Numerical investigation of the flow around circular cylinder with two passive controls

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Abstract. Investigation is done on incompressible flow around circular cylinder with two passive controls. The first passive control has a cylinder type I, placed in front of the cylinder with a fixed distance. The second passive control investigated with two types are ellipse and circle, placed behind the cylinder at varying distances. Reynolds numbers used are 100, 500 and 1000. Variations of the passive control’s shapes, the distance between the passive control and the cylinder, and the variation of the Reynolds number influence the drag coefficient received passive control. The smallest drag coefficient received passive control occurs in the Reynolds number 1000 and the distance $T/D = 1.8$. The drag coefficient received passive control ellipse or circular shape has very small difference, but for comparison investigation, passive control ellipse receives drag coefficient smaller than passive control circle shape.

1. Introduction

The phenomenon of movement of fluid flow across the object plays an important role in the development of the industrial world and technique. One of them is the flow of fluid through the cylinder, as a representation of a pile building or pipes on the offshore oil drilling process. The flow of fluid through the cylinder will stagnate, boundary layer, separation and wake behind the cylinder. The larger the wake of fluid flow, the greater difference in force received between the front of cylinder and beside cylinder. As a result the drag coefficient received by the cylinder is also getting bigger[1]. The drag coefficient received by the cylinder is an attractive phenomenon. In this case is closely related to the durability and strength of the cylinder. If a large drag coefficient can be reduced then the cylinder's durability can last a long time.

In general, to reduce the drag coefficient received the cylinder can be done by giving the passive controller placed around the cylinder with varying shapes, the distance with the cylinder or the number of Reynolds used. Research has been done by using single passive control cylinder I and D with variation of the Reynolds number $>2.3 \times 10^4$. The result is the drag coefficient received by the cylinder is reduced to 50% of the main cylinder without passive control[2].

In this study, the main cylinder will be given by two passive controls. The first passive control is a cylinder type-I with angle 53° at the upright position that is placed in front of the main cylinder with a fixed distance, while the second passive control, there are two types to be studied are the ellipse and
the circle shape placed behind the cylinder with varying distances. Passive control scheme and main cylinder can be seen in the figure 1. Reynolds number used 100, 500 and 1000. Furthermore, will be investigated and compared the influence of distance variation and Reynolds number to the drag coefficient received ellipse and circle passive control.

![Design research with varies of distances](image1)

**Figure 1.** Design research with varies of distances

![Passive control scheme](image2)

**Figure 2.** Passive control scheme

2. Numerical Method

The equations used for unsteady incompressible fluid is the Navier-Stokes equations[3]

\[
\frac{\partial \vec{u}}{\partial t} + \nabla uu + \nabla p = \frac{1}{Re} \nabla^2 \vec{u} \tag{1}
\]

\[
\nabla \vec{u} = 0 \tag{2}
\]

where \(u\) 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 is set initial value for each variable, then find the velocity component \((u^+\) of the momentum equation without the pressure component.

\[
\frac{\partial \vec{u}}{\partial t} + \nabla uu = \frac{1}{Re} \nabla^2 \vec{u} \tag{3}
\]
Equation (3) can be solved using finite difference, like

\[
(u_i)_j = \frac{2u_{i+1} + 3u_i - 6u_{i-1} + u_{i-2}}{6dx} \quad \text{and} \quad (u_j)_i = \frac{2u_{j+1} + 3u_j - 6u_{j-1} + u_{j-2}}{6dy}
\]

\[
(u_{\alpha})_j = \frac{u_{i+1} - 2u_i + u_{i-1}}{dx^2} \quad \text{and} \quad (u_{\beta})_j = \frac{u_{j+1} - 2u_j + u_{j-1}}{dy^2}
\]

Then, second step is find the pressure component using equation

\[

\Delta t \frac{\partial^2 p}{\partial t^2} = \frac{1}{\Delta t} \nabla u^*
\]

Equation (4) can be solved using finite difference and completed using the SOR method. So, the convergence of the solution can be obtained quickly. SOR method can be expressed by

\[
(p_{n})_{i,j} = (1 - \omega)(p_{n-1})_{i,j} + \omega(p_{n})_{i,j}
\]

for choices of \( \omega \) with \( \omega > 1 \)[4]. The last step is correction velocity component using equation as follows:

\[
\frac{\partial u}{\partial t} = -\nabla p
\]

3. Result and Discussion

The fluid flow across the circular cylinder with two passive controls simulated in the 10Dx20D area, \( D \) is the circular cylinder diameter. Circular cylinder is placed in 4D position from front and 5D from above. While the first passive control position is placed in front of the cylinder with fixed distance at the ratio of \( S/D = 2.1 \) and the second passive control is placed behind the circular cylinder with varying distances at the ratio of \( T/D = 0.6, 1.2, 1.8, 2.4, 3 \). Reynolds numbers used are 100, 500 and 1000. While the fluid flow profile can be known with the wake profile at varying distance of 6D, 8.5D and 11D from the center of circular cylinder.

