LAB 11
Pressure Distribution over an airfoil using Pressure Scanner
Debanjan Manna (190255)
AE351
8th March 2022

- **OBJECTIVE :**

  1. To calculate the C_p distribution over an airfoil, and use it to calculate C_l and C_d for the airfoil.

  2. To obtain velocity profile from the wake and use it to calculate the drag coefficient Cd and compare the drag coefficients obtained.

- **EQUIPMENTS AND EXPERIMENTAL DETAILS :**

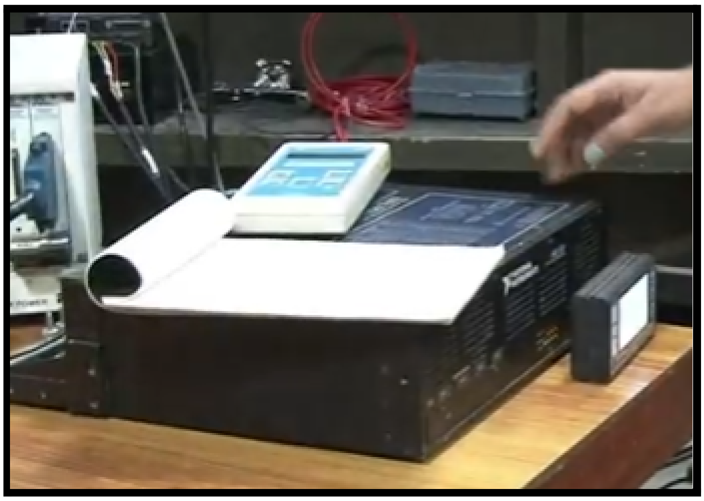
  ➔ We will be using a ***NACA0012 airfoil*** with ***30 ports on its surface*** for *registering static pressure*, mounted in a closed circuit (3D + 2D) wind tunnel. The 30 ports on the airfoil surface were connected to a Pressure scanner (indexed 0) with 31 ports on it.

  ➔ Upper surface of the airfoil had 19 ports (including leading edge, LE and trailing edge, TE) while the lower surface had only 11 ports.

  ➔ The 31st port of this scanner was used to register the wind speed in the tunnel.

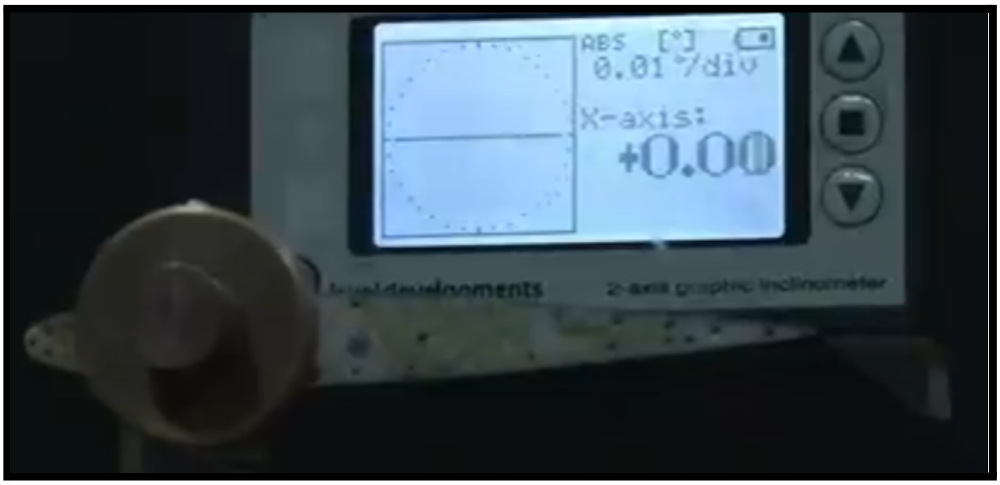
NACA 0012 Airfoil

Chord Length (c) of the Airfoil = 122.5 mm
Span length (s) of the Airfoil = 305 mm.



Motion Drive

PiCIe motion card



Digital Inclinometer

➔ The airfoil was further mounted on a rotating platform driven by a ***gear box***.For the motion of the airfoil we have a ***DC servo motor*** .

