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# Pressure Distribution of Fluid Flow through Triangular and Square Cylinders

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**ABSTRACT**

A flow current passing through a triangular cross section bar and rectangular cross-section bar is often found in structural engineering and transportation. Pressure coefficient distribution around a rectangle bar at the top and bottom of the bar is relatively the same, while the biggest pressure coefficient occurs at the frontal side of the square bar. The interference of the double bar distance against the pressure coefficient indicates that a distance between the bar increase will lift up the pressure coefficient at the surface of the bar back pressure. The maximum pressure point moving forward, and the bar separation would no longer be reduced. If the cross section of the bar becomes larger at a constant fluid velocity, then the point of maximum bar pressure is directed to both sides of the front bar. The separation point of the second cylinder pressure occurs at a point that is almost similar but with a different value. Pressure distributions of fluid flow through triangular and square cylinders were analyzed experimentally at various Reynolds numbers, ReD = 48.708; 64.435; 94.480; 119.509 and 152.449. This Reynolds number is calculated based on the square cylinder diameter. Ratio of distances between the two cylinders to the diameter of the square cylinder (L/D) was varied as 0.5; 1.0 and 1.5. Diameter ratio between triangular and square cylinders, (d/D), was set constantly at 0.5. Also, pressure distributions were analyzed using CFD. Experimental and numerical results showed that the pressure distribution pattern around tested objects and the pressure coefficient decreases as increasing the L/D.The lowest value of the pressure coefficient occurs at the L/D = 1.0 for all Reynolds numbers. Coefficient of pressure is dominantly negative at the front side of the square cylinder, suggesting that arrangement of the triangular cylinder in front of the square one is very effective in drag reduction at square cylinder.



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## INTRODUCTION

Flow across triangular and square cylinders is usually applied in structure engineering and transportation. Installing a triangular cylinder in front of a square cylinder or main cylinder is an attempt to decrease drag or flow resistance. This installation has been widely studied by Lee (Lee, et.al, 2004), Igarashi (Igarashi, 1997), and Tsutsui and Igarashi (Tsutsui, 2002). Tsutsui and Igarashi investigated a flow through a triangular and square cylinder using a small cylinder as a disturbing cylinder. The pressure coefficient distribution around a square cylinder was studied by Liaw, (Liaw, 2005). It is reported that the pressure coefficient distributions of at the upper and lower sides of the cylinder were relatively equal, while the largest pressure coefficient was observed at the center of the frontal side of the square cylinder. In addition, the pressure coefficient at the back side of the cylinder was higher than that of in the upper and lower sides of the cylinder.

Air pressure distribution and drag force in the head of airplane, Boeing 777-200, was investigated by Poernomo, et.al. (Poernomo, 2010). The result shows that the drag forces are ranged from 0.0033 – 0.0041 N at the tested object of the cylinder and at the tested nose are ranged from 0.0011 – 0.0018 N, and ranged from 0.0013 – 0.0027 N at the head of the Boeing 777-200. The effect of the distance of double cylinders toward the pressure coefficient was investigated experimentally by Astawa (Astawa, et.al, 2009). Experimental data were collected based on the variation of a three tube chambers i.e. 1.2D; 1.7D; and 2.2D, three variation of cylinder's diameter (D) i.e. 2, 2.5 and 3 inches, and the free stream velocity was maintained at 6 m/s. The results indicated that increasing the distance between cylinders would increase the surface pressure coefficient of the back cylinder, moves the point of maximum pressure ahead, and the separation of the back cylinder backward > 90. As the cylinder diameter become larger at the constant fluid velocity, the point of maximum pressure of the

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second cylinder was directed to the front side of the cylinder. The separation point of the second cylinder occurred at the pressure point that almost similar but its value was different.

Badami (Badami *et al*., 2012) the comparison of drag coefficient is tabulated for bare cylinder, cylinder with rectangular and triangular wake splitters. Flow past circular cylinder and cylinder with triangular and rectangular wake splitter is performed at a Reynolds number of 5, 20, 40, 50, 80, 100. The wake length was found to be less than that with a rectangular wake splitter when compared between the bare cylinder and cylinder with a triangular wake splitter. Coefficient of drag is found to be less for the triangular wake splitter compared with the bare cylinder & cylinder with rectangular wake splitter.

