The Influence of distance between passive control and circular cylinder on wake

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Abstract. Two passive controls are placed in front of and behind the circular cylinder will reduce the coefficient of drag that is received by the circular cylinder. Passive control located in front of the circular cylinder has a fixed distance, while the passive control behind the circular cylinder has a varied distance. The drag coefficient of the circular cylinder depends on the distance between the circular cylinder and the passive control behind the circular cylinder, thus affecting the wake. In this paper, Reynolds numbers 100, 500 and 1000 will be used to find the wake.

1. Introduction

Offshore buildings, industrial chimneys, long bridge structures and other engineering products are often designed in groups. The geometric shapes of these objects are usually circular cylinders, elliptical cylinders or other shapes, this is a major factor to be considered in designing offshore buildings or other buildings. Fluid flow through a single object or group object will produce different characteristics.

The fluid that flows through the surface of the object, then the flow of particles around the surface of the object will move slowly due to friction force, so that the particle flow velocity around the object will be zero. While the flow of other particles will interact, so the velocity of the flow away from the object will move faster. This is due to increased shear stress. While the shear stress affects the velocity of each layer, the layer is called the boundary layer.

The effect of the shear stress that has an important role of flow characteristics around the object is the concept of boundary layer\cite{1}. The research that has been done is the fluid flow through a circular cylinder\cite{2}, a cylinder of type-$D$, and type-$I$\cite{3, 4}. In addition, the fluid flow through cylinders is grouped with various sizes and configurations, fluid flow through circular cylinder with tandem configuration\cite{5, 6, 7, 8}.

The coefficient of drag of an object can be reduced by increasing the passive object of control in front of or behind objects. 48\% of the drag coefficient can be reduced by adding a passive control in the front of circular cylinder\cite{5}, this is also done with different Reynolds numbers\cite{6}. The passive control can be a cylinder type-$I$ or the other. In this paper, we will use a cylinder...
type-I with a 53° cutting angle because it has the largest wake width compared to the other cutting angle.

The passive controls in front are used in the cylinder type-I with the angle 53° at the upright position, while the passive controls are in the back with the horizontal position of the same shape. The passive control distance in front with a fixed circular cylinder, while the passive control in the rear has varying distances. The Reynolds number used is \( R_e = 100, 500 \) and 1000. How does the wake occur behind the circular cylinder and the effect on the decrease of the drag coefficient?

2. Numerical Method

The equations used for unsteady incompressible fluid is the Navier-Stokes equations

\[
\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot \mathbf{u} \mathbf{u} = -\nabla P + \frac{1}{Re} \nabla^2 \mathbf{u} \tag{1}
\]

\[
\nabla \cdot \mathbf{u} = 0. \tag{2}
\]

where \( \mathbf{u} \) is the velocity, \( Re \) is the Reynolds number, and \( P \) is the pressure. Numerical method and SIMPLE algorithm is used to solve the Navier-Stokes equations. The first step taken is to provide an initial value for each variable, and then, get the speed component of the momentum equation by ignoring the earlier pressure components, so that (1) becomes

\[
\frac{\partial \mathbf{u}}{\partial t} = -\nabla \cdot \mathbf{u} + \frac{1}{Re} \nabla^2 \mathbf{u} \tag{3}
\]

right-hand side is solved using finite difference, like

\[
(f_x)_i = \frac{2f_{i+1} + 3f_i - 6f_{i-1} + f_{i-2}}{6dx} \quad \text{and} \quad (f_x)_j = \frac{2f_{j+1} + 3f_j - 6f_{j-1} + f_{j-2}}{6dy}
\]

\[
(f_{xx})_i = \frac{f_{i+1} - 2f_i + f_{i-1}}{dx^2} \quad \text{and} \quad (f_{yy})_j = \frac{f_{j+1} - 2f_j + f_{j-1}}{dy^2}
\]

and the second step is carried out

\[
\frac{\partial \mathbf{u}}{\partial t} = \frac{\mathbf{u}^{**} - \mathbf{u}^*}{\Delta t} = -\nabla P \tag{4}
\]

We now put divergence on both sides, and the result by considering the equation (2) then \( \nabla \mathbf{u}^{**} = 0 \), the equation becomes

\[
\frac{\nabla \cdot \mathbf{u}^*}{\Delta t} = -\Delta P \tag{5}
\]

Equation (5) is called Poisson’s equation. Completion of the Poisson equation solution will be more quickly to achieve convergence, if using SOR (Successive Over Relaxation)

\[
(P_n)_{i,j} = (1 - \omega)((P_{n-1})_{i,j}) + \omega(P_n)_{i,j} \tag{6}
\]

This equation will yield a value of \( P \). The final step is the correction of velocity equation

\[
\frac{\partial \mathbf{u}}{\partial t} = -\nabla P \tag{7}
\]
3. Main Results
We will simulate the above problems by establishing a system of measuring $10D \times 20D$, where $D$ is the diameter of circular cylinder. The circular cylinder position is located at $4D$ from the front and at $5D$ from top, like Figure 1. Two passive controls have the same form that is cylinder type-1 in diameter $d = D/8$ and cuts of $53^\circ$. Passive controls are located at the front of the circular cylinder that has a distance of $S$ which varies the $S/D = 0.6, 1.2, 1.8$ and $2.4$ in an upright position, while passive controls are located at the back have a spacing $T$ which varies the $T/D = 0.6, 0.9, 1.2, 1.5, 1.8$ and $2.1$ with a horizontal position, as in Figure 2. The wake data is taken at a distance of $6D, 8.5D$ and $11D$ against the circular cylinder.