➔ A ***digital manometer*** was further used to calculate the wind speed of the tunnel.

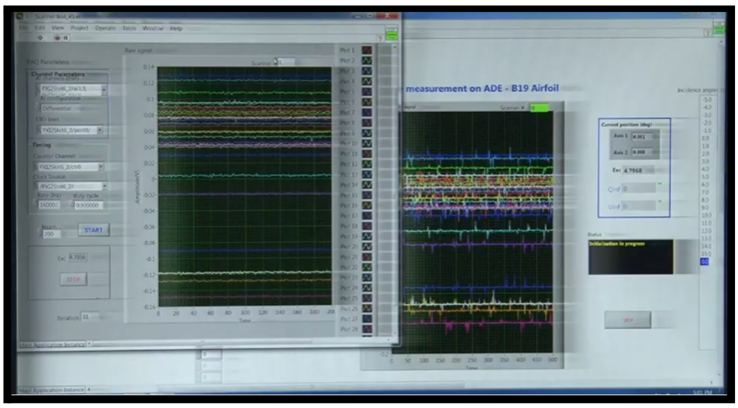
Fig. 2: Digital manometer

➔ The mentioned setup was subjected to three different wind speeds ($U\infty$={8.0,12.0,16.0}ms^{-1}) and 21 different AoA (α={−5,−4,−3,…,13,14,15}°). The AoA variation -5° to 15° at step of 1 deg.

➔ The gear box was coupled with the VI such that after each save for an angle of attack, the angle was changed automatically to the next one.

➔ A wake rake, located at 3.5c from airfoil LE was also used to measure the total pressure in the wake of the airfoil. The rake with 60 ports for total pressure also had several static pressure ports. Two pressure scanners (indexed 1 and 2) were used to accommodate all the ports in the wake rake.

➔ The data acquisition system records the pressures from wake for all the cases of wind speed and angles of attack as mentioned before. Acquisition rate = 16kHz .



The DAQ developed for Acquiring the data

- **PROCEDURE :**

1. Load the calibration file in the VI from the previous experiment.
2. Take no wind data for all the sensors.
3. From speed VI, set the wind speed to the desired value.
4. Start the main VI, and wait for the setup to span from all angles of attack and record pressures from airfoil surface and wake rake.
5. Repeat from step 2 for another wind speed.

- **RESULTS AND DISCUSSION :**

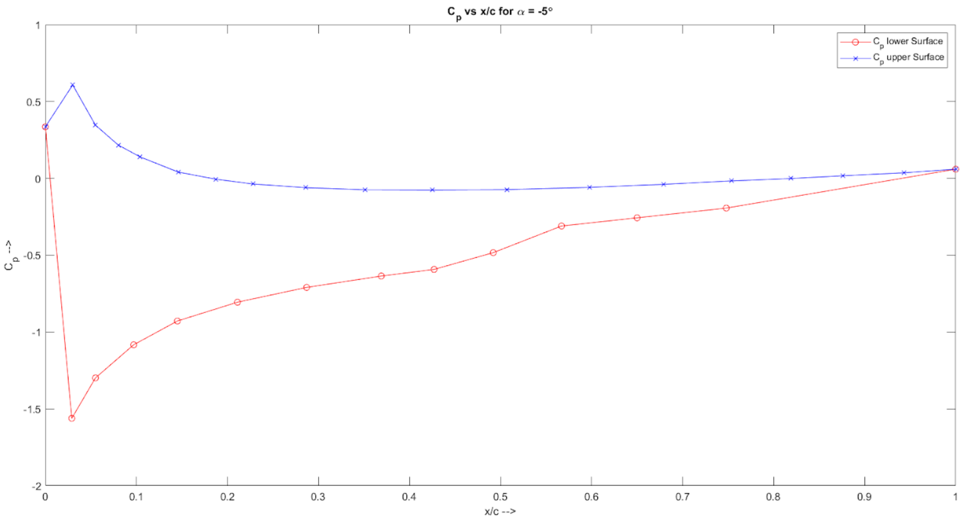
assigned Dataset : U (mps) = 12 || 10 α values = [-5] & [7,15]

