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Flow Around a Cylinder

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Ⅰ.Objective and Requirement

Understand the characteristics of the flow around a cylinder.

Measure the pressure distribution around the cylinder and compare it with the theoretical values.

Determine the pressure drag force on the cylinder.

Ⅱ.Equipment and Principle

1.Pressure cylinder

As shown below, a plain cylinder with a 30 mm diameter, incorporates 10 equispaced tapping points around half of the circumference that allows the pressure distribution around the cylinder to be measured. The cylinder is mounted in the horizontal plane through the side of the working section and can be rotated through 180° to plot the pressure distribution over the whole circumference. The tapping points are all flush with the surface of the cylinder and connected via flexible tubing to a multi-way quick-release connector to suit the manometers.

Pressure Cylinder

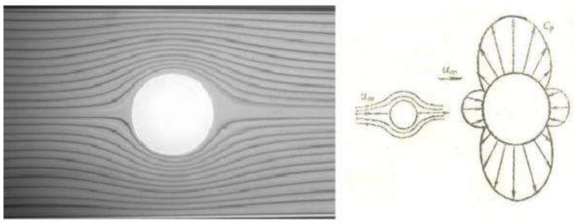
2.Hot Wire Anemometer

Hot wire anemometers are one of the types of thermal anemometers used to measure the direction and velocity of the fluid stream by measuring the heat loss of the wire, which is kept in a fluid stream. The working principle is based on the change in temperature of the wire, which is from high to low. It determines the relationship between the resistance of the wire and the wind speed.

In this experiment, the vortex shedding frequency can be measured with a hot wire in the wake area by analyzing the energy spectrum or autocorrelation function of the signal.

3.Ideal fluid flow around the cylinder

There is no friction for ideal fluid flow around the cylinder, so the flow is steady and symmetric, and the net force on the cylinder is 0.



Flow pattern and pressure distribution for ideal fluid flow around the cylinder

The flow velocity at the surface of the cylinder is:

$$|v| = 2V|sin\theta| \tag{1}$$

The pressure coefficient is:

$$C_p = \frac{P - P_0}{\frac{1}{2}\rho_a V^2} = 1 - 4\,sin^2\theta \tag{2}$$

v is the fluid velocity at the surface of the cylinder

V is the coming wind velocity (Far-field airspeed)

ρ_a is the density of air

θ is the angle between the direction of the tapping point and the direction of the incoming flow

P_0 is the static pressure of the incoming flow

P is the surface pressure acting on the cylinder at the tapping point

4.Real fluid flow around the cylinder

For viscous fluids, due to wall friction and no-slip boundary condition, the boundary layer develops and the fluid cannot be attached to the cylindrical surface as an ideal fluid, resulting in flow separation and vortexing.

The flow is not symmetric and the pressure drag is generated. The pressure coefficient can be calculated as:

$$C_P = \frac{P - P_0}{\frac{1}{2}\rho V^2} = \frac{-\mathrm{h} - (-h_0)}{h_0} = 1 - \frac{h}{h_0} \tag{3}$$

h is the water head measured at the cylinder surface

h_0 is the static pressure of the wind tunnel

5.Pressure Drag on the cylinder

The pressure drag on the cylinder is the horizontal component of the total pressure, and therefore the pressure force per unit length of the cylinder is:

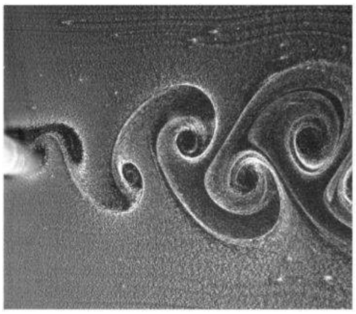
$$\begin{aligned} D &= \oint P * cos\theta ds = \int_0^{2\pi} P * cos\theta * 1 * \frac{d}{2} d\theta = -2 * \frac{d}{2}\rho_{water} g \int_0^{\pi} \mathrm{h}cos\theta d\theta \\ &= -\frac{d}{2}\rho_{water} g * 2 * \begin{pmatrix} \sum_2^9 \mathrm{h}_i * \pi * \frac{20}{180} * \cos(\theta_i) + \\ (\mathrm{h}_1 * \cos(\theta_1) + \mathrm{h}_{10} * \cos(\theta_{10})) * \pi * \frac{10}{180} \end{pmatrix} \\ &= -\frac{\pi}{18}\rho_{water} g d \left(\sum_2^9 2\mathrm{h}_i \cos(\theta_i) + \mathrm{h}_1 \cos(\theta_1) + \mathrm{h}_{10} \cos(\theta_{10}) \right) \end{aligned} \tag{4}$$

