Experiment - 7

Flow over a symmetrical airfoil NACA0015

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1. Aim :

- To find C_p on NACA0015 at various angle of attack.
- To estimate C_l and C_d for various angle of attack.

2. Apparatus :

Required apparatus for performing this experiment are:

- Manometer
- C15-10 Armfield tunnel
- Pitot-static Probe
- Fan
- NACA0015 Symmetric airfoil

3. Theory :

NACA0015 is a relatively thin and symmetric airfoil,so we can apply 'Thin Airfoil Theory' to determine theoretical values of Lift,Drag and moment Coefficients. The angle of attack is the angle between the chord line of an airfoil and an the oncoming air. A symmetrical airfoil generates zero lift at zero angle of attack.On increasing angle of attack ,the air deflects through larger angle and vertical component of airstream velocity increases which generates more Lift.
Coefficients of Lift(C_l) :
Coefficients of Lift is the dimentionless quantity which measure the lift generated by a lifting body to the fluid density around the body.
Theoretically,

$$C_l = 2\pi\alpha$$

C_l can be calculated from pressure tap data as :

$$C_l = \int_{TE}^{LE} \{(C_p)_l - (C_p)_u\} \, d(\frac{y}{c})$$

Drag : Drag is the force which opposes the motion of an object. Drag is calculated by :

$$D = \int_{-\infty}^{\infty} \rho v(V_\infty - v) \, dy$$

Coefficients of Drag : Drag coefficients caused due to skin friction and Drag. Drag coefficients is calculated by :

$$C_d = \frac{D}{(\rho V_\infty^2 d)/2}$$

C_d can be calculated from pressure tap data too as following :

$$C_d = \int_{TE}^{LE} \{(C_p)_l - (C_p)_u\} \, d(\frac{x}{c})$$

Reynolds Number : The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal moment due to variation of velocities.

$$R_e = \frac{\rho V_{\infty d}}{\mu}$$

For a thin airfoil Reynolds No can be calculated as :

$$R_e = \frac{Vc}{\nu}$$

where, V = Flight speed,
c = Chord length ,
ν = Kinematics of the fluid in which the airfoil operates, for the atmosphere at sea level $\nu = 1.46 \times 10^{-5} \frac{m^2}{s}$

4. Procedure :

1. In wind tunnel test section is set.

2. Pitot-static probe is connected to manometer.
3. Fan speed is fixed.
4. Angle of attack is fixed
5. Required readings are taken.

5. Observation :

Air velocity = 15.2 m/s
Angle of attack = 4°

5.1 Pressure distribution and C_p for upper surface of airfoil

Table 1: **Pressure distribution and C_p for upper surface of airfoil**

Port No.	Tapping point location from starting point(in mm)	Stagnation Pressure(in mm of water)	(P- P_∞)(in Pa)	$(C_p)_u$
P_1	0	-4.4	43.164	0.289
P_2	3	-31.1	305.091	2.043
P_3	5	-28.5	279.585	1.872
P_4	7	-30.3	297.243	1.990
P_5	9	-27.7	271.737	1.819
P_6	22	-25.2	247.212	1.655
P_7	29	-24.2	237.402	1.589
P_8	36	-21.6	211.896	1.419
P_9	43	-19.0	186.39	1.248
P_{10}	50	-17.3	169.713	1.136