![Figure 1. Design research system.](image1)

![Figure 2. Schematic of two passive controls and circular cylinder.](image2)

| Table 1. $C_D$ of a cylinder circular without passive control. |
|---|---|---|
| $Re$ | 100 | 500 | 1000 |
| $C_D$ | 1.36 | 1.23 | 1.21 |

The simulation program for calculating the drag coefficient on a single circular cylinder with the Reynolds 100 number is 1.36, while the other researcher is 1.4 by Zulhidayat and by Five is 1.39 [9], meaning the simulation program has a good truth value. Such simulation programs are used by authors for Simulates circular cylinder with one passive control and two passive controls with different Reynolds numbers.

The result of the simulation program obtained the data of drag coefficient of circular cylinder with one passive control in front can be seen in Table 2. From that data it can be seen that
Table 2. $C_D$ of a cylinder circular for Re = 100 with difference $S/D$.

| $Re$ | $S/D$ | 0.6 | 1.2 | 1.8 | 2.4 | 3.0 |
|------|-------|-----|-----|-----|-----|-----|
| 100  | $C_D$ | 1.23| 1.05| 1.04| 1.00| 1.03|
| 500  | $C_D$ | 1.11| 0.93| 0.91| 0.92| 0.95|
| 1000 | $C_D$ | 1.11| 0.94| 0.90| 0.89| 0.91|

The effective passive distance of control to reduce the magnitude of the inhibitory coefficient is at $S/D = 2.4$ for Reynolds 100 and 1000, while for Reynolds 500 is located at the distance $S/D = 1.8$. Therefore the distance is used as a fixed distance for the forward passive control. The following shows the simulation results of the circular cylinder drag coefficient with two passive controls, the forward passive control distance is $S/D = 2.4$ for the Reynolds number 100 and 1000 and $S/D = 1.8$ for Reynolds 500. While the passive distance behind the control is varied, as in Table 3.

Table 3. $C_D$ of a cylinder circular with double control passive.

| $S/D$ | $Re$ | $T/D$ | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 |
|-------|------|-------|-----|-----|-----|-----|-----|-----|
| 2.4   | 100  | $C_D$ | 0.994| 0.965| 0.964| 0.956| 0.949| 0.949|
| 1.8   | 500  | $C_D$ | 0.918| 0.922| 0.921| 0.919| 0.916| 0.912|
| 2.4   | 1000 | $C_D$ | 0.876| 0.854| 0.855| 0.845| 0.837| 0.835|

From Table 1, 2 and 3, it appears that for the 100 Reynolds number is valid

$$C_{D-Single} > C_D(S/D=2.4) > C_D(S/D=2.4,T/D=2.1)$$

and for Reynolds number 500 the following inequality holds

$$C_{D-Single} > C_D(S/D=1.8) > C_D(S/D=1.8,T/D=2.1)$$

and for Reynolds number 1000 the following holds

$$C_{D-Single} > C_D(S/D=2.4) > C_D(S/D=2.4,T/D=2.1)$$

The drag coefficient will be reduced by adding passive controls both in front and behind a single circular cylinder, as in all three equations.

Wake occurring on a single circular cylinder with the Reynolds number 100, further away from the circular cylinder the average speed is higher (see Table 4, column $S_{100}$), as well as Reynolds 500 (column $S_{500}$) and Reynolds number 1000 (column $S_{1000}$). This also occurs in circular cylinders with one passive control in front ($T_{1-100}$, $T_{1-500}$ and $T_{1-1000}$) columns, as well as on circular cylinders with two passive controls in front and rear (column $T_{2-100}$, $T_{2-500}$ and $T_{2-1000}$). More clearly can be seen in Figure 3, 4 and 5.

Table 4. Wake at $x = 10D, 12.5D, 15D$ for $Re = 100, 500, 1000$.

| $x$  | $S_{100}$ | $T_{1-100}$ | $T_{2-100}$ | $S_{500}$ | $T_{1-500}$ | $T_{2-500}$ | $S_{1000}$ | $T_{1-1000}$ | $T_{2-1000}$ |
|------|-----------|-------------|-------------|-----------|-------------|-------------|-----------|-------------|-------------|
| 10D  | 0.943     | 0.938       | 0.927       | 0.924     | 0.922       | 0.923       | 0.945     | 0.944       | 0.940       |
| 12.5D| 0.948     | 0.942       | 0.935       | 0.930     | 0.928       | 0.928       | 0.950     | 0.948       | 0.947       |
| 15D  | 0.951     | 0.943       | 0.940       | 0.934     | 0.931       | 0.932       | 0.953     | 0.951       | 0.950       |
Figure 3. Re=100.  

Figure 4. Re=500.  

Figure 5. Re=1000.  

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