Circular Cylinder Lab Report

by

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Abstract

The main objective of this experiement is to test on the circular cylinder in a wind tunnel and record the pressure distribution over the surface in different test cases. The motivation of using circular cylinder is that the simple shape can help to observe the boundary laryer conditions over tehe surface under different reynolds number[1]. The aim of using tripwire is to evaluate its influence on the reattachment and separation by not changing the reynolds number. Pressure distribution was recorded by the manometer and the height differnces were used to calculate the pressure coefficient. All of the data was recorded by Excel and processed by Matlab.Drag coefficients were calculated to help evaluate the boundary layer condition. Drag coefficients were expected to have a 50% decrease after implementing tripwire.

Contents

1 Introduction and background

In the report, tables and graphs are included to demonstrate the pressure coefficient distribution over the surface of the ciruclar cylinder. The main purpose is to analyse the pressure distribution and drag coefficient among laminar and turbulent boundary layers. The discussion part will demonstrate the mechanism of the laminar and turbulent flow and further information of of this experiment. Potential flow is often described as irrotational,inviscid and incompressible flow. For the ideal condition, the equation of the theoretical pressure coefficient versus angle is[1]:

$$C_P = 1 - 4\sin^2\theta \tag{1}$$

For the sinusoidal wave this equation shows, both lift and drag aroung the circular cylinder would be absolutely 0 due to that the high pressure forming in front of the body is balanced by an equally high pressure on the back of the cylinder[2]. However, this is what happens in real-world flow around the cylinder. Due to the existence of viscosity, non-slip boundary condition could be brought to rest and reversed, this is called flow separation[3].

In this experiment, the separation of the flow decides the pressure drag. The boundray layer condition is determined by the reynolds number. Around the circular cylinder, the area before the separation has the negative pressure gradient, also called favorable pressure gradient. Pressure gradient decreases when y increases. For the area after the separation, the pressure gradient is positive which means it is adverse flow. Pressure gradient increases with increase in y. When reynolds number increases, the boundary layer thickness becomes thicker and the gradient will be steeper, more resistent to the drag[4].

According to Roshko's theory[5], due to the blockage effect, the correction formula for velocity, drag coefficient and pressure coefficient should be:

$$\frac{V}{V'} = 1 + \frac{1}{4}C'_d\left(\frac{d}{h}\right) + 0\cdot 82\left(\frac{d}{h}\right)^2 \tag{2}$$

$$\frac{C_d}{C'_d} = 1 - \frac{1}{2}C'_d\left(\frac{d}{h}\right) - 2\cdot 5\left(\frac{d}{h}\right)^2 \tag{3}$$

$$(C_p - 1) = \left(\frac{V'}{V}\right)^2\left(C'_p - 1\right) \tag{4}$$

2 Method

The apparatus and the procedure of this experiment can be found in the handout [1].

3 Results section

3.1 Table

Below are the experiment results in the table including corrected and uncorrected drag and lift coefficients in four cases.

Table 1: Data in the table

Flow Spped (m/s)	CL (Uncorrected)	CL (corrected)	CD (Uncorrected)	CD (corrected)	CD (Roshko)	Separation (Degree)
16.5666	0.0000	0.0000	1.5165	1.2001	1.0751	80
25.6648	0.0000	0.0000	1.5342	1.2119	1.0846	80
16.7314(wired)	0.0000	0.0000	0.6995	0.6011	0.5593	108
25.6648(wired)	0.0000	0.0000	0.7403	0.6334	0.5885	108

3.2 Graphs

Below, Figure 1 illutrates the pressure coefficient over the surface in 4 test cases with the theoretical pressure distribution and Figure 2 shows the corrected and uncorrected pressure coefficients in all cases.

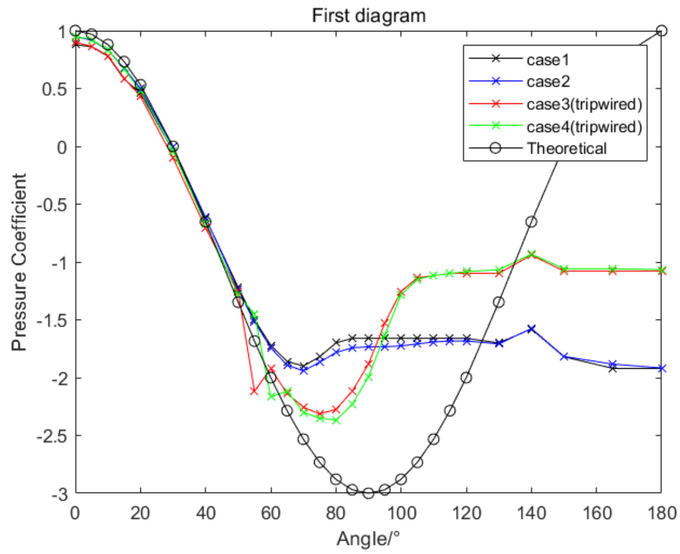

Figure 1: Uncorrected pressure distribution over angle & theoretical distribution over angle