Then the drag coefficient is：

$$C_D = \frac{D}{\frac{1}{2}\rho v_\infty^2 S} = -\frac{\pi}{18} * \frac{\sum_2^9 \mathrm{h}_i * 2 * \cos(\theta_i) + \mathrm{h}_1 * \cos(\theta_1) + \mathrm{h}_{10} * \cos(\theta_{10})}{\mathrm{h}_0} \tag{5}$$

6.Karman vortex street

Under some special flow conditions, the flow around a cylinder produces a regular pattern of alternating vortices known as a von Karman vortex street, shown below.



A typical Karman vortex street behind a cylinder where hydrogen bubble

(Huang, Luofeng & Benites, Daniela & Lyu, Shiyu & smith, tom & Li, Minghao & Shang, yeru &

These vortices produce a sinusoidal force acting on the body perpendicular to the flow. The frequency f of the shedding is related to the diameter d and wind speed V via the Strouhal number Sr such that:

$$\mathrm{Sr} = \frac{fd}{V}$$

For Reynolds number around 300~3×10^5, the vortex street is fully turbulent and Sr~0.21.

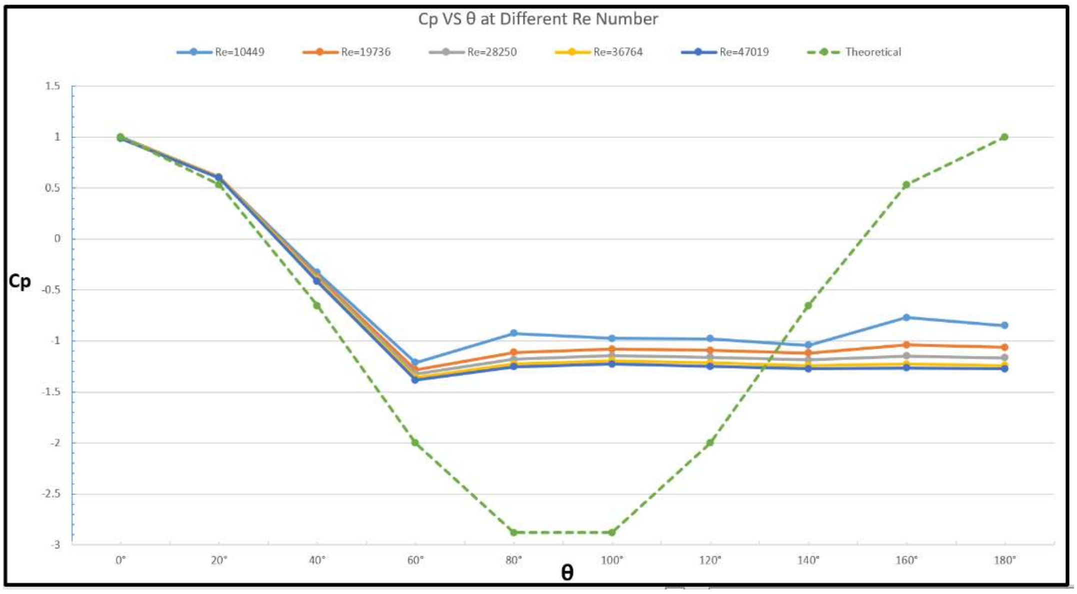
For Reynolds number around 3×10^5~3×10^6, laminar boundary layer has undergone turbulent transition and wake is narrower and disorganized.

For Reynolds number larger than 3×10^6, the turbulent vortex street reestablishes and Sr~0.27.

The vortex shedding frequency can be measured with a hot wire in the wake area by analyzing the energy spectrum or autocorrelation function of the signal.

Ⅲ.Data processing and analyzing

1. Plot Cp vs θ at different Reynolds numbers on the same graph along with the idealized theoretical prediction (with dash line). Describe and discuss the results.