A characteristic of fluid flow through triangular and square cylinders was studied by Salam, (Salam, et.al, 2014). It was analyzed using computational fluid dynamics (CFD) utilizing FLUENT 6.3.26 software and validated by a visualization image of the fluid flow. This study was carried out in a laminar flow at the Reynolds numbers, $Re_D$, of $8.52 \times 10^4$ with a free stream velocity, U, of 8 m/s. The distance ratio between the two cylinders and the diameter of the square cylinder (L/D) were varied to 0.0; 1.0; 2.0; 3.0; 4.0 and 5.0. The diameter ratio between the triangular to square cylinders, (d/D), was set constantly at 0.5. The Result shows that by installing a triangular cylinder in front of a square cylinder would cause a drag reduction within a square cylinder in which the largest reduction was observed at L/D = 1.0.

Based on the above results, the pressure drop reduction and the pressure coefficient of moving object with either the circular geometry or the square cylinders could be obtained by arranging them in tandem formation or by placing a disturbing cylinder in front of those cylinders by circular, square or triangular cylinders, and ajusting their distance and diameter (interaction between the two cylinders). A further question is whether the pressure distribution and the coefficient of pressure, distance of flow separation and vortex of flow through square cylinder experience a significant reduction when being arranged in tandem with or disturbed by the triangular cylinder as shown by a previous study on a circular cylinder being combined to other cylinders.

This study provides an analysis on pressure distribution or coefficient of pressure of fluid flow through tandem between a triangular and a square cylinder. The goal of this study is trying to reduce the drag by estimating relationship between coefficient of pressure and flow separation and vortex that emerges at the interaction between these two cylinders.

## MATERIALS AND METHODS

Experiment was conducted using Sub-Sonic Wind Tunnel manufactured by Plint & Partners LTD. Engineers England. Dimension of its testing section is (500 x310x310) mm made from a transparent acrylic having thickness of 10 mm, thus it is easy to view the position of the tested objects. In addition, the tested objects were tandem between triangular and square cylinders as shown in the figure 1. Square cylinder's length, width and height were equal and referred as square cylinder's diameter (D), i.e. 100 mm. The length of the triangular cylinder sides were also equal and defined as triangular cylinder's diameter (d), i.e. 50 mm or diameter ratio, d/D = 0.5. The tested objects was made of acrylic with thickness of 2 mm. Air flow velocity entering the wind tunnel (U) ranged from 7.6216 to 23.1801 m/s. There were 52 pressure tap points arranged around the surface of the tested objects including 12 points at the triangular cylinders and 40 points at the square cylinder. Distance of each point was 10 mm for the square cylinder and 12.5 mm for the triangular cylinder. The distance ratio between the two cylinders (L) and the square cylinder's diameter (D), L/D were varied from 0.5; 1.0; and 1.5. The pressure distribution was measured by using an open U-tube manometer with red liquid with a specific gravitation of 0.835.

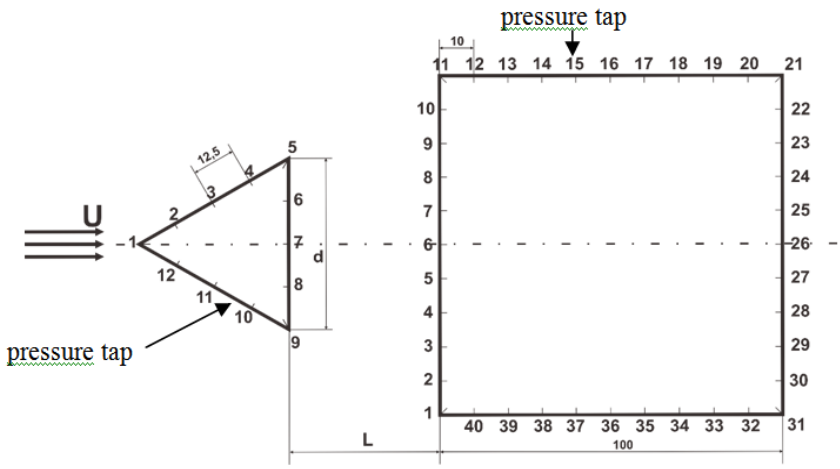


**Fig. 1:** Position of head measurement points at the tested objects.

Pressure coefficient ($C_P$) was determined from the ratio of pressure change before and after flowing through the tested objects to the dynamic pressure (White, 1994) as equation (1),

