LAB 12
Measurement of Pressure Distribution over a Circular Cylinder in the Wind Tunnel
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- **OBJECTIVE :**

  1. Measure and Plot the Cp distribution over the cylinder and compare with theoretical Values.
  2. Calculate Cd distribution over the cylinder.
  3. Plot the variation in Cd Vs Re

- **THEORY :**

The flow past bluff bodies is a widely studied fluid flow problem and the cylinder is a typical bluff body. In case of the inviscid, potential flow assumption, the coefficient of pressure distribution around the cylinder is given by the following equation: $1-4\sin^2\theta$. In this scenario, the drag experienced by the cylinder is 0, as the flow is symmetric about the upstream and downstream locations.
However, in real flows, the body experiences drag due to two reasons:
1. skin-friction drag
2. pressure drag

Skin-friction drag exists because of the no-slip boundary condition on the cylinder surface, and pressure drag exists because of flow separation. When it reaches higher Reynold's number, the B/L turns turbulent causing the flows to stay attached for longer. This drastically reduces pressure drag and this phenomenon is termed 'Drag Crisis'.

- **APPARATUS :**

  - Turbulence level <= 0.1% max speed achievable is 50 m/s
  - Pressure scanner are of +- 20 inch water column equivalent to 5000 Pa
  - Will vary Re. max Re = 2.4* 10^5 which is 35m/s
  - Data Acquisition rate 60,000Hz

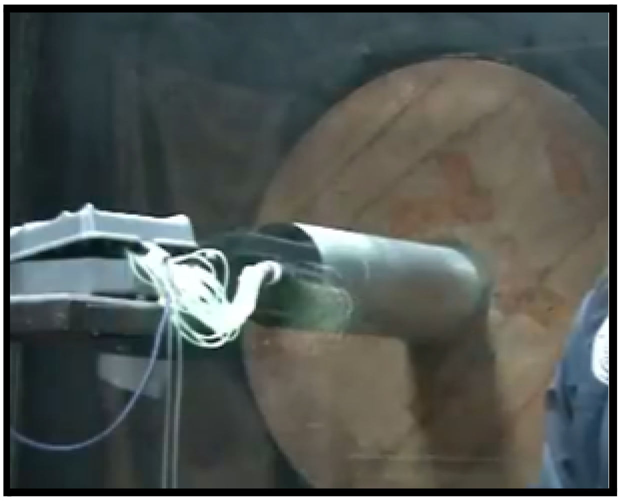
i. Low speed wind tunnel: The open-circuit low turbulence wind tunnel consists of an axial fan driven by a 2HP AC electric motor. The fan acts as a suction device. The honeycomb structure after the contraction chamber makes the flow in the test section quiescent with a turbulence intensity as low as 0.1%.

Sl. No.	Property	Measurement
1	Type	Open – Return Suction Type
2	No. Of Screenings in the settling chamber	6
3	Contraction ratio	16:1

4	Test section dimensions	0.6 m X 0.6 m X 3 m 5
5	Velocity Max.	~ 25 m/s
6	Motor	20 Hp AC

Figure 1: Wind tunnel

ii. Model: The model is a circular cylinder mounted vertically in the test section. It has 30 ports at equal angles along the circumference. 30 pressure ports at 12 deg interval