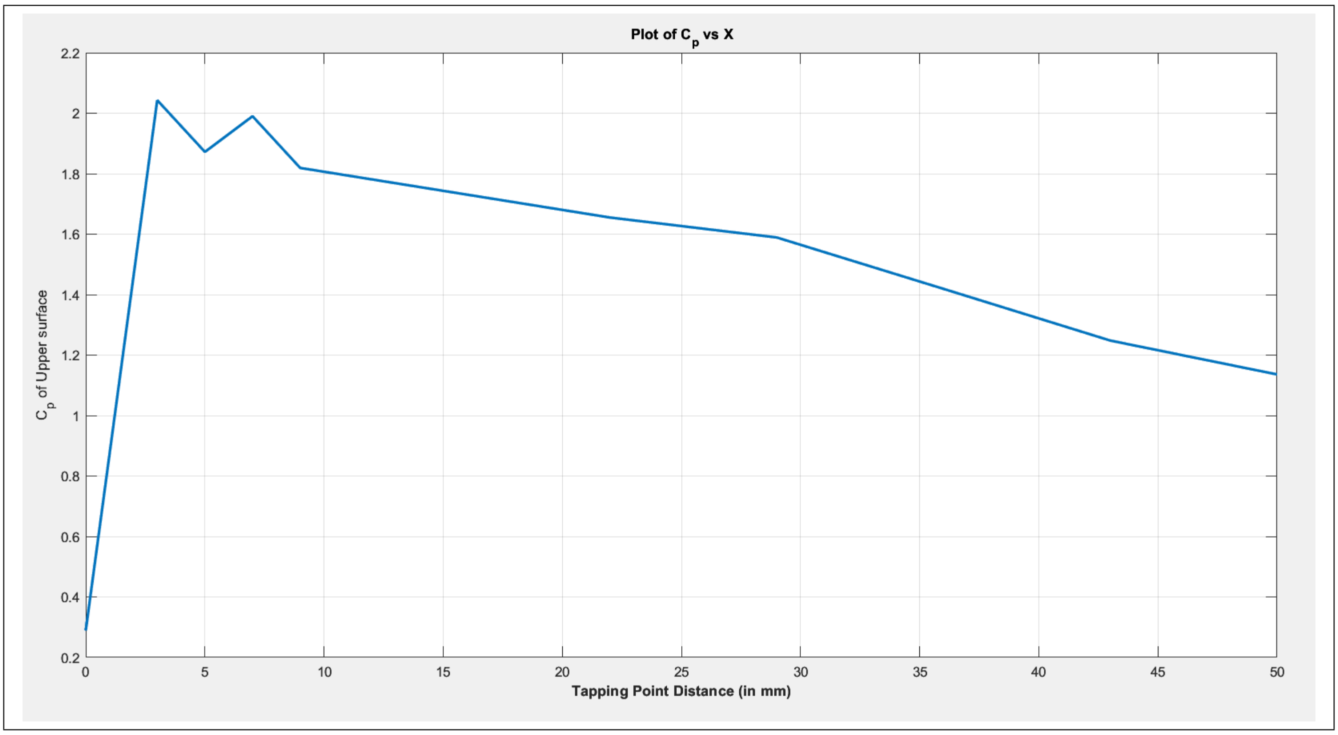

Figure 1: Variation of C_P with X distance of pitot tube

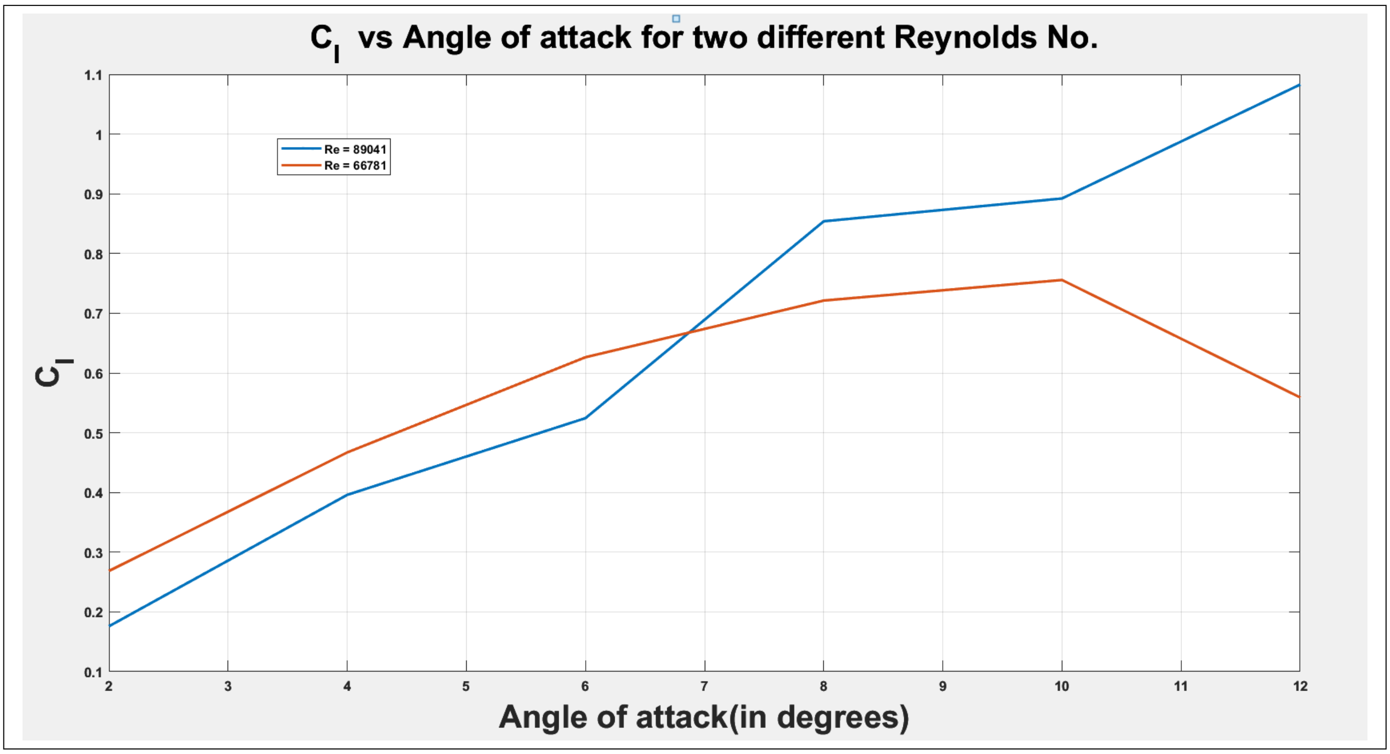

Figure 2: Variation of Coefficients of Lift with Angle of attack for different Reynolds No.