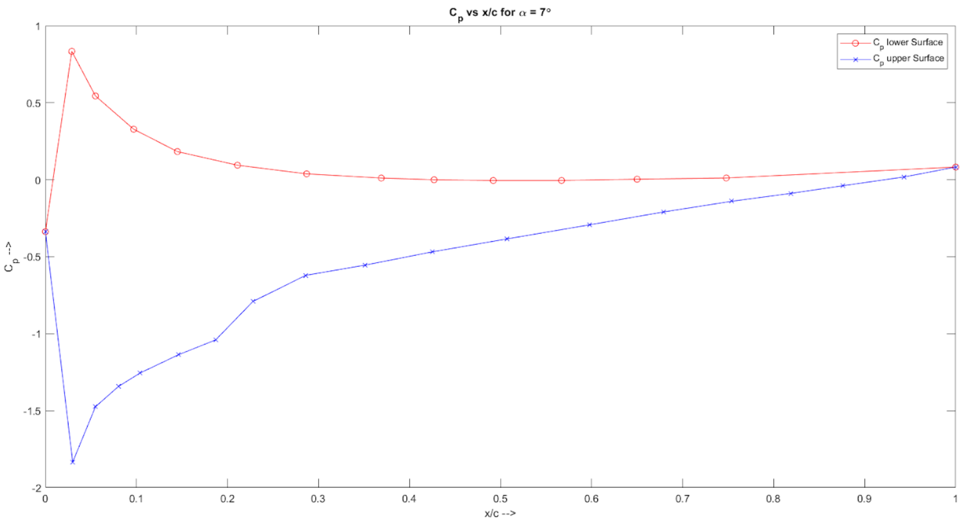
(a) Calculation :

