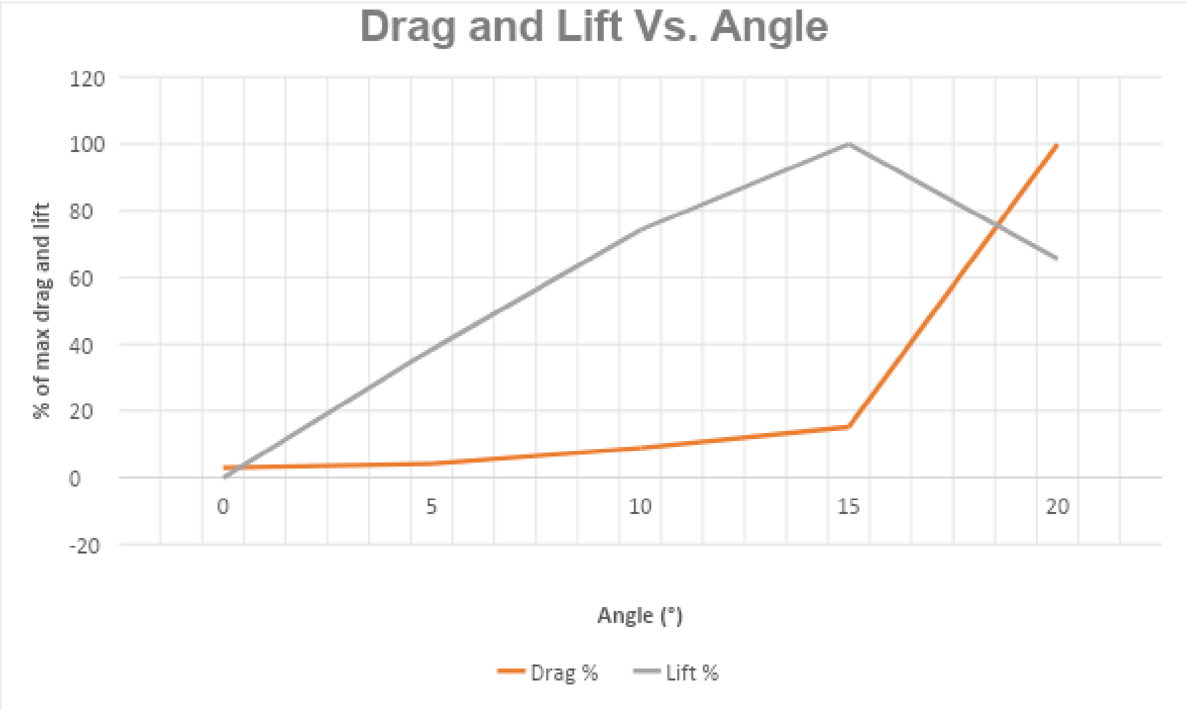

Figure 18: Drag and lift Vs. Angle

This plot is generated to have the drag and lift results as a percentage of the max results of drag and lift so they could be easily compared and combined into a graph.

Approximate intersection points:

1. Intersection @ 0.3° and 3%. Therefor, Drag = 0.007857 and lift = 0.039202
2. Intersection @ 18.5° and 55%. Therefor, Drag = 0.144046 and lift = 0.718705

After the second intersection point at 18.5 degrees is the point where vortex shedding starts to occur because drag has become greater than lift.

D) Generate a plot for Pressure Difference vs. α (for all the α cases) and discuss.