Cylinder model used

Cylinder dia =100mm and Span = 305mm

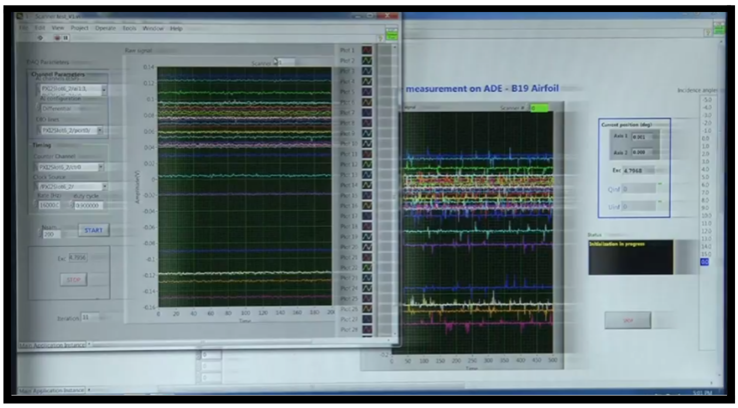
iii. Electronically Scanned Pressure sensor: 32-HD ESP scanners are differential pressure measurement units housing an array of 32 piezo-resistive sensors, one for each pressure port consisting of a Wheatstone bridge diffused onto a single silicon crystal. These scanners have two-position manifolds, one is run-mode and other one is cal-mode. The manifold position can be changed by applying a momentary pulse of control pressure. Run-mode is used to acquire pressure data and cal-mode is used for calibration of pressure ports. In cal-mode position, all sensors are connected to a common calibration pressure port. The accuracy of the scanners is maintained within ±0.05% of full scale pressure range through their periodic calibration. The frequency of calibration is dependent on ambient conditions and it changes with time. Calibration performed immediately before a set of data is acquired assures the highest accuracy of the scanners. The voltage output from the pressure sensors is connected to multiplexers which can acquire data at rate up to 20,000 Hz.

iv. Multiplexer Unit: Each sensor output is selectively routed to the onboard instrumentation amplifier by applying its unique binary address to the multiplexers. The multiplexed and amplified analog outputs of the scanners are capable of driving long lengths (up to 30 fts) of cable to the remote A/D converter of DAQ board. Scanners require 12V DC power supply for the operation of built-in analog/digital devices and a +5V DC power supply as the excitation voltage source for the sensors

v. Digital Interface and Line Driver (DILD) unit for ESP Scanners: The DAQ board provides 5-volts (TTL) logic level signals through its digital I/O lines, whereas the pressure scanners require 12-Volt (CMOS) logic level signals for binary addressing. Thus, there is a logic (TTL-CMOS) level mismatch between DAQ board and scanners. The logic level shifters of the DILD unit compensates for this logic level mismatch. The DILD unit also provides digital fan-out to drive up to 8 pressure scanners, and long cable (30 ft) drive capability. The regulated DC power (12V and 5V) required for the operation of pressure scanners are also supplied by this unit.

vi. Data Acquisition Board: A 14-bit high speed data acquisition board from National Instruments is used for the pressure measurement, which acts as an interface between sensors and computer. The data acquired is digitised and transferred to the computer by the DAQ board.

vii. Pressure Data Acquisition and Analysis Software: Data acquisition and controlling is done by the LabVIEW 12.0 application software. In-house developed pressure data acquisition and analysis software is capable of acquiring the data at desired data acquisition parameters, analysis, and presenting in the engineering units.



The DAQ developed for Acquiring the data

viii. Pitot Static tube: To measure the free stream velocity we have the pitot static tube

- **PROCEDURE :**

1. Measure the cylinder diameter and note down the ambient temperature and pressure which will be used for calculating Reynolds number.
2. Mount the pitot static in the test section to measure the flow velocity.
3. Connect the pitot static tube and static measurement port of the cylinder to the digital manometer.
4. Run the data acquisition VI and take the no wind readings.
5. Increase the speed to the desired value, and after the flow stabilises, save the wind data.
6. Repeat the same for another set of speed.
7. Run the data analysis VI to write the data to a spreadsheet file.