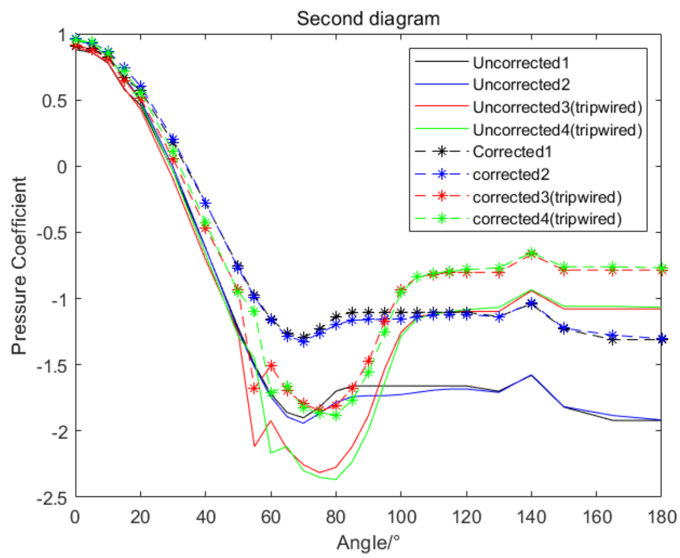

Figure 2: All the corrected and uncorrected pressure distributions over angle

4 Discussion Section

From Figure1, case 1 and 2 are the curves when the cylinder is in 2 different wind velocities without the tripwire. Case 3 and the 4 are the curves when the tripwire was mounted. The difference between the theoretical distribution and the measurd distribution can be seen. Due to the existence of the viscosity, the real-world pressure distribution is not a sin wave which is symmetrical;. In order to change the reynolds number here, the circular cylinder was tested by two flow velocities, 16.6m/s and 25.6m/s. Tripwire was also used to change the boundary layer conditions by changing the separation point over the surface, which can be seen on the diagram, pressure distribution curve moves upwards. According to the equation of reynolds number[6]:

$$\mathrm{Re} = \frac{\rho \mathrm{Uc}}{\mu} \tag{5}$$

Both changes in velocity and dimension will help to change the pressre distribution. Reynolds number is also the ratio of inertial force and viscous force[6]. In this experiment, as potential flow assumes inviscid flow, the reynolds number in this experiment would be very big, which will lead to the turbulent boundary layer. For wind speed of 16.6 m/s, the reynolds number is 1.3003e+05 and reynolds number is 2.0161e+05 which is near the transition number for the wind speed of 26.6 m/s. Tripwire was used to change the boundary layer conditions under the same wind speed. After adding the tripwire, the reynolds numbers were 1.2603e+5 and 1.9373e+5 respectively. It can be the seen that the reynolds number did not vary a lot, which might help to assume that the boundary layer conditions were the same after implementing the tripwire. However, through the table in 2.1, it can be observed that after implementing the tripwire, the drag coefficients dropped from 1.5165 to 0.6995 and 1.5342 to 0.7403 despite the change in the wind speed, drag coefficients still had a 50% decrease on each test wind speed. Thus,it is obvious that separation point has strong influence on the drag coefficient. For the accuracy on different cases, the experiment data was more reliable when the wind speed was bigger as the height difference of the manometer would be bigger,which would reduce the random error of human eyes. However, it is also safe to believe that high wind speed would make the flow in transition state which was less stable, causing fluctuation on the readings.

The wire locations of the tripwire have a critical impact on the aerodynamics performance. The mechanism of the tripwire is to delay the separation of the flow by using the reattachment. Thus when setting the position of the tripwire, the angle should not be too big otherwise there would be no reattachment for the airflow, which could not result in decrease in drag coefficient. Ideally, the position angle should be around degree 60, therefore the separation point will move from degree 80 to about degree 108 over the cylinder's surface[7].