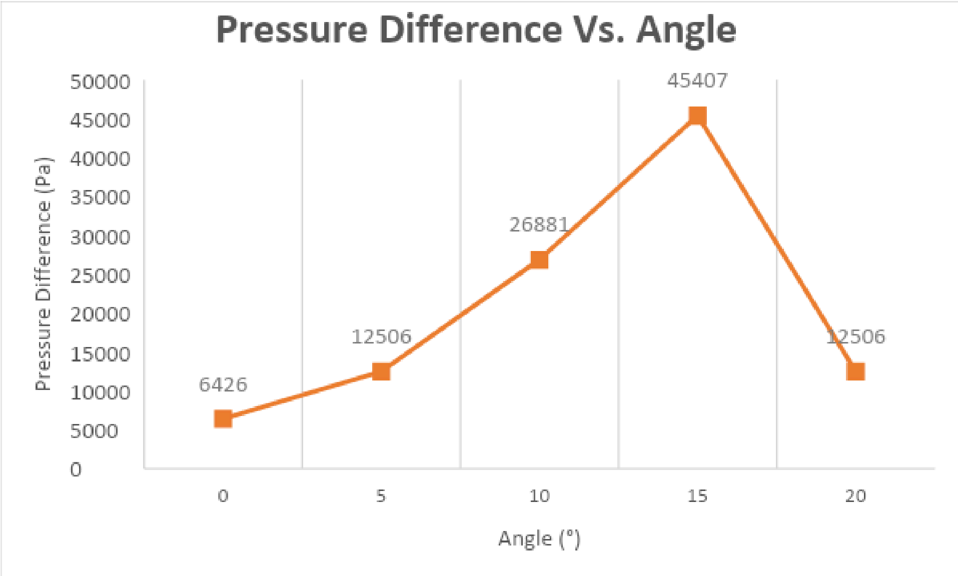

Figure 19: Pressure difference Vs. Angle.

This graph shows that as the angle increases from 0 to 15 degrees the pressure difference increases. The pressure difference increasing during this period because the greater the angle the more surface area and the more air force hitting the aerofoil creating greater pressure at the front compared to the back of the aerofoil. The pressure difference becomes less for the 20 degree angle because vortex shedding happens here which although creates a low pressure system behind the aerofoil the air movement circles back around and puts pressure on the back of the aerofoil. This can be seen clearly in the pressure contour and velocity contour graphs for 20 degrees. Ultimately making the overall pressure difference less.

E) Generate a plot for Skin-Friction Drag/Pressure Drag vs. α (for all the α cases) and approximate the intersection point. Discuss the results.

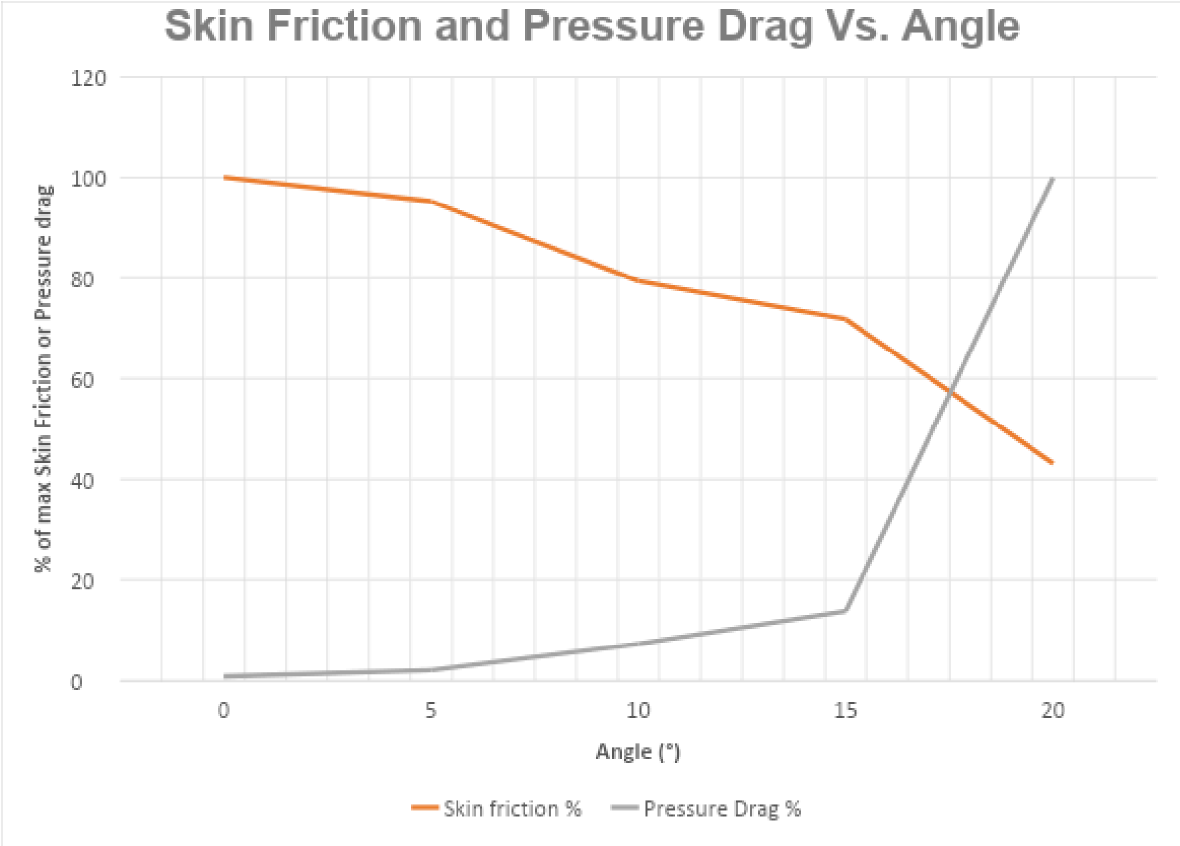

Figure 20: Skin friction and pressure drag Vs. Angle.