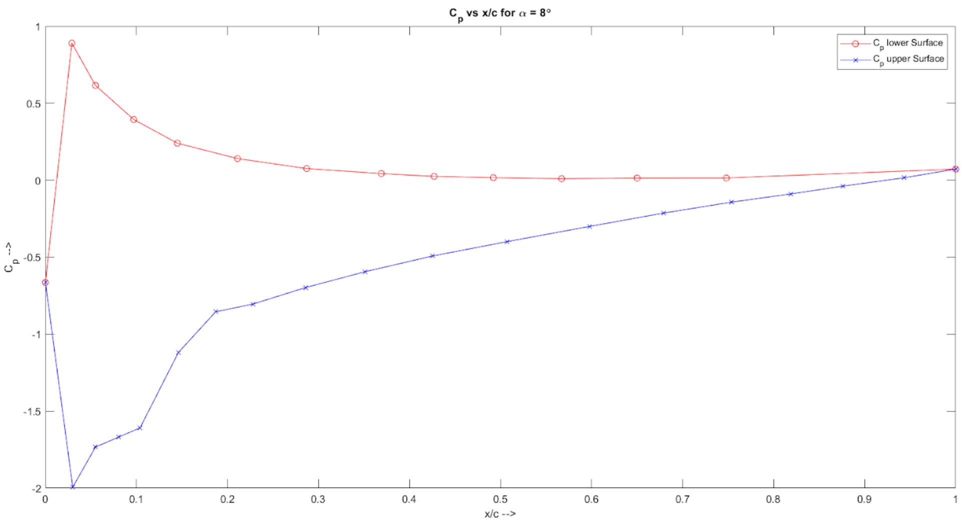
Using airfoil surface data -

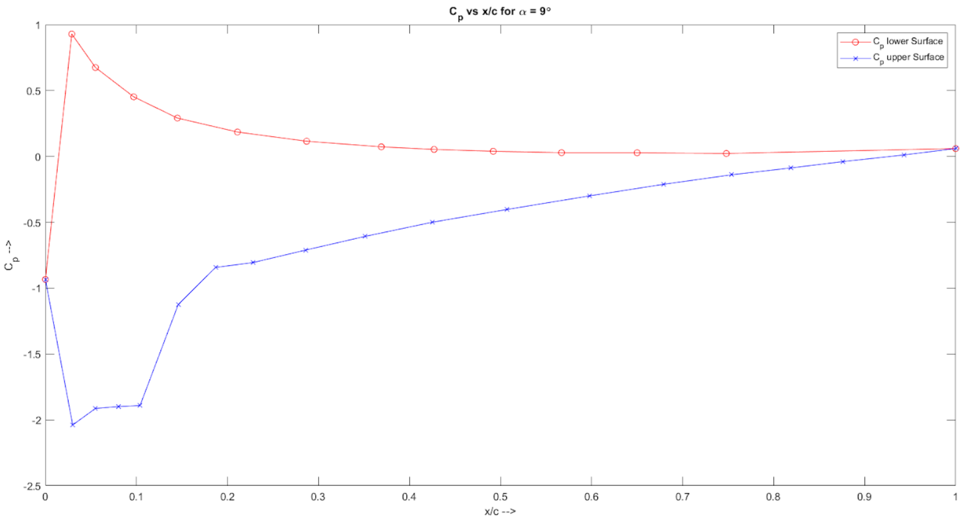
Pressure Coefficient C_p	$C_p = \frac{P-P_\infty}{q_\infty}$ where $q_\infty = \frac{1}{2} * \rho * v_\infty^2$
Normal Coefficient C_n	$C_n = \frac{1}{c} * [\int_0^c (C_{p,l} - C_{p,u})\, dx]$
Axial Coefficient C_a	$C_a = \frac{1}{c} * [\int_0^c (C_{p,u}\frac{dy_u}{dx} - C_{p,l}\frac{dy_l}{dx}) dx]$
Lift Coefficient C_l and Drag Coefficient C_d	$C_l = C_n * cos\alpha - C_a * sin\alpha$ $C_d = C_n * sin\alpha + C_a * cos\alpha$

C_p Plots :

