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The Effect of Size Ratios of the Triangular Disturbance Cylinder to the Square Cylinder to the Flow Drag of Tandem Objects

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ABSTRACT

Airflow drag from the interaction of tandem objects is one of the main factors that must be considered in the design of building and transport vehicles. In order to reduce the air flow drag, a disturbance object is usually added in front of the tandem structures. The geometry of the disturbance object that is quite good at reducing drag is a triangular cylindrical shape. The research aims to analyze the effect of the disturbance size ratio in the form of a triangular cylinder to the drag of fluid flow across square cylinders which are arranged in tandem. The methodology used in this research is experimental. The results obtained indicate that of the seven variations in the ratio of the distance M/D for d/D=0.033, d/D=0.067 and d/D=0.100, the ratio M/D=0.35 has the lowest drag coefficient value compared to the ones of other variation at the value of 0.69, while for d/D=0.67, the lowest drag coefficient is obtained at M/D=0.25, amounting to 0.67. When compared to the three variations of disturbance objects, it shows that d/D=0.067 has the lowest drag coefficient value compared to the variation of d/D=0.033 and d/D=0.100.

Keywords: Disturbance body; tandem square cylinder; triangular cylinder; drag coefficient (CD); Size ratio

1. INTRODUCTION

Flow across tandem square cylinders is common in engineering equipment, building structures, and transport vehicles. In heat exchangers, the tandem arrangement forms an arrangement of inline, staggered, or square arrays. In building and transportation structures, tandem arrangements can be found in cooling towers, chimneys, offshore and port support structures, trains, articulated barges and trucks [1]. Wind and water load on these structures are the main factors that must be considered in the design. Wind and water load in a group structure have different characteristics from a single structure of the same shape. Due to the combined interference of the flow around the clustered structures, various exciting and unexpected phenomena are exhibited.

If fluid flows through an object, it will lose energy due to the drag force caused by the influence of the boundary layer and the flow separation. Drag is caused directly by viscous effects, and flow separation is due to pressure. It is a problem for the transportation industry in increasing the efficiency and stability of the system. A precise cross-sectional shape is designed to reduce the energy loss allowing the fluid to flow through the object without generating flow separation and therefore producing a uniform flow after passing through the object. Various parameters influence the aerodynamic characteristics of the flow across objects have been studied. The large Reynolds number influences the eddy flow due to the interaction of two tandem square cylinders with the addition of inlet disturbance body (IDB). While the action of forces differs between the upstream cylinder and the downstream cylinder, this results in a different characteristic of the drag coefficient [2]. The change in the ratio of the distance of the two cylinders to the width of the cylinder associated with the dimensionless shear parameter affects the magnitude of the Strouhal number in the Interference of two square cylinders installed in tandem has also been investigated [3].

Efforts to reduce the drag force on cylinders that are arranged single or arranged in tandem have been carried out by many researchers using various methods. One method used is to add a inlet disturbance body in front of the cylinder[4]–[9]. Various forms of disturbance body have been studied. Triyogi et al. [10] uses the I-type bluff body form as passive control to reduce the drag on a circular cylinder. The results show that adding the bluff bodies (sliced or circular) as a passive arrangement in front of the large circular cylinder efficiently minimizes the drag of the large cylinder. Alam et al. [11] studied the disturbance effect in the form of a "T" plate in front of circular cylinders arranged in tandem, with variations in cylinder distance to get the optimal position. The optimal result is obtained when the variation of the distance to the cylinder diameter T/D=1.0 - 1.5 is used.

Lee et al.[12], investigated the effect of mounting a control rod on the upstream of the cylinder on the drag characteristics and flow structure. The Reynolds number is approximate Re=20,000. Reduction of the maximum total drag coefficient of the entire system is about 25%. Other variations were made to the L/D and d/D values which resulted in a decrease in the total coefficient of drag of the system. The results showed the ideal disturbance rod diameter ratio as a small control rod, which is at a ratio of d/D=0.233, and the placement of this small control rod in the ratio of distance to cylinder diameter or L/D=2.0 to 2.08.

Widodo et al. [4] found out that the addition of a disturbance cylinder affects the drag coefficient of a tandem circular cylinder in a narrow channel with a square section. The specimen in the form of two circular cylinders with the diameter (D) 25 mm, length (L) 125 mm and disturbance body used was a circular cylinder with the diameter (d) 4 mm with a plain and threaded surface. The object was flowed with air at Reynolds number 1.16 × 105 with S/D variation of 1.5 and 2.5 and constant L/D 2.0. The results showed that the use of both plain and screw surfaced disturbance had an effect on the separation point of the upstream cylinder, but did not have a significant effect on the reattachment point of the downstream cylinder. The plain disturbance surface resulted in the separation point being delayed by 5° rather than without the disturbance cylinder. In contrast, for the screw surface disturbance, the separation point was delayed by 5° more than the use of the disturbance cylinder.