3.1. Validation code

To determine the accuracy of calculations performed by the computer code, we identify with the calculation of the drag coefficient received by a single circular cylinder without passive control. The identification of the drag coefficients is done by Reynolds number 100, then compared with the result of the calculation ever done.

| Table 1. Comparison with other research |
|----------------------------------------|
| Re  | Zulh[5] | Lima[6] | Ding[7] |
|-----|--------|--------|--------|
| 100 | 1.35837 | 1.4    | 1.39   | 1.356   |

Based on the table 1, the results of the calculation drag coefficient obtained is not much different from other researchers. Thus, the computer code that has been created can be used for simulation in this study.

3.2. Pressure distribution

Different shapes of the passive control will obtain different pressure distributions. Based on the Reynolds number used, the effect of the distance variation between the passive control and the main cylinder to the pressure distribution on the passive control is shown in figure 3 and figure 4.

Based on figure 3 and figure 4, the pressure distribution that occurs for all types of variations produces a symmetrical graph. The minimum pressure coefficient occurs at an angle of 50-100 and 250-300. The smallest coefficient occurs when the Reynolds number 1000. The greater of Reynolds number is obtained the smallest drag coefficient. For the variation of distance between the passive
control and the main cylinder T/D, the smallest pressure distribution is obtained when the distance T/D=1.2.

![Figure 3. Pressure distribution of ellipse passive control](image)

![Figure 4. Pressure distribution of circle passive control](image)

The ratio of pressure distribution that occurs in the ellipse or circle passive control is not much different. Passive control elliptical shape accepts a smaller pressure coefficient compared to a circular passive control. To be more accurate, the difference of pressure distribution received by passive
control ellipse and circle at $T/D=1.2$ can be shown in figure 5. Passive control elliptical shape accepts a smaller pressure coefficient compared to a circular passive control.

![Figure 5. Comparison elliptical and circle control passive](image)

3.3. Drag coefficient

The drag coefficient on a single cylinder with $Re$ 100 has been validated in Table 1. Whereas the Reynolds number 500 and 1000 are shown in Table 2.

| Reynolds number | 100  | 500  | 1000 |
|-----------------|------|------|------|
| Cd              | 1.356| 1.231| 1.210|

Based on the Reynolds number, the greater the Reynolds number the smaller the drag coefficient on the cylinder. Furthermore, with a single passive control with a type I cylinder placed in front of the main cylinder, the smallest drag coefficient is obtained at a distance $S/D=2.1$.[3]. Furthermore, with variation of passive control and main cylinder distance, the drag coefficient received by the second passive control is the shape of ellipse or circle shown in table 3.

| T/D | Circle Reynolds number | 100  | 500  | 1000 |
|-----|------------------------|------|------|------|
|     |                        | 100  | 500  | 1000 |
| 0.60| 1.169                  | 1.108| 1.038| 1.161| 1.109| 1.029|
| 1.20| 0.986                  | 0.938| 0.878| 0.977| 0.938| 0.870|
| 1.80| 0.941                  | 0.911| 0.833| 0.932| 0.912| 0.825|
| 2.40| 0.944                  | 0.923| 0.832| 0.935| 0.924| 0.824|
| 3.00| 0.969                  | 0.953| 0.849| 0.960| 0.953| 0.841|

The drag coefficient received by passive control of elliptical shape is generally smaller than the passive control of the circle shape. The drag coefficient on Reynolds number 1000 is smaller than the
drag coefficient on the Reynolds number 500. And the drag coefficient on the Reynolds number 500 is smaller than the drag coefficient on the Reynolds number 100. Thus the smallest drag coefficient occurs in the Reynolds number 1000 at T/D=1.8. This applies to both forms of passive control (ellipse and circle).

3.4. Wake

The fluid flow profile behind the passive control is known through the wake tested on the Reynolds 1000 number with the passive control distance and the main cylinder T/D=1.8. This test is arranged in three variations of the wake position are the distance of 6D, 8.5D and 11D which is measured from the center of the diameter of the cylinder. The wake profile at that distance can be seen in the figure 6 and figure 7.

![Figure 6. Wake of Ellipse passive control](image)

![Figure 7. Wake of Ellipse passive control](image)
4. Conclusion
Investigating fluid flow across the circular cylinder and two passive controls, the object of observation is the passive control placed behind the cylinder with two types of ellipses and circles. The results of the investigation obtained:

- For all variations of distance (T/D) and Reynolds numbers, the average pressure distribution received by the passive control of the ellipse is smaller than the passive control of the circular shape.
- The drag coefficient received by the ellipse passive control is smaller than the passive control of the circle, although the drag coefficient received by the ellipse passive control and the cylinder is almost the same.
- The appearance of wake when the smallest drag coefficient is at the time of Re 1000 and T/D=1.8 occurs in the circular cylinder shows symmetrical results.

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