$$C_p = \frac{p - p_s}{\frac{1}{2}\rho_s v_s^2} \quad (1)$$

Or it could be estimated simpler from the comparison between pressure or head occurred at the tested points of the object's surface to the pressure or head in the free air stream (Poernomo, et.al 2010) as equation (2),

$$C_p = \frac{h_1 - h}{h_1 - h_2} \quad (2)$$

Where ρ = density of air, $h_1 - h$ = pressure change or head of air flow in the tested points of the tested object's surface, $h_1 - h_2$ = pressure change or head of the free air.

This study was carried out in the laminar flow at the Reynolds numbers calculated based on the diameter of the square cylinder, $Re_D$ = 48.708; 64.435; 94.480; 119.509 and 152.449 or at the inlet velocity of the wind tunnel (U) = 7.6216; 10.0824; 14.7591; 18.6689 and 23.1801 (m/s). L/D was varied into 0.5; 1.0 and 1.5, while d/D was set constantly at 0.5.

## RESULTS AND DISCUSSIONS

The experimental result of the pressure coefficient of the air flow through triangular cylinder installed in tandem with square cylinder is shown in the figure 2 for various Reynolds numbers and in the figure 3 for a variety of L/D.

Figure 2 shows that the pressure distribution around the tested objects. The distribution pattern was similar for all Reynolds numbers. The lowest $C_P$ was observed at the highest Reynolds numbers i.e. $Re_D$ = 152.449. $C_P$ of the triangular cylinder showed the highest value at the stagnation point (pressure tap 1) and tend to decrease along the upper side to pressure tap 5, while in the back side of the cylinder tend to constant i.e. from the pressure tap 5 - 9 and then it increased from pressure tap 9 at the lower side of the cylinder until pressure tap 12, where its increase pattern was similar to that in the upper side. $C_P$ of the square cylinder reaches the highest value at the tap 2 and 10, whereas in the middle part (from tap 2 – 10) of the front side of the cylinder tend to constant at lower value.