Zhang et al. [13] studied the mechanism of formation and convection of eddies out of the cylinder with the upstream rod. It was found out that the average drag force can be reduced by the upstream rod, especially in the cavity flow mode with rod diameter d/D = 0.3 and 0.5. Tsutsui and Igarashi [14], investigated the reduction of drag forces against circular cylinders in airflow. In this study, two cylinders installed disturbance bodies were located in the upstream part of the cylinder. The results show that the flow pattern changes depending on the disturbance diameter, distance and Reynolds number. The cylinder diameter of the specimen is 40 mm, and the disturbance diameter is from 1 to 10 mm. The Reynolds number based on the cylinder diameter is from 1.5×10^4 to 6.2×10^4. The total drag reduction, which includes the drag of the body is 63% compared to that of a single cylinder.

Salam et al. [6], examined the flow drag across square cylinders in a tandem arrangement, with the addition of an inlet disturbance body (IDB) in the form of a circular cylinder, analyzed by computational fluid dynamics (CFD) simulation with the FLUENT 6.3.26 program and experiments. The research was carried out at the Re_D number = 30,625 to 96,250. The ratio of the IDB circular cylinder diameter to the square cylinder diameter (d/D) is varied by 3 (three) levels, namely, d/D = 0.08; 0.14 and 0.20, while the ratio of the distance between the two cylinders and the diameter of the square cylinder (L/D) is varied by 8 (eight) levels from L/D = 0.0 to 1.0. The experimental results show a pattern of drag coefficient (CD) and pressure coefficient (CP), decreasing with increasing L/D and d/D, and the lowest CD and CP values (CD=1.67 and CP=0.87) at L/D=0.43 and d/D=0.14 for all levels of Reynolds number. The circular cylinder placement as IDB installed before the tandem of the square cylinder results in a drag reduction of the square cylinder from CD=2.13 to CD=1.67 or 21.6% and reducing the pressure distribution from CP=1.02 to CP=0.87 or 14.7%. Salam et al [15] have conducted experimental studies on flow separation through three square cylinders arranged in serial and parallel arrays.

In engineering applications, many constructions use cylinders; this has prompted researchers to research flow across cylinders. Therefore, until recently, the study of flow across cylinders remains an important one in fluid mechanics. Also, it is essential to carry out a study with a cylinder as an object because the projection of a cylinder shape can be applied to various equipment used in the industry [16].

Based on the description above, the study examines the effect of variations in the size ratio and distance of triangular cylinders as a disturbance to the reduction of the drag coefficient on a tandem square cylinder.

2. MATERIAL AND METHOD

This research was conducted experimentally by placing the test object in a subsonic wind tunnel and then directly measuring the drag force to determine the value of the CD drag coefficient. The study was conducted with three variations in the size ratio of the triangular cylinder disturbance, namely 0.033; 0.067; and 0.10, as well as seven ratios of disturbance body distance to the square cylinder, namely 0; 0.05; 0.15; 0.25; 0.35; 0.45 and 0.55. Besides, this research was also carried out at five levels of airflow velocity (U).

A. Test Models

The test models are in the form of a square cylinder, attached behind a triangular cylinder as the disturbance object. The square cylinder models were made of two pieces with the same width, height and length (D). In comparison, the disturbance cylinder in the form of a triangular cylinder was made of 3 (three) variation with different diameters (d). The material used in the manufacture of the test models are acrylic with a thickness of 2 mm. The test object size is adjusted to the size of the test section of the wind tunnel, where in order to get acceptable measurement results. The ratio of the cross-sectional area of the test object to the cross-sectional area of the channel or wind tunnel test section cannot exceed 1:3 ratio. Figure 1 below shows the position of the IDB cylinder (d) with a square cylinder in a tandem arrangement (D), where the diameter of the square cylinder (1) is the same as the square cylinder (2), the addition of the IDB cylinder is installed at the front. At the same time, the size is made smaller than the ones on the square cylinders.

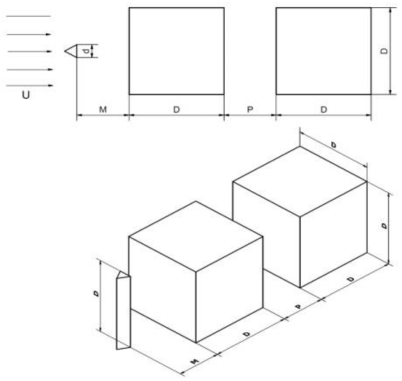


Figure 1. Addition of an inlet disturbance body (IDB) to square cylinders in tandem arrangement.