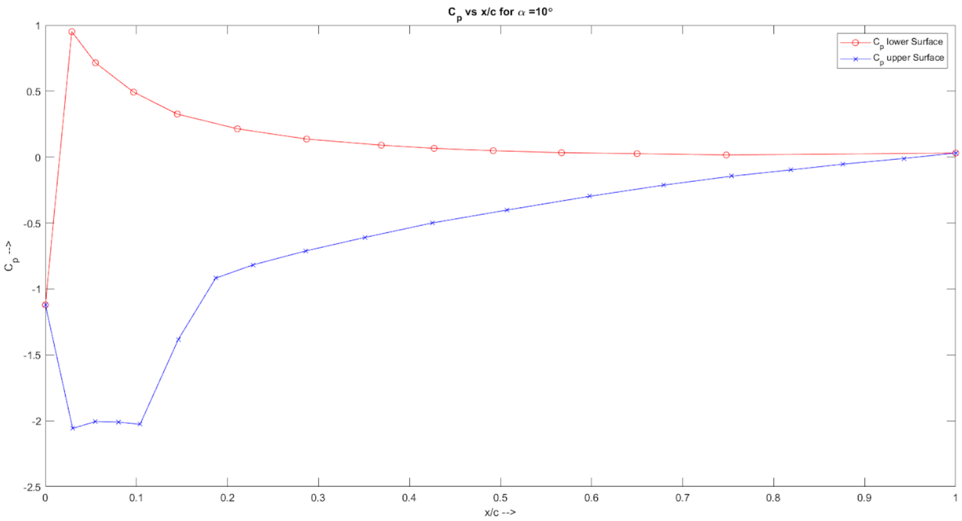

C_p vs x/c for α = -5°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->


C_p vs x/c for α = 7°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->

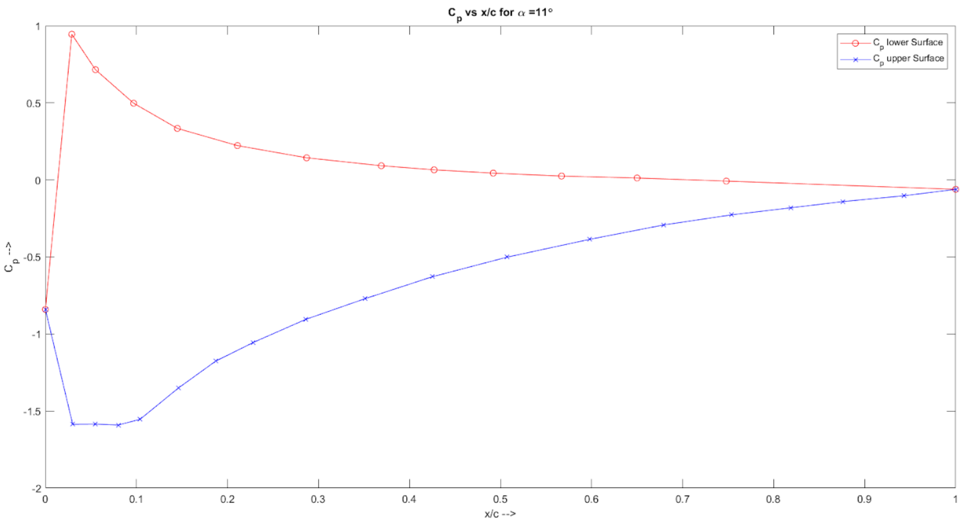

C_p vs x/c for α = 8°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->



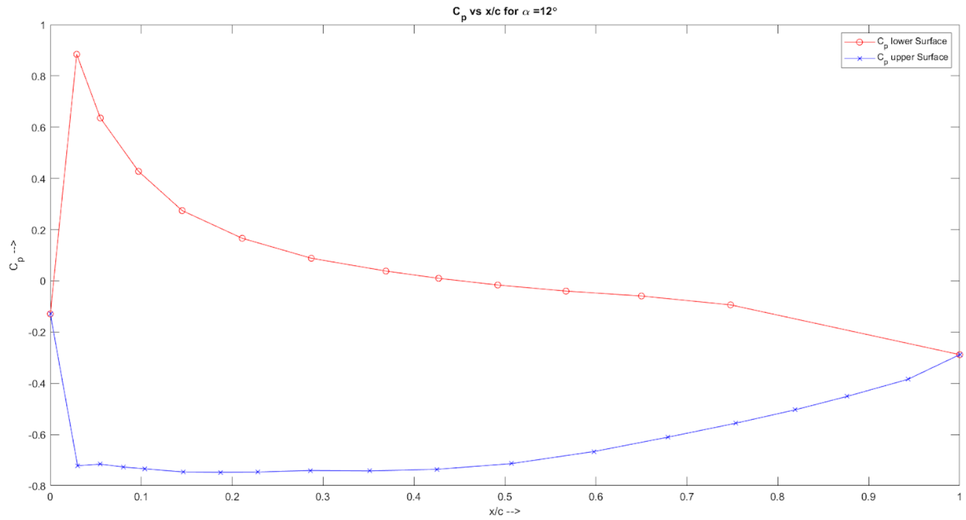
C_p vs x/c for α = 9°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->