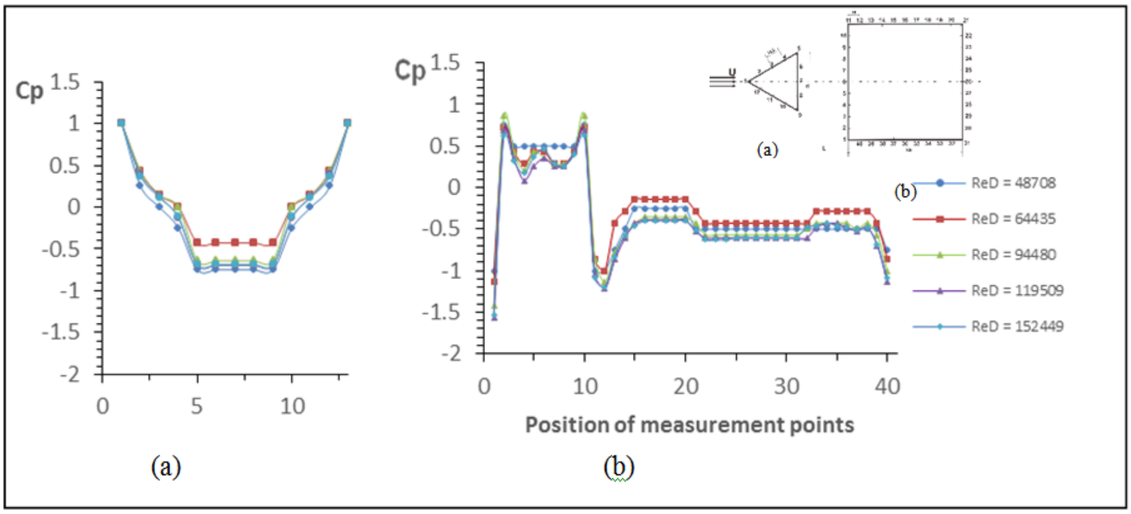


**Fig. 2:** $C_P$ distribution surrounding tandem cylinders between (a) the triangular cylinder and (b) square cylinder at L/D = 1.0 for five Reynolds numbers.

This pattern was created by the wake of triangular cylinder in front of the square cylinder. This condition also explained why the square cylinder experienced a drag reduction. Profiles of the pressure coefficient distribution at the upper and lower sides of the square cylinder were similar. Meanwhile along the back side of the cylinder, the coefficient of pressure was the smallest. Cp at the front side was positive, and in the three other sides, all had negative values.

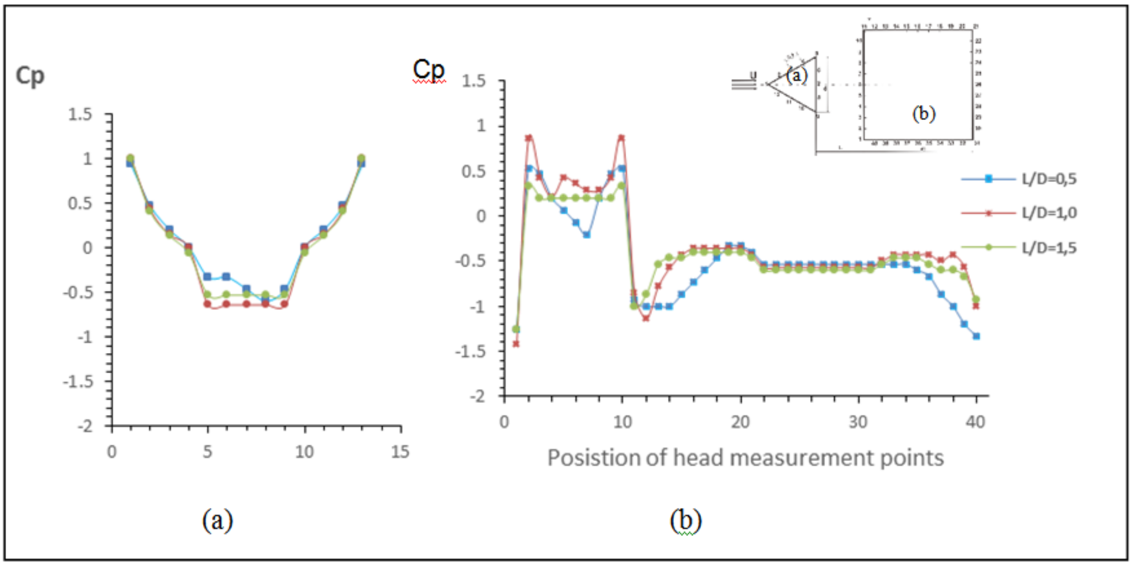


**Fig. 3:** $C_P$ distribution surrounding tandem cylinder between (a) triangular cylinder and (b) square cylinder at $Re_D$ = 94.480 for three L/D.

Figure 3 shows distribution pattern of $C_P$ at each L/D that was relatively similar, likewise, if compared to the figure 2, their patterns were also relatively similar. This indicated that pattern of pressure distribution is fully depend on object's shapes (whether triangular or square cylinders), while distance alteration of both cylinders only affected the value of $C_p$. Ranges of the negative values of $C_p$ were more dominant than the positive one, revealed that vortex and flow separation almost occur at all surface of the cylinder's sides.