Re	Cp(0°)	Cp(20°)	Cp(40°)	Cp(60°)	Cp(80°)	Cp(100°)	Cp(120°)	Cp(140°)	Cp(160°)	Cp(180°)
10449	1.00	0.61	-0.33	-1.21	-0.93	-0.97	-0.98	-1.04	-0.77	-0.85
19736	1.00	0.61	-0.37	-1.28	-1.11	-1.08	-1.09	-1.12	-1.04	-1.06
28250	0.99	0.61	-0.38	-1.32	-1.18	-1.14	-1.16	-1.19	-1.15	-1.17
36764	0.99	0.60	-0.40	-1.36	-1.23	-1.20	-1.22	-1.24	-1.23	-1.24
47019	0.99	0.60	-0.42	-1.38	-1.25	-1.23	-1.25	-1.27	-1.26	-1.27
Theoretical	1.00	0.53	-0.65	-2.00	-2.88	-2.88	-2.00	-0.65	0.53	1.00

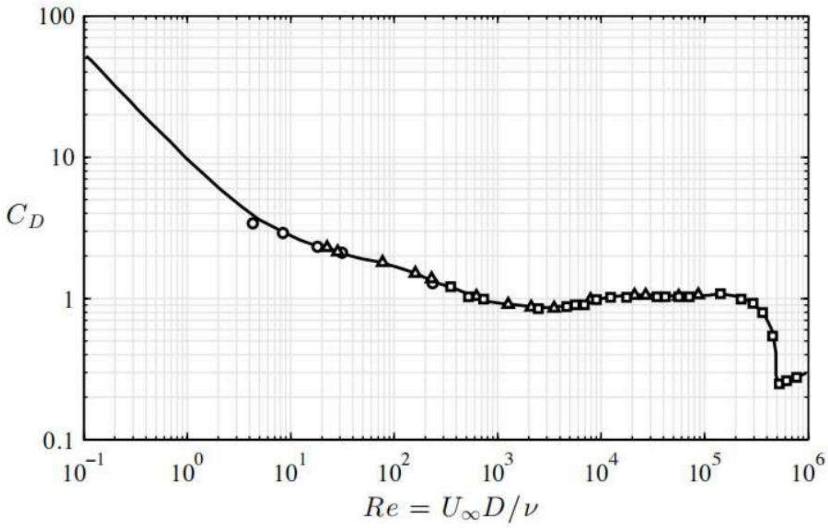
Description

Theoretically, the flow is steady and symmetric for ideal fluid flow around the cylinder, so the pressure coefficients on the cylindrical surface are symmetrical as shown above. Experimentally, on the one side, the results show that the pressure coefficient increases with the increase of the Reynolds number at the same measurement angle. On the other side, Under the same Reynolds number condition, the pressure coefficient decreases with the increase of the measured angle and reaches the minimum value when the measured angle is 60°, rising slightly when the measured angle is 80°, and then tends to be stable.

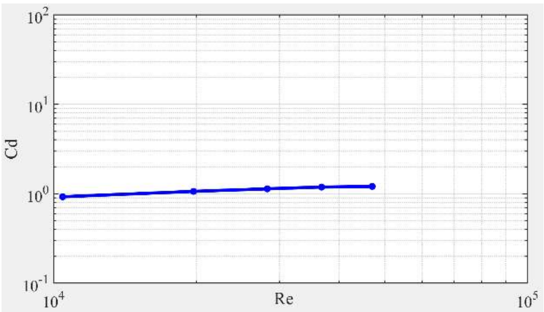
Discussion

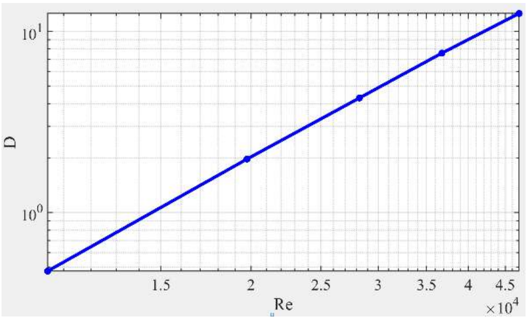
In actual fluid flow around the cylinder, the influence of the viscosity makes the pressure before and after the division of the asymmetry, forming vortexes at the back of the cylinder due to the viscous boundary layer separation, so that the actual cylinder pressure distribution on the cylinder surface different from the theoretical one. The pressure can't return to the same level as the front, and the pressure at the back of the cylinder from the separation point is approximately the pressure at the separation point.

