Reduction of $C_d$ in circular cylinder using two passive control at $Re = 1000$ and 5000

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Abstract. There are many ways to reduce the drag force of an object, one of them by adding another smaller object called the passive control. Two passive controls will be placed in front and rear of the main object. The main object is a circular cylinder, the passive control that is in front is the cylinder type-I and the rear is an elliptical or circular cylinder. The distance between the main object with the two passive controls is varied and the Reynolds number used is 1000 and 5000. We want to find the effective distance of the main object with both passive controls so that the drag coefficient of the main object is minimal compared to the non-passive control or with one passive control in front of.

1. Introduction
Research conducted by researchers aims to get new technology, where the new technology is expected to change the behavior of users of these new technologies. Research on the flow of fluids through an object with the aim of reducing the drag force of the object is mostly done by the researchers. Some researchers used one passive control placed in front of various shapes, such as cylindrical cylinders, type-I cylinders, type-D cylinders etc.

Industrial chimneys, the structure of the offshore, the structure of the flyover and others, designing such examples in groups. Circular cylinders, elliptical cylinders or other shapes are commonly used objects. The value of the drag coefficient depending on the geometrical shape of the object, so that a different geometric shape the drag coefficient values are also different. Fluid flow across an object or multiple grouped objects will produce different flow characteristics. This happens because of the interaction between the fluid flow and the object.

Fluid flow through the surface of an object then the flow moving around the object will flow slowly even the flow attached to the object will have zero speed. This is caused by the friction between the fluid with the object. While other streams will interact, so the flow rate of the object will move faster. This indicates an increase in shear stress which will affect the flow velocity in each layer, called the boundary layer.

Research has been conducted on the flow of fluids through a single object, such as a single cylindrical circular object[2], or a modified cylinder such as a cylinder type-I or a cylinder type-D[3, 4]. While research has been conducted on fluid flow through more than one object, ie fluid flow through more than one cylinder of various sizes and configurations, fluid flow through
circular cylinder with tandem configuration[5, 6, 7, 8] and its elliptical cylindrical side-by-side configuration[9, 10]. The above studies use the boundary layer concept, and the concept of the boundary layer can find the answer to the effect of shear stress having a very important role in the characteristics of the current around the object[1].

If an object is passed by a fluid, then the object will produce a drag force, while the drag force is influenced by several parameters, one of which is the drag coefficient. How to reduce drag on objects passed by fluid, one way is to add a smaller object in front of the main object called passive control. The addition of passive control is carried out to reduce the drag coefficient of 48%[5], also done with different Reynolds numbers and resulting in lower drag coefficient[6]. The cylinder type-\(I\) is a circular cylinder by cutting the left and right by a certain angle, so the cylinder is shaped like I. The best cutting edge is \(53^\circ\), this is because the wake occurs wider than the other angle, formed also wider and more annoying flow stronger on the object wall.

In this paper, two passive controls will be used, ie, passive controls in front of the cylindrical type-\(I\) with the angle is \(53^\circ\) and passive controls behind the circular cylinders and elliptical cylinders. The position of the passive control in front is perpendicular to the flow, while the passive control in the rear is landscape. The distance between the passive control in front and the circular cylinder has varying distances, as well as the distance between the passive control in rear and the circular cylinder. The Reynolds number used is \(R_e = 1000\) and 5000. When do these two passive controls effectively decrease the drag coefficient?

2. **Numerical Method**

The above-mentioned problem can be solved by using the unsteady incompressible fluid equation of Navier-Stokes equations.

\[
\frac{\partial \mathbf{v}}{\partial t} + \nabla \cdot \mathbf{vv} = -\nabla P + \frac{1}{Re} \nabla^2 \mathbf{v} \quad (1)
\]

\[
\nabla \cdot \mathbf{v} = 0. \quad (2)
\]

where \(Re\) is the Reynolds number, \(\mathbf{v}\) is the velocity, and \(P\) is the pressure. SIMPLE algorithm and numerical methods will be used to solve the Navier-Stokes equation. First thing to do is give the initial value for each variable. By ignoring the pressure component we will find the velocity component of the momentum equation, so (1) becomes

\[
\frac{\partial \mathbf{v}}{\partial t} = -\nabla \cdot \mathbf{vv} + \frac{1}{Re} \nabla^2 \mathbf{v} \quad (3)
\]

by using the finite difference method, like

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

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

afterwards

\[
\frac{\partial \mathbf{v}}{\partial t} = \frac{\mathbf{v^{**}} - \mathbf{v^*}}{\Delta t} = -\nabla P \quad (4)
\]

because equation (2) then equation (4) becomes

\[
\frac{\nabla \cdot \mathbf{v^*}}{\Delta t} = -\Delta P \quad (5)
\]
by using SOR (Successive Over Relaxation)

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

(6)

the result in value \(P\) and the last step is

\[\frac{\partial v}{\partial t} = -\nabla P\] 

(7)

Figure 1. Design research system.

Figure 2. Schematic of two passive controls and circular cylinder.

3. Main Results

Our research system is \(10D \times 20D\), where \(D\) is the diameter of the circular cylinder and is placed at a distance \(4D\) from the front of the system and in the center of the system, like Figure 1.

In this paper, we use two passive controls. The first passive control is an cylinder type-I and is placed in front of a circular cylinder with varying distances, ie \(S/D = 0.6, 1.2, 1.8, 2.4\) and \(3.0\). The second passive control are circular cylindrical and elliptical cylinders. The second passive control is placed rear of the circular cylinder at varying distances, ie \(T/D = 0.6, 0.9, 1.2, 1.5, 1.8\) and \(2.1\) as in Figure 2.
The drag coefficient of a single circular cylinder has been obtained by using the simulation program, the results are compared with experimental results and other simulation programs. We calculate the drag coefficient of a single circular cylinder with \( R_e = 100 \) is 1.356, while other researchers with the same Reynolds number, such as Zulhidayat is 1.4 and by Five is 1.39[12]. In this paper will be simulated circular cylinder with two passive controls, and the Reynolds number used is 1000 and 5000. The drag coefficient for single circular cylinder with \( R_e = 1000 \) is 1.21, and for \( R_e = 5000 \) is 1.51.

Table 1. \( C_D \) of a cylinder circular for \( R_e = 1000 \) and 5000 with difference \( S/D \).

| \( S/D \) | 0.6 | 1.2 | 1.8 | 2.4 | 3.0 |
|-----------|-----|-----|-----|-----|-----|
| \( C_{D_{1000}} \) | 1.114 | 0.946 | 0.896 | 0.894 | 0.911 |
| \( C_{D_{5000}} \) | 1.455 | 1.273 | 1.221 | 1.224 | 1.216 |

Table 1 is data of the drag coefficient of a circular cylinder with a passive control cylindrical type-I is located at the front with varying distances. From the table it shows that for Reynold number \( R_e = 1000 \), the best distance to get the minimum drag coefficient is \( S/D = 2.4 \) with the value of the drag coefficient is 0.894, while for Reynolds number \( R_e = 5000 \), the best distance for get the minimum drag coefficient is \( S/D = 1.8 \) or \( S/D = 3.0 \) with a drag coefficient of 1.221 or 1.216. The value of the drag coefficient is still smaller than the drag coefficient without passive control.

3.1. Reynold number \( R_e = 1000 \)

Table 2. \( C_D \) with passive control cylinder elips for \( R_e = 1000 \) with difference \( T/D \).

| \( C_{D_E} \) | \( S/D \) |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( T/D \) | 0.6 | 1.2 | 1.8 | 2.4 | 3.0 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 |
| 0.6 | 1.090 | 0.923 | 0.874 | 0.872 | 0.889 | 1.090 | 0.923 | 0.874 | 0.872 | 0.889 |
| 0.9 | 1.056 | 0.892 | 0.843 | 0.842 | 0.860 | 1.056 | 0.892 | 0.843 | 0.842 | 0.860 |
| 1.2 | 1.061 | 0.896 | 0.847 | 0.846 | 0.863 | 1.061 | 0.896 | 0.847 | 0.846 | 0.863 |
| 1.5 | 1.049 | 0.885 | 0.837 | 0.836 | 0.853 | 1.049 | 0.885 | 0.837 | 0.836 | 0.853 |
| 1.8 | 1.036 | 0.874 | 0.828 | 0.827 | 0.844 | 1.036 | 0.874 | 0.828 | 0.827 | 0.844 |
| 2.1 | 1.029 | 0.870 | 0.825 | 0.824 | 0.841 | 1.029 | 0.870 | 0.825 | 0.824 | 0.841 |

The drag coefficient of a single circular cylinder with two passive controls on the front and the rear. Passive control in front of circular cylinder is cylinder type-I, while passive control in rear of circular cylinder is elliptical cylinder. Data drag coefficient with Reynolds number \( R_e = 1000 \) and configuration as above, can be seen in Table 2. It appears that the passive control in rear it has a significant effect on the drag coefficient, since the drag coefficient is still smaller than that of a passive control just in front it or without passive control. Minimal drag coefficient of this configuration is 0.824, this occurs is the \( S/D = 2.4 \) and \( T/D = 2.1 \).

Passive control in front of the circular cylinder is the cylinder type-I, while the passive control behind the circular cylinder is a small circular cylinder. The data of the drag coefficient with the Reynolds number \( R_e = 1000 \) and the configuration as above, can be seen in Table 3. It appears that the passive control behind it has a significant effect on the drag coefficient, since the drag coefficient is still smaller than that of a passive control just in front of it or without passive control. the minimum drag coefficient of the configuration is 0.832, this occurs at \( S/D = 2.4 \) and \( T/D = 2.1 \).
Table 3. $C_D$ with passive control cylinder circular for $Re = 1000$ with difference $T/D$.

| $C_D$ | $S/D$ |
|-------|-------|
| $T/D$ | 0.6   | 1.2   | 1.8   | 2.4   | 3.0   |
| 0.6   | 1.092 | 0.925 | 0.876 | 0.874 | 0.891 |
| 0.9   | 1.066 | 0.901 | 0.852 | 0.851 | 0.868 |
| 1.2   | 1.067 | 0.902 | 0.853 | 0.852 | 0.869 |
| 1.5   | 1.055 | 0.891 | 0.843 | 0.842 | 0.859 |
| 1.8   | 1.043 | 0.882 | 0.835 | 0.834 | 0.851 |
| 2.1   | 1.038 | 0.878 | 0.833 | 0.832 | 0.849 |

**Figure 3.** $C_D$ Cylinder Elips $Re = 1000$.

**Figure 4.** $C_D$ Cylinder Circular $Re = 1000$.

The graph of Table 2 is Figure 3 and Table 3 is Figure 4. From the two figures shows that the minimum drag coefficient to Reynolds $Re = 1000$ is the configuration of passive control in the back is circular cylinder with a distance of $S/D = 2.4$ and $T/D = 2.1$. Elliptical cylinder passive controls that are within $S/D = 2.4$ and $T/D = 2.1$ are better than the circular cylindrical passive control that are within $S/D = 2.4$ and $T/D = 2.1$, in other words passive controls in the form of elliptical cylinder is more effective compared with passive control in the form of circular cylinder.

3.2. **Reynolds number** $Re = 5000$

Table 4. $C_D$ with passive control cylinder elips for $Re = 5000$ with diference $T/D$.

| $C_D$ | $S/D$ |
|-------|-------|
| $T/D$ | 0.6   | 1.2   | 1.8   | 2.4   | 3.0   |
| 0.6   | 1.155 | 1.005 | 0.967 | 0.986 | 0.982 |
| 0.9   | 1.172 | 1.016 | 0.991 | 0.983 | 0.991 |
| 1.2   | 1.151 | 1.004 | 0.967 | 0.980 | 0.976 |
| 1.5   | 1.368 | 0.941 | 0.906 | 0.925 | 0.957 |
| 1.8   | 1.461 | 1.225 | 1.183 | 1.193 | 1.193 |
| 2.1   | 1.404 | 1.229 | 1.160 | 1.163 | 1.157 |

The drag coefficient of a circular cylinder with two passive controls on the front and the rear. Passive control in front of circular cylinder is cylinder type-I, while passive control in rear of circular cylinder is elliptical cylinder. Data drag coefficient with Reynolds number $Re = 5000$ and configuration as above, can be seen in Table 4. It appears that the passive control in rear it has a significant effect on the drag coefficient, since the drag coefficient is still smaller than
that of a passive control just in front it or without passive control. Minimal drag coefficient of this configuration is 0.906, this occurs is the $S/D = 1.8$ and $T/D = 1.5$.

\textbf{Table 5.} $C_D$ with passive control cylinder circular for $Re = 5000$ with difference $T/D$.

| $T/D$ | $S/D$ | $C_D$ |
|-------|-------|-------|
| 0.6   | 1.012 | 0.973 |
| 0.9   | 1.043 | 1.015 |
| 1.2   | 0.977 | 0.990 |
| 1.5   | 0.916 | 1.265 |
| 1.8   | 1.224 | 1.195 |
| 2.1   | 1.209 | 1.191 |

The drag coefficient of a circular cylinder with two passive controls on the front and rear. Passive control in front of the circular cylinder is the cylinder type-I, while the passive control behind the circular cylinder is a small circular cylinder. The data of the drag coefficient with the Reynolds number $R_e = 5000$ and the configuration as above, can be seen in Table 5. It appears that the passive control behind it has a significant effect on the drag coefficient, since the drag coefficient is still smaller than that of a passive control just in front of it or without passive control. the minimum drag coefficient of the configuration is 0.916, this occurs at $S/D = 1.8$ and $T/D = 1.5$.

\textbf{Figure 5.} $C_D$ Cylinder Elips $Re = 5000$. \hspace{1cm} \textbf{Figure 6.} $C_D$ Cylinder Circular $Re = 5000$.

The graph of Table 4 is Figure 5 and Table 3 is Figure 4. From the two figures shows that the minimum drag coefficient to Reynolds $R_e = 5000$ is the configuration of passive control in the back is circular cylinder with a distance of $S/D = 1.8$ and $T/D = 1.5$. Elliptical cylinder passive controls that are within $S/D = 1.8$ and $T/D = 1.5$ are better than the circular cylindrical passive controls that are within $S/D = 1.8$ and $T/D = 1.5$, in other words passive control in the form of elliptical cylinder is more effective compared with passive control in the form of circular cylinder.

3.3. \textit{Wake}

We show that the wake occurs for both passive controls with $R_e = 1000$ and 5000. We have shown that the drag coefficient of the main circular cylinder that there is a significant decrease.

We show that the decrease of the drag coefficient also affects the magnitude of the average velocity behind the circular cylinder. The velocity data we took from a distance of $6D$, $8.5D$ and $11D$ from a circular cylinder center or a distance of $10D$, $12.5D$ and $15D$ from the front of the system, like Figure 1.
Table 6. $C_D$ for $Re = 1000$ and $5000$.

| Re  | Single | 1 PC | 2 PC | Circ | Elips |
|-----|--------|------|------|------|-------|
| 1000| 1.21   | 0.896| 0.832| 25.95%| 31.24%| 31.90%|
| 5000| 1.51   | 1.216| 0.916| 19.47%| 39.34%| 40.00%|

Figure 7. Wake of $Re = 1000$.

Figure 8. Wake of $Re = 5000$.

From both figures, the flow velocity near the circular cylinder (ie, 6D from the center of the circular cylinder) and will increase as the distance farther away from the center of the circular cylinder and will return equally to the speed without passive control. The decrease in flow velocity behind the circular cylinder corresponds to a decrease in inhibitory coefficient as in Table 6.

4. Conclusion
The reduction of the drag coefficient in circular cylinder can be done by giving passive control. Passive control placement can be placed in front of and or behind. The inhibitory coefficient can be reduced by up to 40% if using passive front pass controls in the form of an cylinder type-I and an ellipse-shaped cylindrical backward control rather than a passive control drag coefficient, this is reinforced by decreasing flow velocity behind the circular cylinder.

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