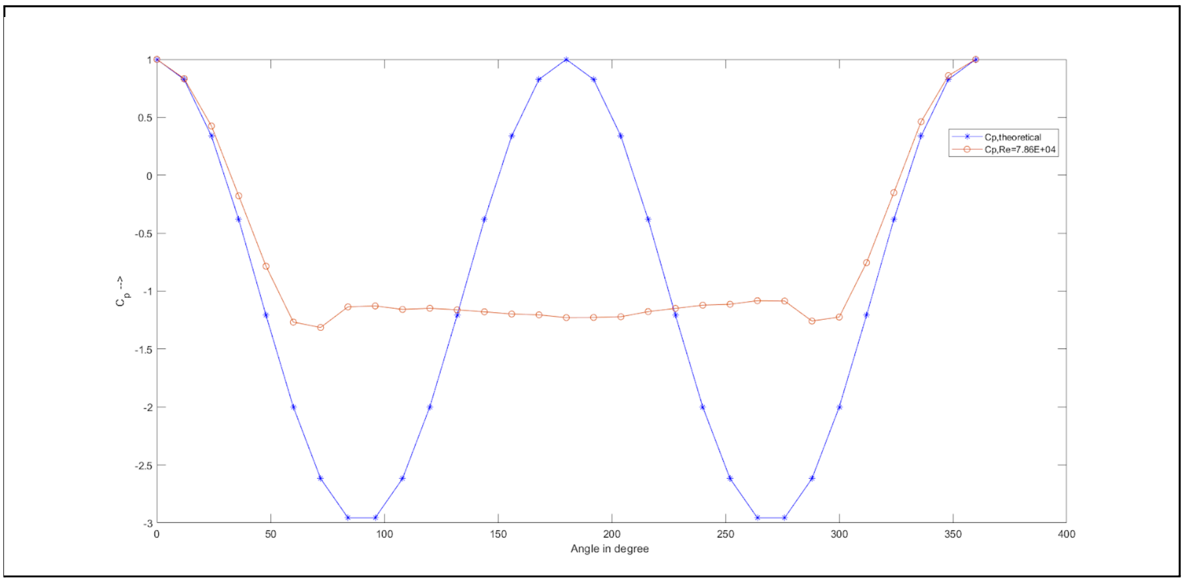
- **RESULTS AND DISCUSSION :**

assigned Dataset : Batch 2

(a) Calculation :

Reynolds number, Re_D	$Re_D = \frac{UD}{\nu}$ cylinder diameter D undisturbed free-stream velocity U Kinematic viscosity $\boldsymbol{\nu}$
Pressure Coefficient C_p	$C_p = \frac{P-P_\infty}{q_\infty}$ where $q_\infty = \frac{1}{2} * \rho * v_\infty^{\ 2}$
Drag Coefficient C_d	$C_d = -0.5 * \int_0^{2\pi} C_p cos\theta d\theta$

C_p Plots :