After putting a tripwire on the surface of the circular cylinder boundary layer transfer to turbulent flow. Under almost the same speed which made no difference in reynolds number, the drag coefficients still dropped dramatically from the table 1. The tripwire made the separation point move from the frontal surface to the rear surface. The turbulent flow has many advantages. It can mix flow more effectively and more importantly, the turbulent boundary layers separate less readily than laminer ones. This is also the reason why the turbulent flow is more resistent to the drag. More momentum appear near the wall help to overcome adverse pressure gradients which was mentioned in the Introduction part. As a result, the turbulent boundary layer can withstand higher adverse pressure gradient's than laminar ones[4]. The drag on the circular cylinder will decrease as the drag coefficient decreases. Recalled the data in the table 2.1, using figure 2 in Reference [5], the equivlent reynolds number for the circular cylinder with tripwire under two wind speeds can be concluded. For the wind speed of 16.6 m/s with tripwire, the equivlent reynolds number is 3.8e+05 and the reynolds number is 3.6e+05 for the flow speed of 25.6 m/s. This is not always the case as the reynolds number should be bigger for higher wind speed. This phenomenon might be caused by the inconsistent position of the tripwire, leading to different patterns of reattchment and separation.

Due to the large frontal area of the cylinder compared to the cross-section area of the wind tunnel, the correction should be implemented to find the corrected wind velocities, drag and pressure coefficients. All the correction formulas are givn in the Introduction part. Corrected wind speed need to be found first by equation (2). With the corrected wind speeds, the corrected pressure coefficients thus could be concluded. Correct drag coefficient can be obtained by equation (4). The blockage effect actually assumes that the free stream velocity around the cylinder is higher, which would lead to lower pressure measure by the manometer. The pressure coefficient will be bigger. Thus the uncorrected pressure coefficients were actually overestimated.

Some random error also occurred in this experiment. The mininum division value of the manometer is 0.05 inch. Also, the 25th manometer tube was always higher than the tubes nearby, which was a kind of systematic error, making the pressure gradient smaller than the actual one. The viscosity is largely determined by the temperature. During the experiment, the temperature was not consistent throughout the whole process. Someone opened the window during the test, thus the temperature was lower for the cylinder with the tripwire. The decrease in temperature would result in the lower viscosity of fluids. Therefore, the calculated drag coefficients would be underestimated.

5 Conclusion

The aim of the whole experiment is to analyze the pressure distribution over the surface of the circular cylinder. It is obvious that inviscid, incompressible and irrotational flow assumed by potential flow which can not be applied to the real conditions. In conclusion, from the table and graphs, it can be deducted that using a tripwire is a very efficient way to change the boundary layer and separation point, making the flow to turbulent. However, Several improvements can still be applied to this experiment like using bigger wind tunnel to avoid correction and blockage effect and keeping the temperature constant to make the results more reliable and accurate.

References

[1] Vicent MR. Measurement of the pressure distribution on a circular cylinder. Imperial College Aeronautics Department; 2019.

[2] Johnson JHC. Resolution of d'Alembert's Paradox. Pennsylvania State University; 2008.

[3] Morrison J. Introduction to aerodynamics section 3-2. Imperial College Aeronautics Department; 2019.

[4] Morrison J. Introduction to aerodynamics section 3-4. Imperial College Aeronautics Department; 2019.

[5] Roshko A. Experiments on the flow past a circulat Cylinder at very high reynolds number. Journal of Fluid Mechanics; 1961.

[6] Morrison J. Introduction to aerodynamics. Imperial College Aeronautics Department; 2018.

[7] Igarashi T. Effect of tripping wires on the flow around a circular cylinder normal to air stream. Bulletin of JSME; 1986.

A Appendix

The appendix of this lab report is

- The matlab source code.
- The unprocessed, raw experimental readings.