From table 1, it can be seen that the lowest $C_p$ was found at L/D = 1.0 for all Reynolds numbers except at $Re_D$ = 64.435 for the square cylinder that occurred at L/D = 0.5. Interesting phenomenon of pressure coefficient alteration pattern at L/D =0.5 was also demonstrated in figure 3 for both triangular and square cylinders. This showed that adequately strong flow separation and vortex occured on the certain side of the cylinder wall at L/D = 0.5 that distorted the pressure distribution. All the smallest Cp values from table 1 were negative, indicating that there were quite large flow separation and strong vortex occurred in this area.

**Table 1:** Minimum pressure coefficient various $Re_D$ at L/D = 0.5; 1.0 and 1.5 (TC = Triangular Cylinder; SC = Square Cylinder).

| L/D | $Cp_{min}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Re_D$ = 48.708 | | $Re_D$ = 64.435 | | $Re_D$ = 94.480 | | $Re_D$ =119.509 | | $Re_D$ =152.449 | |
| | TC | SC | TC | SC | TC | SC | TC | SC | TC | SC |
| 0,5 | -0,50 | -1,25 | -0,43 | -1,29 | -0,60 | -1,33 | -0,58 | -1,33 | -0,62 | -1,33 |
| 1,0 | -0,75 | -1,00 | -0,43 | -1,14 | -0,64 | -1,43 | -0,70 | -1,57 | -0,69 | -1,54 |
| 1,5 | -0,50 | -1,00 | -0,43 | -1,00 | -0,53 | -1,27 | -0,50 | -1,21 | -0,51 | -1,24 |

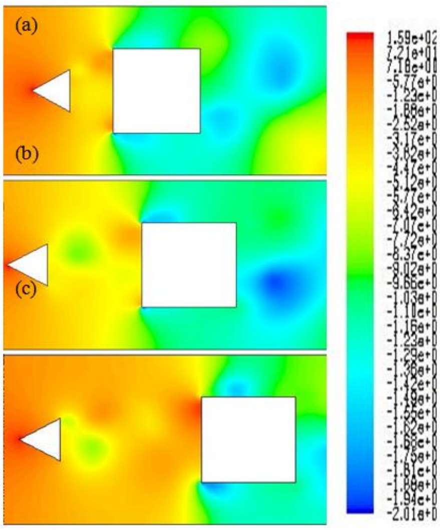


**Fig. 4:** Pressure coefficient contour $Re_D$ = 94.480. (a) L/D=0.5; (b) L/D=1.0; and (c) L/D= 1.5.

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Characteristics of the pressure coefficient distribution of flow through the tandem cylinders as shown in the figure 3 was explained with pressure distribution from CFD Fluent program as shown in the figure 4. It appeared that the most stable and the smallest fluctuation of pressure alteration was reached at L/D = 1.0. This was caused by the fact that areas of pressure changes after passing the triangular cylinder and above the square cylinder were the lowest, therefore, it did not strong enough to push the flow over them. At L/D >1.0, the pressure changes between the triangular and square cylinders were getting higher and strong enough to push the flow over them, hence the pressure coefficient were larger. This condition indicated that the least coefficient of pressure and drag were found at L/D = 1.0. Different condition was obtained at L/D = 0.5 and L/D = 1.5 where the coefficient of pressure and drag increased and reached maximum value at L/D = 1.5.

### *Conclusion:*

Experimental analysis and CFD numeric simulation of fluid flow through tandem between triangular and square cylinders at d/D = 0.5 and the Reynolds numbers $Re_D$ = 48.708; 64.435; 94.480; 119.509 and 152.449 with L/D = 0.5; 1.0; and 1.5 showed that:

a. The coefficient of pressure changed with the distance between the two cylinders and it reached the smallest at L/D = 1.0.
b. Pattern of the pressure coefficient distribution was almost similar for all Reynolds numbers and L/D though the values of the pressure coefficient change with the Reynolds numbers and L/D.
c. Pattern of the pressure distribution is mostly depend on the cylinder geometry either triangular or square cylinders, whereas the ratio of the distance of the two cylinders to the main cylinder diameter just influence high and low values of the coefficient of pressure.
d. Coefficient of pressure is dominantly negative at the front side of the square cylinder, suggesting that arrangement of the triangular cylinder in front of the square one is very effective in drag reduction at square cylinder.

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