Table 2: **Calculation of C_p of Upper surface of Airfoil**

Port No.	Tapping point location from starting point(in mm)	Stagnation Pressure(in mm of water)	(P- P_∞)(in Pa)	$(C_p)_l$
P_1	0	-6.9	67.689	0.453
P_2	3	-10.5	103.005	0.690
P_3	5	-9.6	94.176	0.630
P_4	7	-13.6	133.416	0.893
P_5	9	-16.1	157.941	1.057
P_6	22	-16.7	163.827	1.097
P_7	29	-16.2	158.922	1.064
P_8	36	-14.3	140.283	0.939
P_9	43	-14.9	146.169	0.979
P_{10}	50	-14.1	138.321	0.926

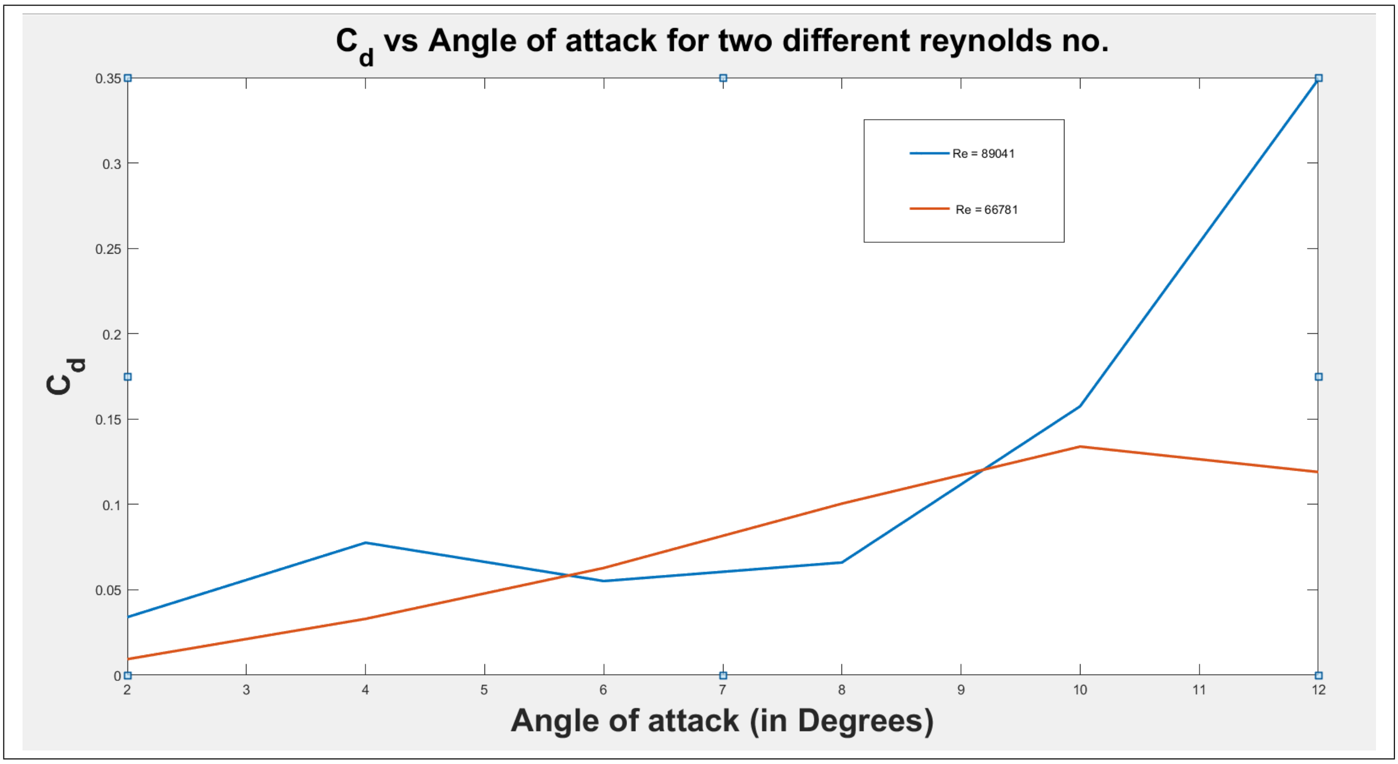

Figure 3: Variation of Coefficients of Drag with Angle of attack for different Reynolds No.