A.1 Code

The data is preocessed by Matlab

```
clear
clc

D1=load('First.mat');
D2=load('second.mat');
D3=load('Third.mat');
D4=load('Forth.mat');
D1=table2array(D1.first);
D2=table2array(D2.Second);
D3=table2array(D3.Third);
D4=table2array(D4.Fourth);


V(1)=sqrt((8.55-6.05).*rho.*g.*sin(pitch).*0.0254.*2./1.225);
V(2)=sqrt((8.6-2.6).*rho.*g.*sin(pitch).*0.0254.*2./1.225);
V(3)=sqrt((8.9-6.35).*rho.*g.*sin(pitch).*0.0254.*2./1.225);
V(4)=sqrt((9.4-3.4).*rho.*g.*sin(pitch).*0.0254.*2./1.225);
g=9.81;
rho=789;
pitch=20*pi/180;
hm=[D1(2:28,3),D2(2:28,3),D3(2:28,3),D4(2:28,3)];
angle_measure=D1(2:28,2);
hf=[8.55,8.6,8.9,9.4];
theta_rad=deg2rad(angle_measure);
theta_a=angle_measure;

%iterate through each case from 1 to 4
for time=1:4
    Re(time)=1.225*V(time)*0.00102/(1.79*10^(-5));
    Cp(:,time)=(hf(time)-hm(:,time)).*rho.*g.*sin(pitch).*0.0254./(0.5
    *1.225*V(time).^2);

    CD(time)=trapz(theta_rad,Cp(:,time).*cos(theta_rad));
    %this is the incorrected CD

    %wall interference correction
    ratio=0.102/0.46;

    V_corrected(:,time)=V(time).*(1+0.25.*CD(time).*ratio+0.82.*ratio^2);
    Cp_corrected(:,time)=1+((V_corrected(time)./V(time)).^2).*
    (Cp(:,time)-1);

    CD_corrected(time)=trapz(theta_rad,Cp_corrected(:,time)
    .*cos(theta_rad));
    %corrected CD;
```

```
    CD_eqn(time)=CD(time).*(1-0.5.*CD(time).*ratio-2.5.*ratio^2);
    %correction using Roshko
end

%The value of the CD corrected, incorrected, CD_eqn.


Cp_theoretical=1-4.*(sin(theta_a*pi/180)).^2;

plot(theta_a,Cp(:,1),'kx-');
hold on
plot(theta_a,Cp(:,2),'bx-');
hold on
plot(theta_a,Cp(:,3),'rx-');
hold on
plot(theta_a,Cp(:,4),'gx-');
hold on
plot(theta_a,Cp_theoretical,'k-o');
legend('case1','case2','case3','case4','Theoretical');
title('First diagram');
xlabel('Angle');
ylabel('Pressure Coefficient');

hold off

plot(theta_a,Cp(:,1),'k-');
hold on
plot(theta_a,Cp(:,2),'b-');
hold on
plot(theta_a,Cp(:,3),'r-');
hold on
plot(theta_a,Cp(:,4),'g-');
hold on
plot(theta_a,Cp_corrected(:,1),'.k--');
hold on
plot(theta_a,Cp_corrected(:,2),'.b--');
hold on
plot(theta_a,Cp_corrected(:,3),'.r--');
hold on
plot(theta_a,Cp_corrected(:,4),'.g--');
legend('Uncorrected1','Uncorrected2','Umcorrected3(tripwired)',
'Uncorrected4(tripwired)','Corrected1','corrected2','corrected3(tripwired)
','corrected4(tripwired)');
title('Second diagram');
xlabel('Angle/');
ylabel('Pressure Coefficient');

hold off
```

A.2 Data

Hole No.	Theta (degrees)	Manometer Height (in)	Manometer Height (in)	Manometer Height (in)	Manometer Height (in)
1	-30	8.7	8.6	9.1	9.6
2	0	6.35	2.9	6.6	3.7
3	5	6.4	3.1	6.7	3.85
4	10	6.6	3.6	6.9	4.4
5	15	7.1	4.55	7.4	5.4
6	20	7.4	5.6	7.8	6.5
7	30	8.65	8.65	9.15	9.65
8	40	10.1	12.3	10.7	13.4
9	50	11.6	16.05	12.1	17.1
10	55	12.3	17.7	14.3	18.1
11	60	12.85	19.05	13.8	22.4
12	65	13.2	19.95	14.35	22.1
13	70	13.3	20.25	14.65	23.2
14	75	13.1	19.8	14.8	23.5
15	80	12.8	19.3	14.7	23.6
16	85	12.7	19.05	14.3	22.8
17	90	12.7	19	13.7	21.35
18	95	12.7	19	12.8	19.2
19	100	12.7	18.95	12.1	17.1
20	105	12.7	18.85	11.8	16.3
21	110	12.7	18.75	11.75	16.1
22	115	12.7	18.7	11.7	16
23	120	12.7	18.7	11.7	15.9
24	130	12.8	18.85	11.7	15.8
25	140	12.5	18.05	11.3	15
26	150	13.1	19.5	11.65	15.75
27	165	13.35	19.9	11.65	15.75
28	180	13.35	20.1	11.65	15.8
29	Total P	8.55	8.6	8.9	9.4
30	Static P	6.05	2.6	6.35	3.4