Approximate intersection point:

1. Angle @ 17.5° and 57.5%, therefor, Skin Friction = 15.03945 and Pressure Drag = 702.0362

There is an inverse relationship here between skin friction and pressure drag. As the pressure drag increases with the angle the skin friction decreases.

5. Run 3D steady cases at $\alpha = 0°$ and $\alpha = 5°$:

A) Calculated and tabulated drag coefficient (C_D) and the lift coefficient (C_L) results.

	Cd	Cl
α= 0°	0.0090008495	0.0057123254
α= 5°	0.014252633	0.51082061

Table 7- $0°$ & $5°$ drag and lift coefficients

B) **Plot** the **pressure contour** and **velocity streamline at the middle of the XY Plane**.

α= 0°

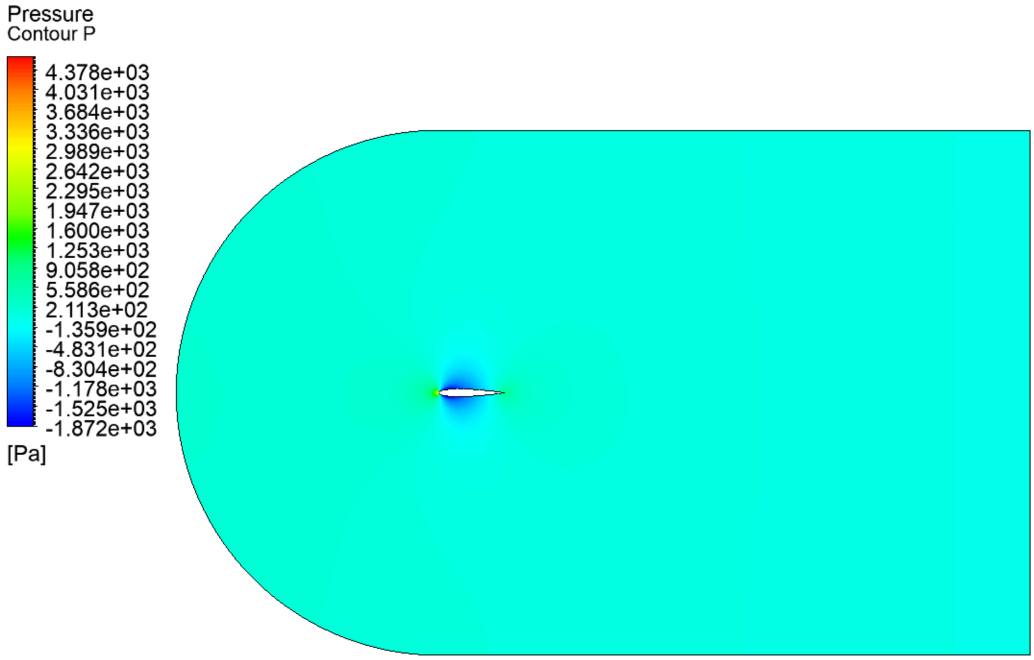

Figure 21: 3D pressure contour for 0 degrees

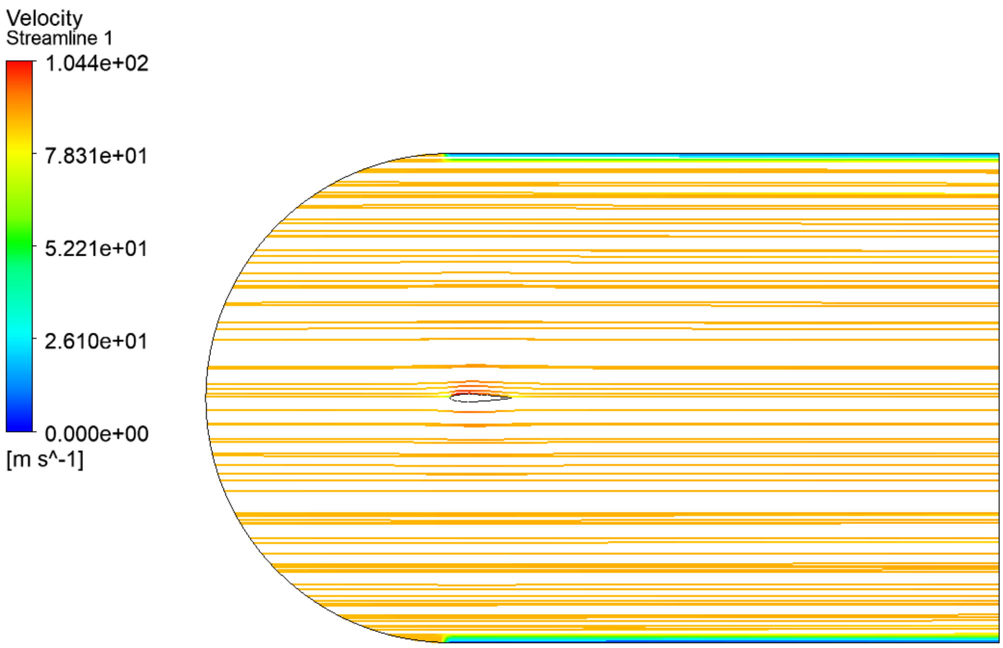

Figure 22: 3D velocity streamline for 0 degrees

α= 5°

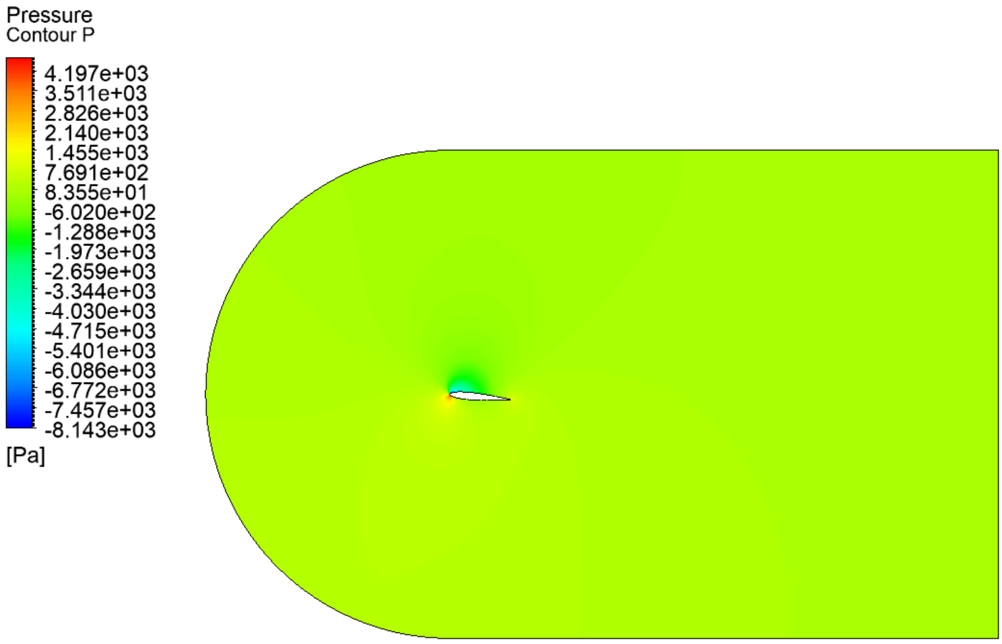

Figure 23: 3D pressure contour for 5 degrees

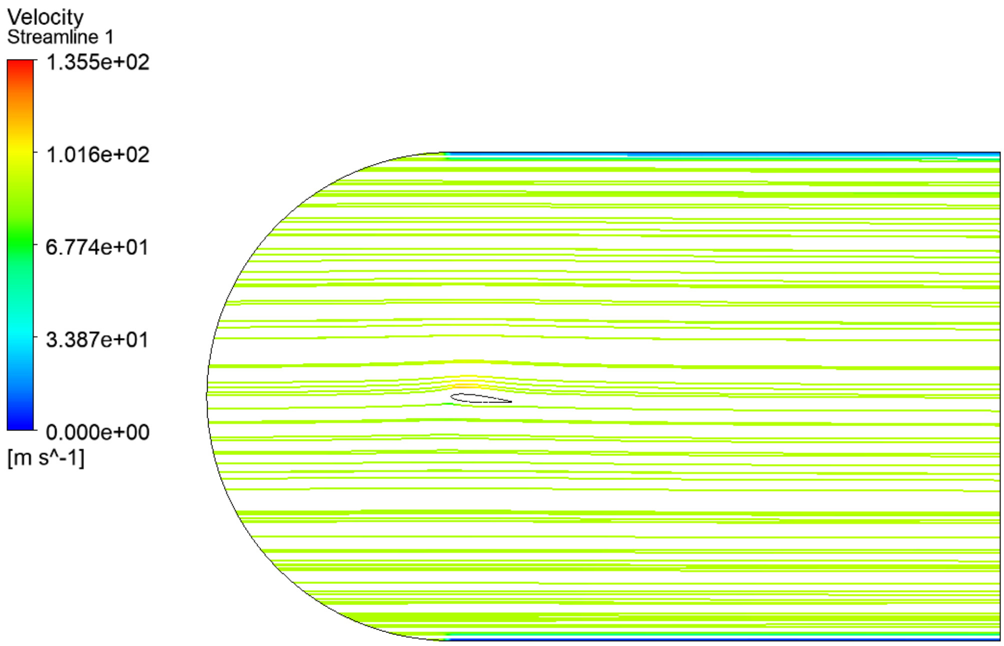

Figure 24: 3D velocity streamline for 5 degrees

Discussion:

Compare and **discuss** the **2D** and **3D** results **at $\alpha = 0°$ and $\alpha = 5°$. Discuss and compare all of the 2D vs. 3D simulation results in Q.5, providing logical explanations for the source of any numerical discrepancies.**

The results for 2D and 3D at 0° and 5° are in general very similar and show the same trends. At 0 degrees both lift results are approximately 0 for 2D and 3D. Whilst 3D results for lift and drag are slightly higher than there 2D counterparts. The reason that there is slightly more drag and lift is because there is more surface area due to the extra dimension.

D1: Provide a high-quality discussion on the general flow behaviour of the 2D NACA0012 aerofoil at the different angles of attack using all of the results obtained in Q.1,2,3,4, clearly discussing how the results and flow physics change based on the angle of attack.