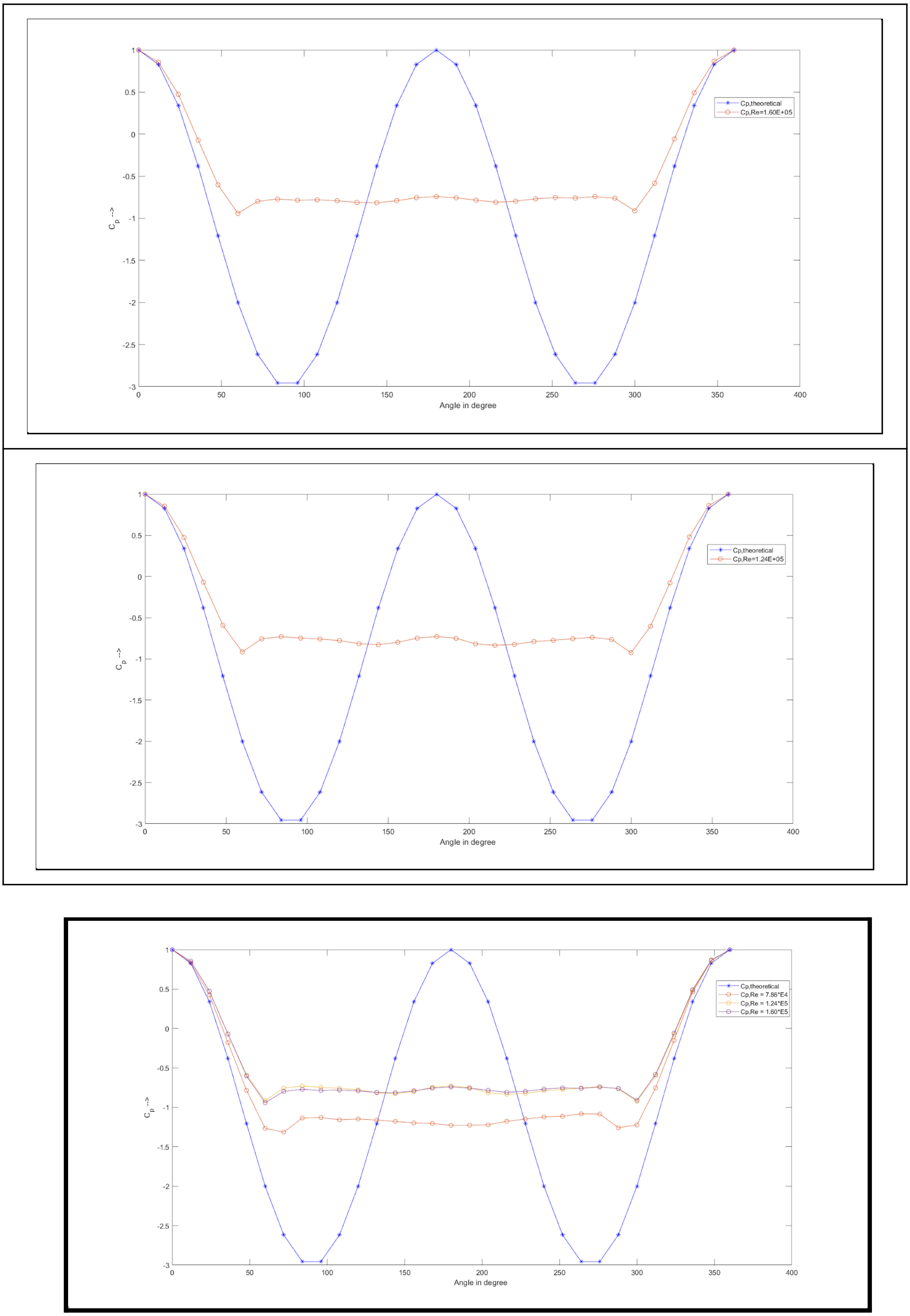


Fig1. Cp vs Theta for BATCH2 data

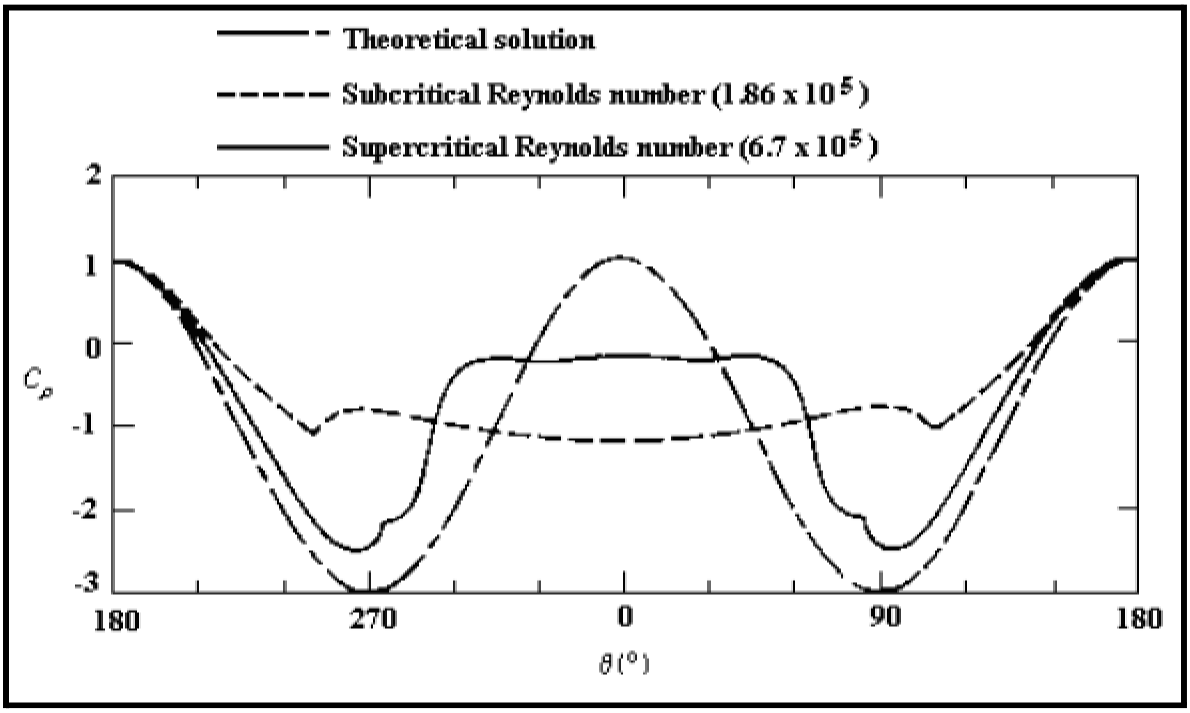
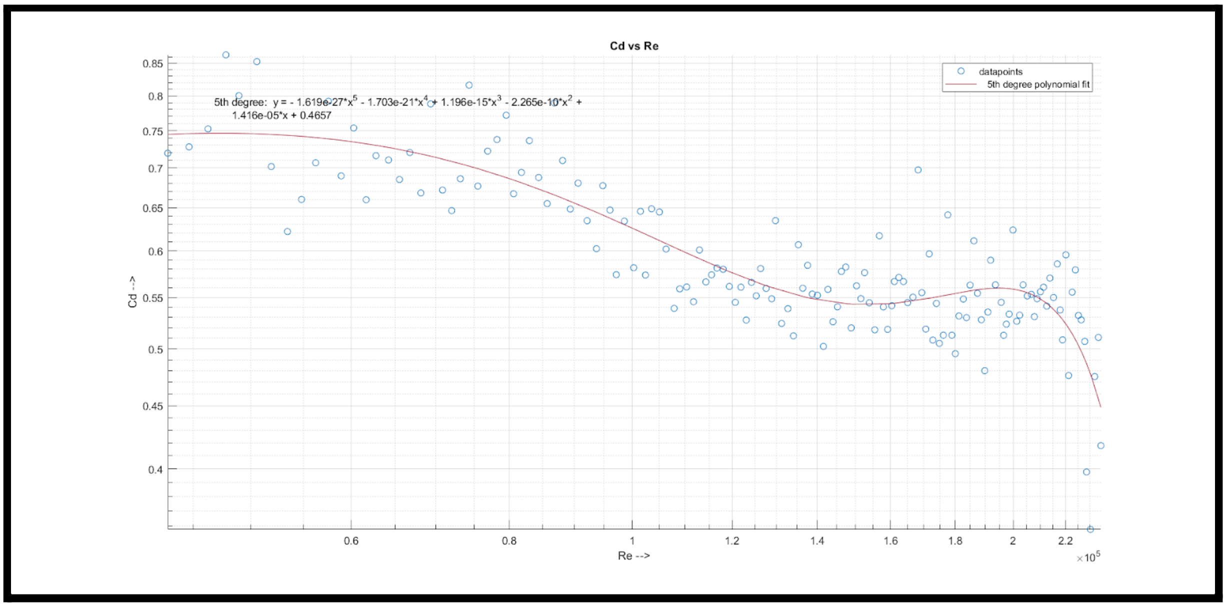


Fig2. Cp vs Theta from Lab manual

Comparing the two plots, the Cp vs Re distribution for the data given falls in the sub-critical Reynold's Number category. This is because the maximum suction falls between (-1.5,-0.8).

C_d Plot :