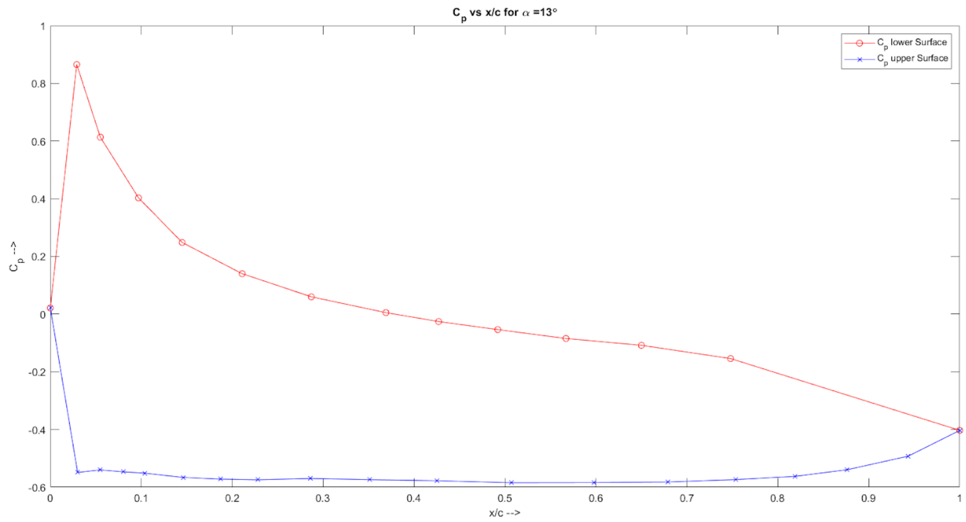


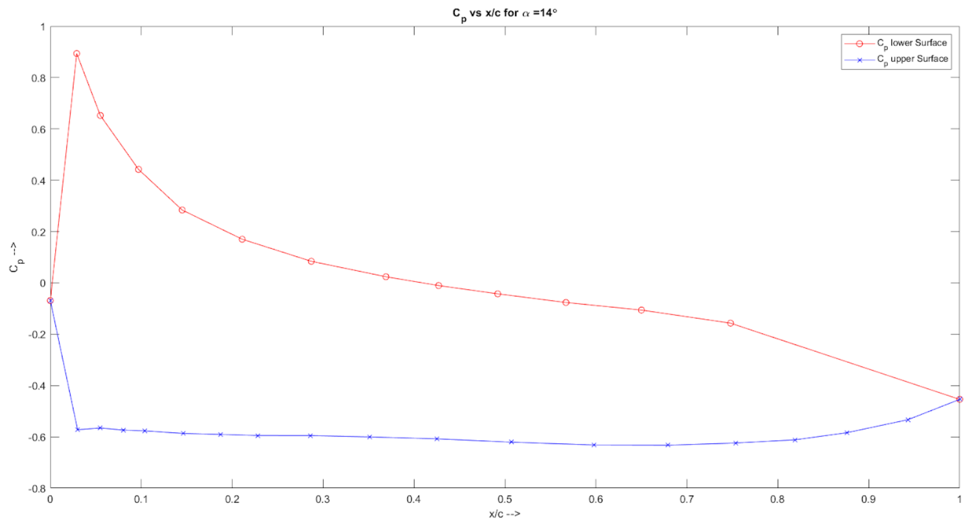
C_p vs x/c for α =10°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->