Table 3: **Determination of X and Corresponding Y**

Port No.	Tapping point location from starting point(in mm)(X)	Corresponding value of Y (in mm)	ΔX	ΔY
P_1	0	0	0	0
P_2	3	2.7908	3	2.7908
P_3	5	3.4465	2	0.6557
P_4	7	3.9062	2	0.4597
P_5	9	4.2417	2	0.3355
P_6	22	4.8504	13	0.6087
P_7	29	4.5502	7	-0.3002
P_8	36	4.0008	7	-0.5494
P_9	43	3.2724	7	-0.7284
P_{10}	50	2.4031	7	-0.8693

6. Calculations :

Density of air = 1.293 m^3
Density of Water(ρ_w) = 1000 Kg/m^3

6.1 Calculation of Coefficient of Lift(C_l)

Coefficient of Lift(C_l) is calculated by ,
For 10 ports,

$$C_l = \int_{TE}^{LE} \{(C_p)_l - (C_p)_u\}\, d(\frac{y}{c}) \approx \sum_{i=1}^{9} \frac{\{((C_p)_l - (C_p)_u)_{avg}\}_i (\Delta y)_i}{c}$$

Where, $(((C_p)_l - (C_p)_u)_{avg})_i = \frac{((C_p)_l-(C_p)_u)_i+((C_p)_l-(C_p)_u)_{i+1}}{2}$
$\Delta y = y_{i+1} - y_i$
c = Chord length = 65 mm

For port 1 & 2,

$$((C_p)_l - (C_p)_u)_{avg}) = \frac{((C_p)_l - (C_p)_u)_i + ((C_p)_l - (C_p)_u)_{i+1}}{2}$$
$$= \frac{(0.453 - 0.289) + (0.690 - 2.043)}{2}$$
$$\Delta y = y_2 - y_1 = 2.7908mm$$
$$\therefore (C_l)_1 = -0.0255$$

In this way can get C_d contribution due to each port.
Therefore

$$\boxed{C_l = 0.0436}$$

6.2 Calculation of Coefficient of Drag(C_d) :

Coefficient of Drag(D) is calculated by ,
For 10 ports,

$$C_d = \int_{TE}^{LE} \{(C_p)_l - (C_p)_u\}\, d(\frac{x}{c}) \approx \sum_{i=1}^{9} \frac{\{((C_p)_l - (C_p)_u)_{avg}\}_i (\Delta x)_i}{c}$$

Where, $(((C_p)_l - (C_p)_u)_{avg})_i = \frac{((C_p)_l-(C_p)_u)_i+((C_p)_l-(C_p)_u)_{i+1}}{2}$
$\Delta x = x_{i+1} - x_i$
c = Chord length = 65 mm

For port 1 & 2,

$$((C_p)_l - (C_p)_u)_{avg}) = \frac{((C_p)_l - (C_p)_u)_i + ((C_p)_l - (C_p)_u)_{i+1}}{2}$$
$$= \frac{(0.453 - 0.289) + (0.690 - 2.043)}{2}$$
$$\Delta x = x_2 - x_1 = 3mm$$
$$\therefore (C_d)_1 = -0.027$$

In this way can get C_d contribution due to each port.
Therefore
C_d = [0.027+0.0399+0.036+0.0286+0.13+0.057+0.054+0.04+0.026]= 0.4385

$$\boxed{C_d = 0.4385}$$

6.3 Calculation of Reynolds number(R_e):

$$ReynoldsNo.(R_e) = \frac{Vc}{\nu}$$

where,
$\nu = KinematicViscosity = 1.46 \times 10^{-5} \frac{m^2}{s}$(for the atmosphere at sea level.)
V = Flight speed
c = Chord length
Reynolds No.(Re) = $\frac{Vc}{\nu}$

For velocity(V) = 15.2 m/s,

$$\begin{aligned} R_e &= \frac{Vc}{\nu} \\ &= \frac{15.2 \times 65 \times 10^{-3}}{1.46 \times 10^{-5}} \\ R_e &= 67671.23 \end{aligned}$$

7. Sources of Error:

- Error due to instrumental defect.
- Error may occur in taking readings before flow becomes steady.
- Error due to environmental effect like temperature,pressure change.
- Error in measurement due to presence of zero error in parameters.
- Dimensional error may occurs

8. Conclusion :

- On increasing angle of attack more lift is generated.
- On increasing angle of attack Coefficient of Drag increases.
- At 0° Angle of attack pressure distribution line is symmetry about each other on both upper and lower surface.
- As angle of attack increases at leading edge flow seperation occurs and at trailing edge pressure rises suddenly.