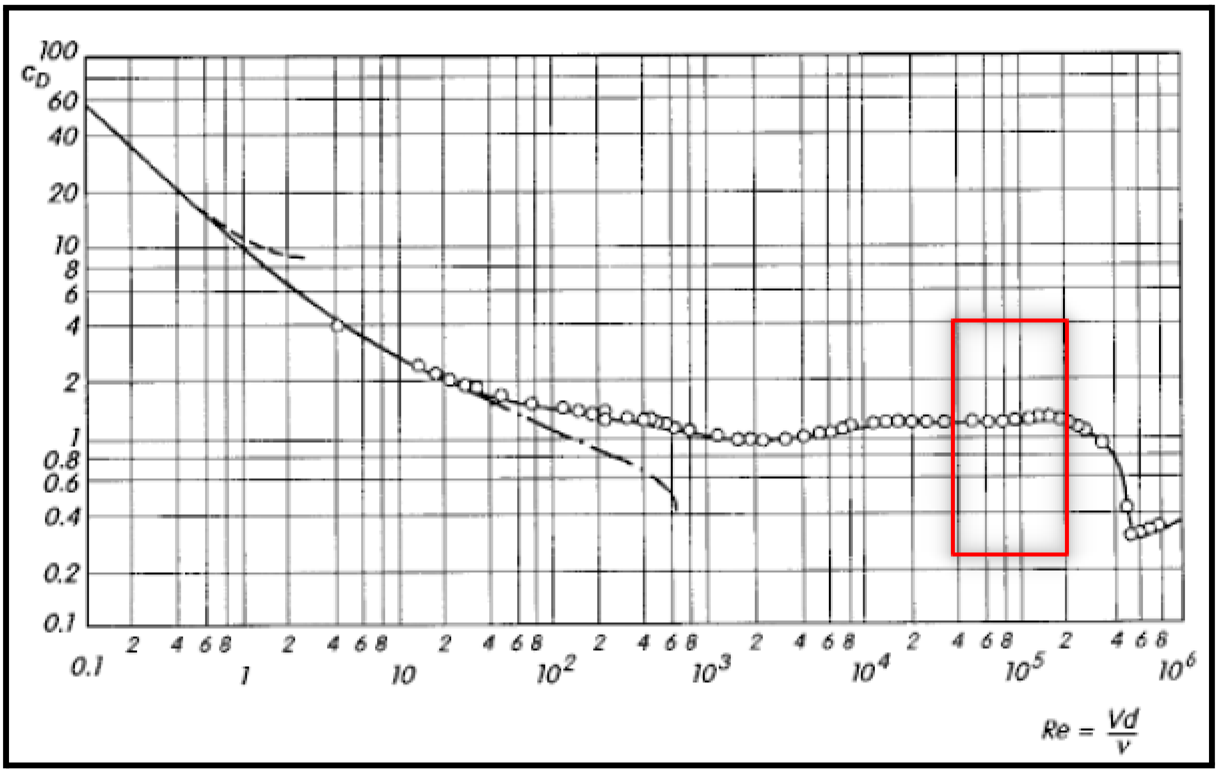


Fig4. Cd vs Re from Lab Manual

On comparing Fig.3 and Fig.4, it is clear that the Reynold's Number of the experiment carried out in Fig.3 lies between the marked red lines of Fig.4.
The Cd values for the experiment carried out lie in the range (0.75,1.25) while for the data from literature lie in the range (1,1.5). This shows appreciable similarity. The difference in the values could be due to the reason that the friction drag measured in both cases could be different. Even though it is a smooth cylinder, it has surface roughness which causes friction drag. The level of roughness for the two sets of data could be different and that could lead to the difference in Cd value**.**

(b) Inconsistencies :

The results of the experiment are in appreciable agreement with previous data for flow in the Sub-Critical Region.
The following inconsistencies were observed in the results of the experiment:

1. It was expected that peak suction would increase with increase in Re, but Fig.1 suggests that the opposite happens.
2. The Cd values are slightly lower than expected but this could be because of difference in skin friction drag as explained earlier.
3. The given formula of Cd resulted in a negative value of Cd, so the modulus had to be taken to arrive at the actual value**.**

- **Precaution :**

1. Before the start of the experiment ensure that the cylinder stagnation point is at 0 deg
2. Blockage ratio (Projected area of model / Cross Section area of Windtunnel) <= 5%