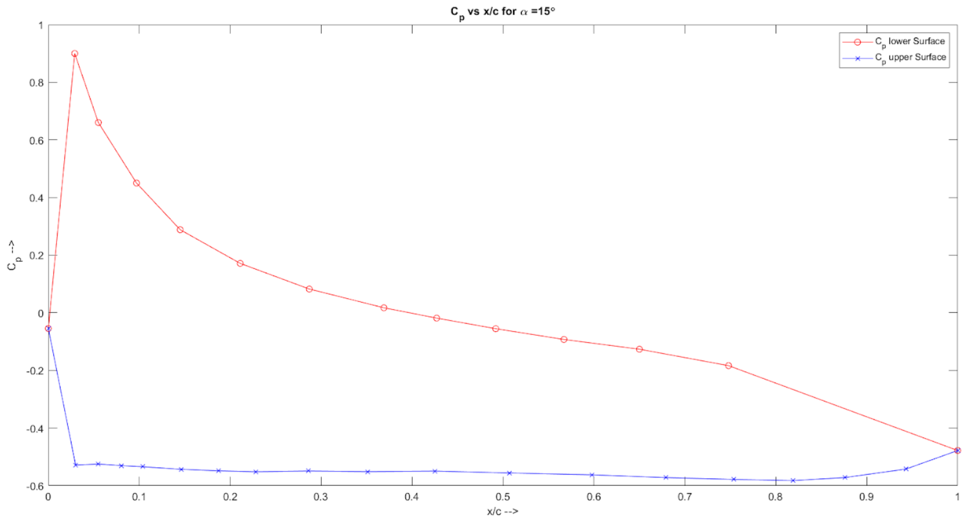


C_p vs x/c for α =11°
C_p lower Surface
C_p upper Surface
C_p -->
x/c -->

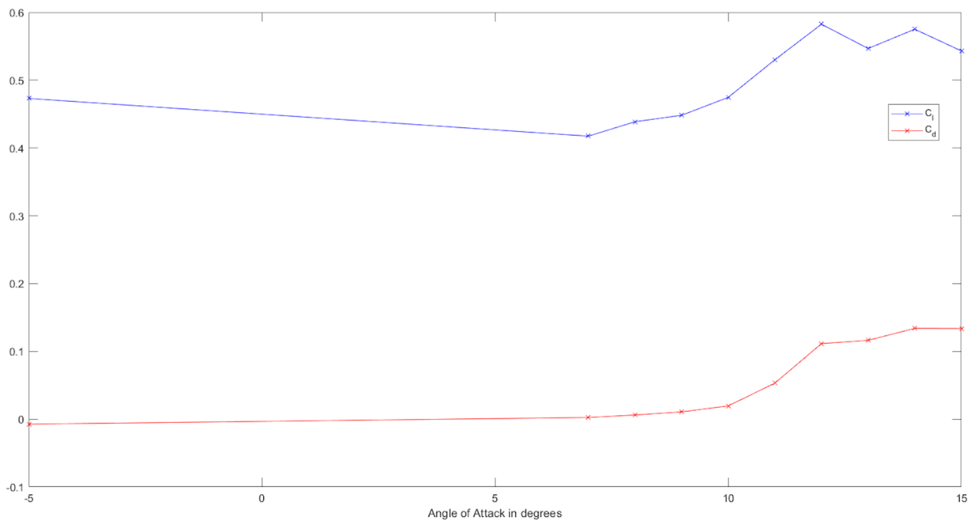

Cp vs x/c for α =12°
Cp lower Surface
Cp upper Surface
Cp -->
x/c -->


Cp vs x/c for α =13°
Cp lower Surface
Cp upper Surface
Cp -->
x/c -->


Cp vs x/c for α =14°
Cp lower Surface
Cp upper Surface
Cp -->
x/c -->



C_l vs AoA and C_d vs AoA Plot :



Using Wake Rake data -

Drag Coefficient C_d	$C_d = \frac{\int_0^{610} \rho u(u-U_\infty)dy}{1/2*\rho*U_\infty^2*L_{ref}}$ here L_{ref} = 610 mm
Obtaining Velocity Profile	• $P_{total} = P + \frac{1}{2}\rho v^2$ ○ $v = \sqrt{2 * \frac{P_{total}-P}{\rho}}$ • $q_\infty = \frac{1}{2}\rho U_\infty^2$

	○ $U_{\infty} = \sqrt{2 * \frac{q_{\infty}}{\rho}}$

AoA (in deg)	Cd [*Using airfoil surface data*]	Cd [*Using Wake Rake data*]
-5	**-0.00747**	**0.01862**
7	**0.002385**	**0.05281**
8	**0.006099**	**0.05223**
9	**0.010634**	**0.05455**
10	**0.019434**	**0.05530**
11	**0.053078**	**0.06623**
12	**0.111350**	**0.07514**
13	**0.116194**	**0.07205**
14	**0.133852**	**0.07474**
15	**0.133551**	**0.07287**

(b) Observations :

1. From the airfoil surface data, it is quite evident that drag coefficient is not at all correct as there are some negative values for cd.
2. cl values show a strong linear trend which is expected.
3. cd values suffer a heavy loss in accuracy because
   a. not only pressure but shear forces distribution also contributes to the drag on an airfoil.
   b. Of the poor resolution of ports on the airfoil surface, the slope of the airfoil is not correctly accounted for, this is a byproduct of there not being sufficient ports.

- ***airfoil surface data (obtained using the 31 ports)* is only reliable for calculation of lift coefficient, not for drag coefficient.**

(c) Precaution:

1. Ensure that the maximum pressure at any port should be within the range of the sensor.
2. Before the start of the experiment ensure that your airfoil is at 0deg Angle of Attack