Different angles of attack for air approaching a NACA0012 aerofoil have a different effect on the drag, lift, pressure difference, pressure drag force and the skin friction. The overall patterns of the results show that as the angle increases drag increases, while skin friction decreases. However, for pressure drag and lift as the angle increases from 0 to 15 these results increase but decrease when the angle reaches 20 degrees. The reason why some of these results do not follow a steady increasing or decreasing trend is because at a 20 degree angle of attack the aerofoil changes from being a relatively streamlined body to a bluff body. This is due to the fact that there is a now a much larger surface area facing the direction of air flow. The bluff body produces vortex shedding which can be seen in Graph XX which in turn creates the massive drag coefficient and pressure drag force results for 20 degrees. This is why the lift result and the pressure difference results decrease for 20 degrees.

D2: Provide a high-quality and comprehensive comparison between the lift coefficient and drag coefficient at the different angles of attack, clearly discussing the relationship between the two parameters.

The drag coefficient tells us the numerical representation to the resistance of an object based on its shape and surface area in a fluid environment. On the other hand, lift tells us a shapes ability to lift in the vertical y direction caused by the oncoming wind. Lift and drag coefficients have an important and co-dependent relationship with one another. Drag directly affects lift and vice versa. When the attack angle is increased to 20 degrees the drag is significantly increased which in turn negatively affects the lift.