3. Ensure that the maximum pressure at any port should be within the range of the sensor.

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

Cp Calculation -

```
%% Dataset
Angles = (0:12:348)'; % in degrees
cylinder_dia = 0.100 ; % in m
cylinder_span = 0.305 ; % in m
Viscosity = 1.81*10^-5 ; % viscosity of air in Pa.S at 25deg C
rho = 1.184 ; % density of air in kg/m^3
Pressure = [
   87.10191 72.91167    37.9926     -13.44178    -65.35959    -106.54676
-110.49359  -95.3258    -94.61049   -97.19377    -96.34289    -97.51694
-98.93449   -100.56821  -101.19451  -103.24507   -103.1136    -102.58394
-98.80074   -96.45013   -94.0555    -93.39553    -90.76656    -91.02906
-105.74578  -102.82098  -62.73351   -11.11725    41.19468     75.15166;
      216.89573   185.97714   105.62432   -9.51218    -120.63177  -189.02377
      -155.29684  -149.64784  -153.37488  -155.95703  -159.83605  -167.94584
      -170.48817  -164.20531  -153.41828  -149.46237  -153.92578  -168.32525
      -172.08825  -169.66468  -162.41159  -158.98018  -155.25659  -151.47165
      -157.22779  -191.08762  -122.97787  -11.27479   106.79157   187.78013;
      364.16561   312.09513   176.36751   -17.24517   -206.54388  -327.56184
      -276.20896  -266.62869  -271.71264  -269.87238  -273.83688  -280.9481
      -282.35472  -273.78473  -261.11609  -256.0278   -261.49598  -271.36434
      -279.96623  -275.6527   -265.70488  -260.38383  -262.47796  -256.28995
      -263.21801  -316.22997  -199.61434  -12.83034   183.12669   316.97779;
];
freeStream_DynamicPressure= [85.40511; 211.99871; 356.17322] ;
% Calculation of Atmospheric P_infinity
% Pressure (:,1) contains the Stagnation pressure
P_infinity = Pressure(:,1) - freeStream_DynamicPressure;
%% calculation of Re
Re = (cylinder_dia / Viscosity) * (sqrt(2*rho*freeStream_DynamicPressure));
%% calculation of Cp
% Cp theoretical
Cp_theoretical = 1-4*(sind(Angles)).^2;
% Cp from Experimental data
Cp = (Pressure - P_infinity)./freeStream_DynamicPressure;
Cp = [ Cp [1;1;1]];
for i =1:3
   figure(i);
   plot([Angles;360],[Cp_theoretical;1],"-*b");
   hold on;
   plot([Angles;360],Cp(i,:),"-o");
   legend("Cp,theoretical",['Cp,Re=',num2str(Re(i,1),'%.2E')]);
   xlabel("Angle in degree ");
   ylabel("C_p -->");
end
figure(4)
plot([Angles;360],[Cp_theoretical;1],"-*b");
hold on;
plot([Angles;360],Cp,"-o");
xlabel("Angle in degree ");
ylabel("C_p -->");
```

Cd Calculation -

```
%% Dataset
Angles = (0:12:348)'; % in degrees
cylinder_dia = 0.100 ; % in m
cylinder_span = 0.305 ; % in m
Viscosity = 1.81*10^-5 ; % viscosity of air in Pa.S at 25deg C
rho = 1.184 ; % density of air in kg/m^3
% Pressures are in Pa
Pressure_import = importdata("DATA for Students.xlsx");
All_Pressure = Pressure_import.data.PressureData (:,3:end);
freeStream_DynamicPressure = Pressure_import.data.PressureData(:,2);
% Calculation of Atmospheric P_infinity
% Pressure (:,1) contains the Stagnation pressure
P_infinity = All_Pressure(:,1) - freeStream_DynamicPressure;
%% calculation of Cp
% Cp theoretical
%Cp_theoretical = 1-4*(sind(Angles)).^2;
%plot([Angles;360],[Cp_theoretical;1],"-*b");
%hold on;
% Cp from Experimental data
Cp = (All_Pressure - P_infinity)./freeStream_DynamicPressure;
%plot(Angles,Cp,"-o");
%hold on;
%% calculation of Re
Re = (cylinder_dia / Viscosity) *
(sqrt(2*rho*freeStream_DynamicPressure));
%% calculation of Cd
% Cd theoretical
Cd_theoretical = 0;
% Cd from Experimental data
Y = Cp .* (cosd(Angles))';
Cd = zeros(151,1);
for i=1:151
   Cd(i,1) = -0.5*trapz([Angles;360],[Y(i,:),1]);
end
plot(Re,Cd,"-*r");
```

- **References:**

1. Pictures and descriptions from Google, Lectures and Lecture Notes of AE351 (Lab12)
2. Schlichting, ``Boundary Layer Theory,'' McGraw Hill Book Co., New York, 1960.
3. Morkovin, ``Flow Around Circular Cylinder - A Kaleidoscope of Challenging Fluid Phenomena,'' Symposium on fully separated flows, ASME, 1964.

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