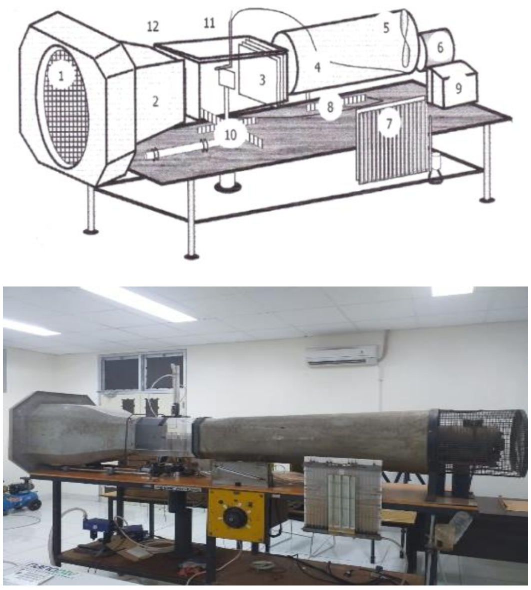


Figure 2. Sub-sonic wind tunnel: 1. Intake; 2. Diffuser; 3. Working section; 4. Divergent section; 5. Fan; 6. Electric motor; 7. Pressure manometer; 8. Speed manometer; 9. Voltage regulator; 10. drag balance; 11. Pitot tube; 12. Static tapping.

B. Experimental Set-up

This research was conducted at the Laboratory of Fluid Mechanics, Department of Mechanical Engineering, Faculty of Engineering, Hasanuddin University. Experimental testing using a subsonic wind tunnel (Plint & Partners LTD Engineers), with a maximum airflow velocity through the test section (300 mm × 300 mm) a maximum of 42.7 m/s (Figure 2). The component balance which measures the drag forces on cylinder models mounted in Subsonic Wind Tunnel. The balance mechanism allows test models with a rigid assisting arm to be mounted and held securely in position in the testing section of the wind tunnel.

3. Results And Discussions

The experimental results of air through square cylinders arranged in tandem with the addition of disturbance (IDB) with 3 variations, namely d/D: 0.033; 0.067 and 0.100 with a distance ratio of M/D=0.00; 0.05; 0.15; 0.25; 0.35; 0.45 and 0.55. The test was carried out with 5 levels of speed at the number Re: 0.5×10^5; 0.7×10^5; 0.8×10^5; 0.9×10^5; and 1.0×10^5. The results of the calculation of the value of the drag coefficient are shown in Table 1 below. 1. Drag coefficient of rectangular cylinder arranged in tandem with disturbance object (IDB) d/D=0.033; 0.067; 0.010.

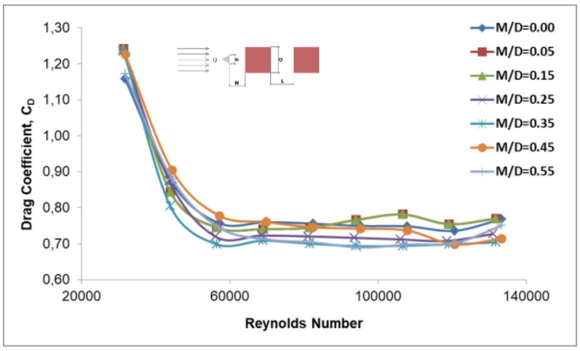
Table 1. Drag coefficient values at various reynolds numbers, cylinder spacing ratios and disturbance object size ratios

Δ = 0,5 cm	d/D = 0,033				
M/D	Re=0,5E+05	Re=0,7E+05	Re=0,8E+05	Re=0,9E+05	Re=1,0E+05
0	0.7571	0.7603	0.7560	0.7496	0.7486
0.05	0.7450	0.7410	0.7447	0.7663	0.7815
0.15	0.7412	0.7371	0.7409	0.7318	0.7360
0.25	0.7200	0.7230	0.7206	0.7166	0.7122
0.35	0.6988	0.7088	0.7003	0.6937	0.6944
0.45	0.7782	0.7603	0.7459	0.7420	0.7368
0.55	0.7450	0.7125	0.7039	0.6897	0.6980