C) Real world scenario involving an aeroplane:

Aerofoils are a common and practical application on vehicles that travel fast through a fluid. They can be used as aeroplane wings, helicopter blades and as F1 supercar spoilers. The ultimate use of aerofoils is to angle the aerofoil to create a required amount of lift and/or downforce with as little drag as possible. In the real world example of a plane wing an adjustable aerofoil will allow for ascent or descent as well as efficient cruising. Reduced drag allows for decreased power required and fuel consumed and will enable a plane to reach faster speeds.

Based on the results from the calculations above, 15 degrees is the most optimal angle of attack for take off. This is because it clearly has the most lift at 1.3067358 with also having the biggest difference to the drag force as seen in graph XXX. The reason 15 degrees is the most ideal angle is because it is angled enough to produce enough up force without being counteracted by drag. This can be seen with a 20 degree angle where the greater angle shows more face to the oncoming air creating more drag and less lift. Whilst not enough angle produces less drag but also much less lift.

The ideal angle of attack for the most efficient cruise control conditions is 5 degrees. This is because it has significantly low drag at 0.010710396 while also producing lift. This lift will help to counteract the weight of the plane and keep it at a steady altitude while cruising. The reason why 0 degrees is not efficient is that the lift is 0 and the weight of the plane will decrease altitude over time. At 10 and 15 degrees At 20 degrees there is large drag and vortex shedding which can often create oscillating or vibrations which is not suitable for cruising.

Conclusion: