The effectiveness of passive control to reduce the drag coefficient

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Abstract. The drag coefficient of an object can be reduced by adding another smaller object placed in front of the main object, this has been done in previous research. In this paper, it will be added another smaller object and placed behind the main object in hopes will reduce the drag coefficient of the main object. The distance between the main object and the object in front is fixed, but with the object behind it has a varying distance. Reynolds numbers used were 100 and will be found the drag coefficient of the main objects are influenced by the distance of the object behind, so that the drag coefficient received by the main object to be effective.

1. Introduction

New technologies can be created by conducting ongoing research, with the new technology expected to change the behavior of its users. Research related to fluid flow can be done by experiment or by simulation. One of the fluid flow research is to calculate the drag coefficient of an object flowed by fluid.

Offshore structures, flyover structures, industrial chimneys are usually designed in groups. These objects are usually circular cylinders, elliptical cylinders or other shapes. The main factor that distinguishes from these objects is the geometry form, this causes the value of different inhibitory coefficients. This is due to the fluid flow through which objects or multiple clustered objects will produce different characteristics. In fact, there are many interactions between the fluid flow and some objects.

The laminar or turbulent flow through the object surface, the flow of particles around the surface of the object will move slowly this is due to the friction force, so that the particle flow velocity around the object will be zero. While other particle currents will flow and interact, so the velocity of the flow away from the object will move faster. This shows an increase in shear stress that will affect the flow velocity in each layer, called the boundary layer.

The concept of the boundary layer of finding answers to the effects of shear stress has a very important role in the characteristics of the flow around the object[1]. Some research has been done is the fluid flow through a circular cylinder[2], or fluid flow one cylinder is modified into silinder type-I or type-D[3, 4]. In addition, the fluid flow through more than one cylinder with
a variety of sizes and configurations, the fluid flow through a circular cylinder with a tandem configuration [5, 6, 7, 8].

Fluid flow through an object will produce a drag, drag is influenced by several parameters, one of which is the drag coefficient. Ways to reduce the drag force on an object is to add smaller objects in front of the main objects is called passive control. This is done to reduce the drag coefficient by 48% [5], also performed with different Reynolds numbers and result in a lower drag coefficient [6].

Characteristics of fluid flow through cylinder type-\(D\) and type-\(I\) indicate that cutting corners to reach 53\(^{\circ}\), the drag coefficient reaches 50\% of drag coefficient of circular cylinder. If \(\theta_s > 60^{\circ}\), then the drag coefficient will be greater than the drag coefficient when \(\theta_s > 60^{\circ}\) [3]. Cylinder type-\(I\) to the angle 65\(^{\circ}\) as a passive control with \(Re = 3.8 \times 10^4\) provide drag coefficient reductions of 7\% is smaller than the circular cylinder without cutting [7]. Cylinder type-\(I\) with cutting angles \(\theta_s = 65^{\circ}\) has a drag coefficient greater than cylinder type-\(I\) with cutting angles \(0^{\circ} \leq \theta_s < 65^{\circ}\). Formed in control passive cylinder with cutting angle \(\theta_s = 65^{\circ}\) larger [9]. All of the above results are based on experimental research.

Cylinders type-\(I\) with cutting angle 53\(^{\circ}\) has the largest wake width compared to the other cutting angle. The formed shear layer is also suspected of greater width and the disturbing flow is stronger on the object wall. The change of laminar flow to turbulent flow becomes faster, turbulent flow will withstand friction force and result in delayed separation point, so the wake will be more narrow.

Therefore, the passive control used is cylinder type-\(I\) with an angle of 53\(^{\circ}\), both passive controls in front and behind. The passive position of the controls in front is upright and the passive controls behind are horizontal. The distance of passive control in front with circular cylinder is fixed, while the passive control behind the range varies. The Reynolds number used is \(Re = 100\). When do these two passive controls effectively decrease the drag coefficient?

2. Numerical method
To solve the above problem, the equation used is the incompressible and unsteady fluid equation, the Navier-Stokes equation.

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

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

where \(Re\): Reynolds number, \(\mathbf{u}\): velocity, and \(P\): 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

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

the right part is completed by using different methods until, like

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

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

the next step is

\[
\frac{\partial \mathbf{u}}{\partial t} = \frac{\mathbf{u}^{**} - \mathbf{u}^*}{\Delta t} = -\nabla P \tag{4}
\]
divergences on both sides, and in consideration of the equation (2) then $\nabla \mathbf{u}^{**} = 0$, then the equation becomes

$$\frac{\nabla \cdot \mathbf{u}^*}{\Delta t} = -\Delta P$$  \hspace{1cm} (5)

This 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)

$$(P_n)_{i,j} = (1 - \omega)((P_{n-1})_{i,j}) + \omega(P_n)_{i,j}$$  \hspace{1cm} (6)

This equation will result in a $P$ value. The last step is the correction of the velocity equations

$$\frac{\partial \mathbf{u}}{\partial t} = -\nabla P$$  \hspace{1cm} (7)

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

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

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 or bluff body. The circular cylinder position is located at $4D$ from the front and at $5D$ from top or bottom, like Figure 1. Two passive controls have
the same shape of the cylinder type-I with a diameter of \( d = D/8 \) and the cutting angle of 53\(^0\). Passive controls located in front of the circular cylinder have a distance of \( S \) and remain \( S/D = 2.4 \) with the upright position, while the passive control located behind the range \( T \) is varying \( T/D = 0.6, 0.9, 1.2, 1.5, 1.8 \) and 2.1 in a horizontal position, as in Figure 2.

The simulation program has a good truth value and the simulation program has been compared with the value generated by experiments and other simulation programs that other researchers have done in calculating the drag coefficient on a single circular cylinder. In the simulation program we calculate the drag coefficient on a single circular cylinder with a Reynolds 100 number is 1.36, while the other researchers are 1.4 by Zulhidayat and by Lima is 1.39\[10\], meaning the simulation program used by the writer can be used to simulate the cylinder Circular with two passive controls.

| Table 1. \( C_D \) of a cylinder circular for Re = 100 with difference \( S/D \). |
| --- | --- | --- | --- | --- |
| \( S/D \) | 0.6 | 1.2 | 1.8 | 2.4 | 3.0 |
| \( C_D \) | 1.23 | 1.05 | 1.04 | 1.00 | 1.03 |

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 1. From the data it is seen that the effective passive range of control to reduce the magnitude of the inhibitory coefficient lies at \( S/D = 2.4 \), therefore the fixed distance for the forward passive control used in this paper is \( S/D = 2.4 \). The following shows the simulation results of the circular cylinder drag coefficient with two passive controls, the forward passive control distance is \( S/D = 2.4 \) and the control passive distance behind is varied, as in Table 2 and the graph can be seen as in Figure 3.

| Table 2. \( C_D \) of a cylinder circular for Re = 100 with difference \( T/D \). |
| --- | --- | --- | --- | --- | --- | --- | --- |
| \( T/D \) | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.1 | 2.4 | 2.7 |
| \( C_D \) | 0.994 | 0.965 | 0.964 | 0.956 | 0.949 | 0.949 | 0.954 | 0.966 |

**Figure 3.** The drag coefficient of a circular cylinder with Re=100.

Using the graphic approach in Figure 3 and the data in Table 2 we find an equation

\[
y = 0,0091 \ x^3 - 0,0242 \ x^2 - 0,0138 \ x + 1,0002
\]  

\( (8) \)
Table 3. Average velocity of wake.

| Distance          | 5D   | 7.5D | 10D  |
|-------------------|------|------|------|
| Single            | 0.943| 0.948| 0.951|
| S/D=1.24          | 0.938| 0.942| 0.943|
| S/D=1.24, T/D=1.8 | 0.927| 0.935| 0.940|
| S/D=1.24, T/D=2.1 | 0.927| 0.934| 0.939|

From Equation ref p-drag we get the minimum of the drag coefficient ie at the distance $T/D = 2.023$ with the big drag coefficient is 0.9485.

When viewed from the wake that occurs behind the circular cylinder, ie at a distance of 10D, 12.5D and 15D from the front of the system or 5D, 7.5D and 10D from the center of the circular cylinder, can be seen in Table 3 and some of the following figures. In Table 3 we can show the average velocity of the wake occurring behind the circular cylinder. For circular cylinders without passive controls visible further from the center of the circular cylinder the average velocity increases, this is because the effect of circular silnder has begun to decrease. Once coupled with the passive control in front with a distance of $S/D = 2.4$, the average velocity decreases at each place, but further away from the circular cylinder the average velocity also increases. Likewise, the passive addition of the controls behind (the third and fourth rows) has almost the same average speed. The decrease in wake velocity as in Table 3, shows the decrease of the inhibitory coefficients described above.

Figure 4. Wake of Cylinder Circular.

Figure 5. Wake of Cylinder Circular with Passive Control on the Front.

Decrease in the drag coefficient caused by the passive addition of the controls either front or front and rear, results in a decrease in the average velocity of the wake behind the circular cylinder. The speed graph of the wake behind the circular cylinder without passive control looks like a wide or diffuse parabola. The farther away from the circular cylinder, the wake occurs wider, as in Fig. 4. For circular cylinders with passive controls on the front, it appears that the parabolant is somewhat narrowed compared to the previous parabola, as in Fig. 5. Similarly Fig. 6 and Fig. 7, the parabola graph becomes narrower. In other words, the smaller the average velocity of the wake or the narrower the wake occurs, the drag coefficient will also be smaller.

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Figure 6. Wake of Cylinder Circular with Passive Control on the Front and Back.

Figure 7. Wake of Cylinder Circular with Passive Control on the Front and Back.

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