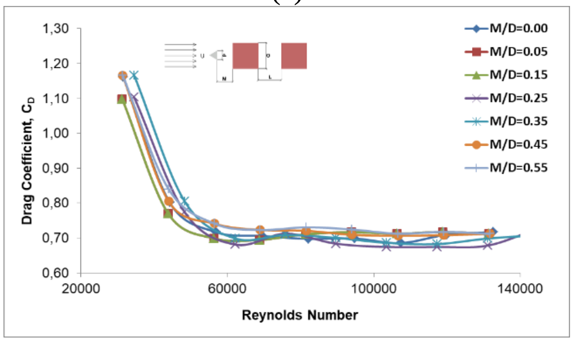
Δ = 1,0 cm	d/D = 0,067				
M/D	Re=0,5E+05	Re=0,7E+05	Re=0,8E+05	Re=0,9E+05	Re=1,0E+05
0	0.7169	0.7058	0.6973	0.6984	0.6855
0.05	0.6988	0.6946	0.7105	0.7166	0.7122
0.15	0.7024	0.7125	0.6937	0.7280	0.7517
0.25	0.6811	0.7125	0.6835	0.6743	0.6741
0.35	0.6988	0.7088	0.7003	0.6861	0.6825
0.45	0.7412	0.7230	0.7206	0.7090	0.7063
0.55	0.7412	0.7230	0.7308	0.7242	0.7122

Δ = 1,5 cm	d/D = 0,100				
M/D	Re=0,5E+05	Re=0,7E+05	Re=0,8E+05	Re=0,9E+05	Re=1,0E+05
0	0.7571	0.7603	0.7560	0.7496	0.7486
0.05	0.7151	0.7040	0.7258	0.7420	0.7074
0.15	0.7450	0.7410	0.7447	0.7356	0.7398
0.25	0.7237	0.7267	0.7243	0.7203	0.7159
0.35	0.7024	0.7125	0.7039	0.6973	0.6980
0.45	0.7876	0.7694	0.7549	0.7510	0.7457
0.55	0.7450	0.7125	0.7039	0.6897	0.6980

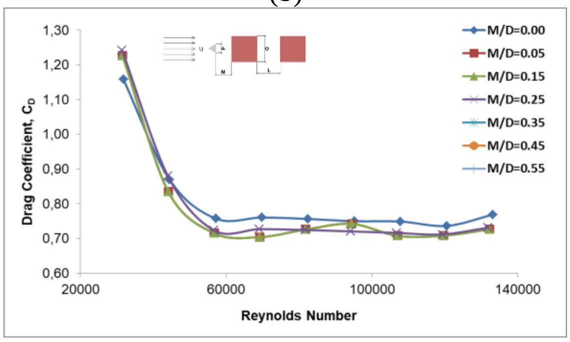
Figure 3 shows the comparison between the drag coefficient (CD) against the Reynold number (Re) of the five M/D distance ratios. In Figure 3(a), for the disturbance object (IDB) d/D=0.033, it can be seen that for all variations in the M/D distance ratio, the drag coefficient value has decreased very drastically as the Reynolds number is added up to Reynolds number 0.5×10^5. After that, the change in the value of the drag coefficient tends to be constant as the Reynold number increases. From the seven variations of the M/D distance ratio, it can be seen that the M/D=0.35 has the lowest drag coefficient value compared to those on other M/Ds. In Figure 3(b), for the disturbance object (IDB) with d/D=0.067, it can be seen that the trend of CD value changes as the Reynolds number increases, giving the same information as Figure 3(a). For the seven variations of M/D distance ratios, it can be seen that the lowest value of the drag coefficient is found at the M/D ratio between 0.25 and 0.35 when compared to those on other M/D ratios.



(a)



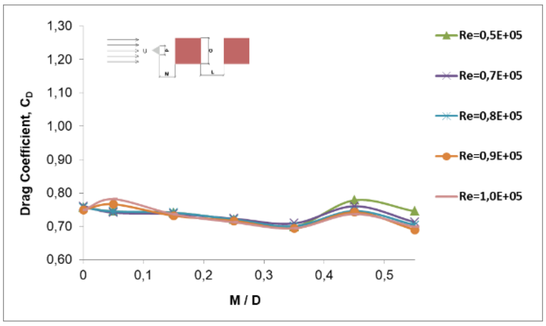
(b)



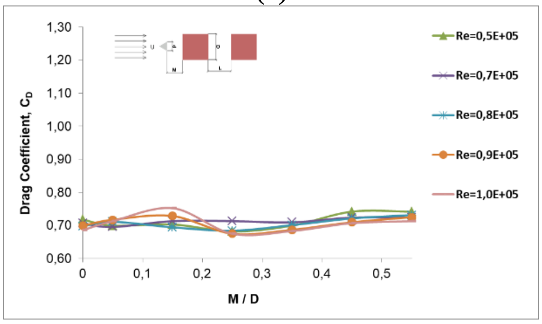
(c)