- ***The MATLAB Code used for the Calculations:***

```
%% uploading the dataset
A = importdata("U12mps.xlsx");
%% Creating a suitable Datastructure
mat = zeros(3,32,10);
% All the AoAs
AoA = [-5,(7:1:15)]';
% the 1st 2D array will contain the data for AoA = -5 deg
mat (:,:,1) = A.data(3:5,:);
% the 2nd 2D array will contain the data for AoA = 7 deg and so on ..
for i=2:10
   mat(:,:,i) = A.data(63+5*(i-2):65+5*(i-2),:);
end
%
x_by_c_upper =
[0.000;0.030;0.055;0.080;0.104;0.146;0.187;0.228;0.286;0.351;0.425;0.507;0.5
98;0.679;0.754;0.819;0.876;0.943;1];
y_by_c_upper =
[0.000;0.028;0.037;0.043;0.047;0.053;0.056;0.059;0.060;0.060;0.057;0.053;0.0
47;0.040;0.033;0.026;0.020;0.011;0.000];
x_by_c_lower =
[0.000;0.029;0.055;0.097;0.145;0.211;0.287;0.369;0.427;0.492;0.567;0.650;0.7
48;1.000];
y_by_c_lower =
[0.000;-0.028;-0.037;-0.046;-0.053;-0.058;-0.060;-0.059;-0.057;-0.054;-0.049
;-0.043;-0.033;0.000];
slope_lower = diff(y_by_c_lower)./diff(x_by_c_lower);
temp = slope_lower(end,1);
slope_lower = [slope_lower;temp];
slope_upper = diff(y_by_c_upper)./diff(x_by_c_upper);
temp = slope_upper(end,1);
slope_upper = [slope_upper;temp];
%% C_p Calculation
C_n = zeros(10,1);
C_a = zeros(10,1);
C_l = zeros(10,1);
C_d = zeros(10,1);
Cd_wake = zeros(10,1);
L_ref = 610;
u = zeros(10,61);
y = [0; 20 ;40; 60; 80; 100; 120; 140; 150; 160; 170; 180; 190; 200; 210;
220; 230; 240; 245; 250; 255; 260; 265; 270; 275; 280; 285; 290; 295; 300;
305; 310; 315; 320; 325; 330; 335; 340; 345; 350; 355; 360; 365; 370; 380;
390; 400; 410; 420; 430; 440; 450; 460; 470; 490; 510; 530; 550; 570; 590;
610];
% density of the Liquid
rho = 1.225;
for i = 1:10
   % dynamic Pressure -- Port31
   q_infinity = mat(1,32,i);
   u_infinity = sqrt(2*q_infinity/rho);
   P_static = (mat(3,31,i)+mat(3,32,i))/2;
   P  = [mat(2,1:14,i),mat(2,16:end,i),mat(3,1:30,i)];
   u(i,:) = sqrt(2*(P - P_static)/rho);
   Cd_wake(i,1) = trapz(y,u(i,:).*(u(i,:)-u_infinity))
/(0.5*u_infinity^2*L_ref);
   % I have considered that each pressure gauge measures the Gauge pressure
   Cp = mat(1,:,i)./q_infinity;
   Cp_upper = (Cp(1:1:19))';
   Cp_lower = ([Cp(1),Cp(31:-1:19)])';
   C_n(i,1) = - trapz(x_by_c_lower,Cp_lower) - trapz(x_by_c_upper,Cp_upper);
```

```
   C_a(i,1) = trapz(x_by_c_lower,Cp_lower.*slope_lower) +
trapz(x_by_c_upper,Cp_upper.*slope_upper);
   C_l(i,1) = C_n(i,1) * cosd(AoA(i,1)) - C_a(i,1) * sind(AoA(i,1));

   C_d(i,1) = C_n(i,1) * sind(AoA(i,1)) + C_a(i,1) * cosd(AoA(i,1));
end
%% C_n Calculation using the C_p data
figure(11)
plot(AoA(1:end),C_l(1:end),"-xb");
hold on;
plot(AoA(1:end),C_d(1:end),"-xr");
xlabel("Angle of Attack in degrees");
legend("C_l", "C_d");
%% Calculation of C_d from Wake
% have imported y values from the dataset
```

- **References:**

1. Pictures and descriptions from Google, Lectures and Lecture Notes of AE351 (Lab11)
2. Fundamental of Aerodynamics - J. D. Anderson.
3. NI manual for DAQ cards used.

****