2.Estimate the pressure drag and pressure drag coefficient for each Reynolds number and plot D vs Re and C_p vs Re respectively. Describe and discuss the results (compare with the following figure).



Re	D	Cd
10449	0.47	0.93
19736	1.97	1.06
28250	4.29	1.14
36764	7.60	1.19
47019	12.58	1.21





Description

From the experimental results, with the increase of Reynolds number, the pressure coefficient changes within a small range and is almost at a stable level, which is consistent with the result that when the Re is $10^4 \sim 10^5$ in the reference image. Pressure drag increases with increasing Reynolds number.

Discussion

In the reference figure, the boundary layer starts to separate from the front of the cylinder from about Re=10^4, and the vortex street breaks into turbulence, forming a wide separation area. Pressure drag is proportional to the quadratic of the velocity, that is, C_D almost does not change with Re.

In the experimental results, the C_D VS Re figure is roughly consistent with the reference image, and the D VS Re figure is linear after coordinate logarithmic processing, which is roughly consistent with the description of the reference figure.

3.Analyze the vortex shedding frequency and compare them with the theoretical values.

should show how you get the frequency −3

Velocity m/s	Frequency Hz	Sr
5.4	38.7	0.22
10.2	72.7	0.21
14.6	104.9	0.22
19.0	135.9	0.21
24.3	173.7	0.21

After averaging the data in the above table, we obtain Sr=0.214, which is close to the theoretical value that Sr~0.21 for the Reynolds number around 300~3×10^5.

Ⅳ.Questions

1 . Discuss the possible experimental errors and make improvement suggestions.

Experimental errors

1) Before the experiment, it was not checked that the upper opening hole of the wind tunnel test section was not closed, and the whole experiment process was carried out in the test section with the upper opening hole, which may affect the flow field. Namely some air flow would escape from the hole, which may cause the measured pressure to be low. −2

2) In the whole process of the experiment, physical quantities related to temperature, such as air density and air viscosity coefficient, were calculated according to the temperature measured before the experiment began, but in fact, the temperature fluctuated in a small range, which would lead to certain errors in the calculation results compared with the actual case.

Improvement suggestions

1) Before conducting experiments, strictly check whether the experimental

equipment meets the experimental standards.

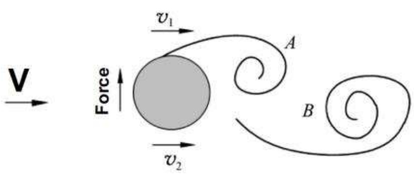
2）The device that can record the real-time temperature is added in the experiment process, and the recorded temperature and the measured wind speed can achieve one-to-one correspondence, so that the physical quantity changing with the temperature can be calculated more accurately and more accurate experimental results can be obtained

3）The measuring points around the cylinder surface can be appropriately increased to obtain a smoother Cp VS θ figure.

2．Search for Karman vortex street, and discuss its causes and hazards in detail

Causes

Under certain conditions, the flow of a fluid that has a constant flow (the pressure, velocity, and density at any point in the fluid do not change with time) around certain objects, the sides of an object periodically drop off regular, counter-rotating, double-row-line vortices. At first, the two line vortices move forward, and then they start to interfere with each other, and they attract each other, and the interference gets stronger and stronger, forming what's called a nonlinear Vortex Street. In fluid mechanics, the two rows of alternating vortices created by this fluid as it moves around an object are called Carmen Vortex Streets.



Hazards

The alternative emission of vortices behind the Karman vortex street will generate alternating lateral force perpendicular to the flow direction of the object, forcing the object to generate vibration. When the emission frequency is coupled with the natural frequency of the object structure, resonance will occur, causing damage. In the 20th century, the collapse of Tacoma Narrows Bridge was the most far-reaching accident that damaged the bridge on Carmen Vortex Street.

Vibration of Tacoma Narrows Bridge