Figure 3. The relationship between drag coefficient and Reynolds number: (a).d/D=0.033, (b).d/D = 0.067, (c).d/D = 0.100

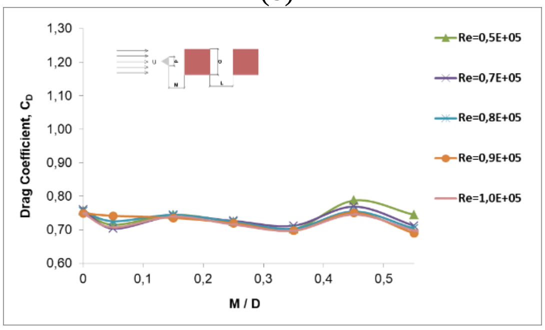
Likewise in Figure 3(c), for the disturbance object (IDB) d/D =0.100, the same pattern is seen for the change in the CD value with the addition of the Reynolds number which is the same as in Figure 3(a), where the drag coefficient value decreases, which is significant with the addition of Reynolds number to Reynolds number 0.5×10^5. After Reynolds 0.5×10^5, the change in the value of the drag coefficient does not change significantly as the Reynolds number is added. From the seven variations of the M/D distance ratio, it can be seen that the M/D ratio of 0.35 also has the lowest drag coefficient value compared to the ones on others.



(a)



(b)



(c)

Figure 4. Relationship between drag coefficent and ratio M/D: (a). d/D=0.033, (b). d/D=0.067, (c). d/D=0.100

Figure 4 shows the comparison between the drag coefficient (CD) to the distance ratio M/D of the five levels of airflow velocity; in this case, the Reynolds number. Figure 2 (a) for disturbance (IDB) d/D=0.033, it can be seen that the value of the drag coefficient has decreased with increasing the distance ratio M/D to the optimum point at M/D=0.35. Following that, the drag coefficient increases again. An exciting finding is in the ratio of the farthest distance M/D=5.5, which again decreased the drag coefficient. In Figure 2(b) for the disturbance object (IDB) d/D=0.067, it can be seen that the drag coefficient value also decreases with the addition of the M/D distance ratio, but the optimum point is between M/D=0.2–0.3. Then after that, the drag coefficient increases again. Then for Figure 2(c) for the disturbance object (IDB) d/D=0.10, it can be seen that the drag coefficient value decreases with the addition of the M/D distance ratio, the optimum point is found at M/D=0.35. Subsequently, the drag coefficient increases again.

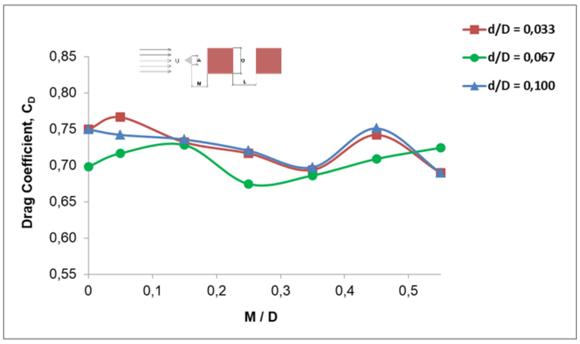


Figure 5. The relationship between drag coefficient CD and ratio M/D at difference disturbance size ratio.

Figure 5 shows the relationship between CD to M/D of three variations of d/D disturbance objects for the velocity level at Reynolds number 0.9×10^5. From the figure, it can be seen that for the three variations of disturbance objects, d/D=0.067 has the lowest drag coefficient value in comparison with a variation of d/D=0.033 and d/D=0.100.

4. Conclusions

Experimental study of the reduction of flow drag through square cylinders arranged in tandem with variations in the size of the triangular disturbance cylinder, d/D, distance ratio, M/D and Reynolds number Re=0.2×10^5 to 1.3×10^5, it can be concluded:

The greater the Reynold number (Re), the smaller the drag coefficient for each variation in the size of the triangular disturbance cylinder d/D, and the distance ratio M/D.

The optimal distance ratio for the variation d/D=0.033 and d/D =0.100 which results in the lowest drag coefficient value obtained at

M/D=0.35, and for the distance variation d/D=0.067, it is found at M/D=0.25.

The addition of a disturbance object in the form of a triangular cylinder in front of square cylinders in a tandem arrangement can reduce the flow drag for all velocity levels (Reynolds's number), where the smallest drag coefficient value is found at the variation d/D=0.067.

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