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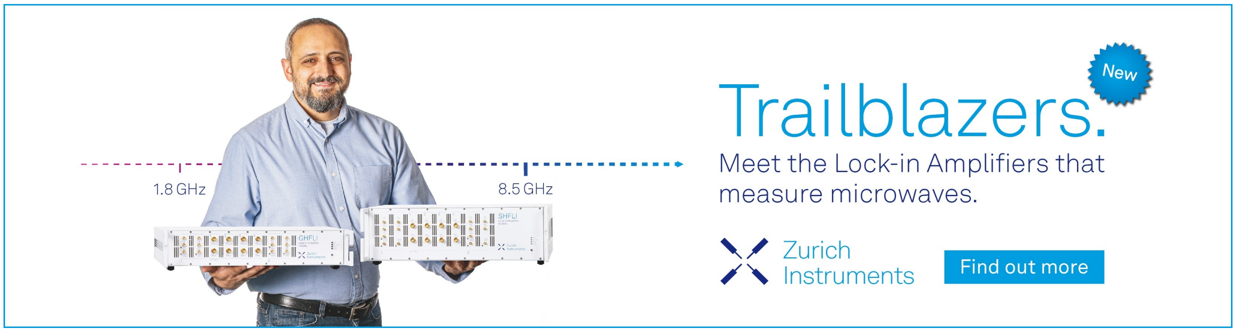

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Effects of the Application of Inlet Disturbance Bodies to Drag Coefficients of Tandem Arranged Square Cylinders

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Abstract. Fluid flow through square cylinders arranged in tandem with triangular cylinders as inlet disturbance bodies (IDB) was analyzed computationally and experimentally at five levels of Reynolds number. The variations in the ratio of the distance between square and triangular cylinders were assigned as M/D=0.00, M/D=0.05, M/D=0.15, M/D=0.25, M/D=0.35, M/D=0.45, and M/D=0.55. The results are in the form of velocity pathlines validated by flow visualization, computational pressure contours, and drag coefficient through experimental testing. The results show that the smallest boundary layer thickness was obtained in the model with a distance ratio of M/D=0.35, by both computational and experimental approaches. The minimal pressure contour characteristics as well as the lowest drag coefficient were also obtained at the ratio of the distance M/D=0.35 at an upstream velocity of 9 m/s of 0.6588.

INTRODUCTION

Some findings in investigating the characteristics of the flow through tandem-arranged objects have been obtained and developed through the philosophy of the boundary layer, flow separation, and vortices. The boundary layer is widely known to very influential to drag forces experienced by objects and their vicinities passed by fluid flow.

Previous research works have been carried out to determine the flow phenomenon across tandem objects and its effect on drag forces [1]–[8]. The body geometry that is commonly used is a cylindrical shape, often found in land transport vehicles such as trains and trailers and in marine transportation such as barges. The reduction of drag can be obtained through flow field engineering by adding an object so called as inlet disturbance body, placed in front of the main object.

Alam et al. researched square structures arranged in tandem with variations in the ratio of the distance between the upstream disturbances body and the main circular cylinder L/D, the ratio of the diameter of the upstream disturbance body to the main circular cylinder, and the Reynolds number. The boundary layer separated from the surface of the distribution body will form a free shear layer by producing discrete vortices and hitting the circular front surface of the main cylinder. The free shear layer then interacts with the boundary layer on the main cylinder which is located behind it. This causes the transition of the laminar boundary layer to become turbulent in the main cylinder to occur earlier so that there is a delay in separation and reduction of drag [9].

Salam et al conducted a similar study regarding the effect of adding an Inlet Disturbance Body (IDB) in the form of a circular cylinder to the drag that acts on a square cylinder in a tandem arrangement through a numerical simulation approach utilizing the computational fluid dynamic method and experimental testing utilizing the subsonic wind tunnel facility. The Reynolds numbers used were in the range of 30,625 to 96,250. The ratio of IDB diameter and square cylinder diameter

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(d/D) were 0.08, 0.14, and 0.20, respectively, with the ratio of the distance between the IDB and the square cylinder (L/D) varied from 0.0 to 1.0. The results showed a decrease in the amount of drag coefficient (Cd) and pressure coefficient (Cp) along with the increase in the ratio of L/D and d/D. The highest reduction in drag coefficient was 21.5962% and the reduction in pressure coefficient was 14.7059 at L/D=0.43 and d/D=0.14 [10]. Salam et al. also investigated flow Separation occurred on square cylinders arranged serial and parallel and found out that the smallest flow separation for serial and parallel configuration of was at M/D=0.6 [11].

Tsutsui and Igarashi investigated the reduction of drag on circular cylinders through the application of a jamming rod in front of the object. The results showed that the disturbance diameter and Reynolds number affected the flow pattern. A 63% reduction in resistance was also found [12].

METHOD

The research was initiated by numerical simulation using computational fluid dynamic software Fluent 6.3.26 before validated by experimental test. For numerical simulation, the test model was designed using the Autodesk inventor device and defined into the computational domain and through the meshing process utilizing the Gambit 2.4 device. Numerical simulations were focused on analyzing flow phenomena in the form of velocity pathlines and pressure contours. Details of the test model and computational conditions are shown in Figure 1 and Table 1.

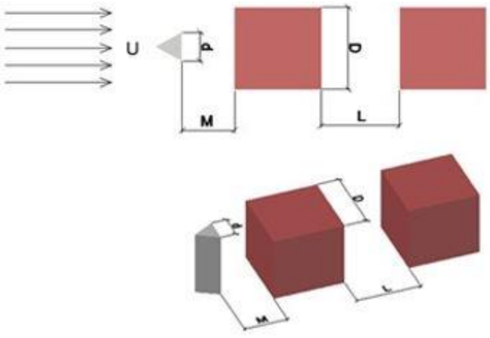


FIGURE 1. Test model

Table 1. Computational condition

Fluid properties	Density	1.186 kg/m^3
	Viscosity	0.000018348kg/Ms
Boundary condition	Test model	Wall
	Inlet	Velocity inlet
	Outlet	Pressure outlet
	Wall	Wall
Upstream velocity		5 m/s, 7 m/s, 9 m/s, 17 m/s, 21 m/s

The rectangular cylinder used was a 0.1 m long and 0.1 m high object. The disturbance object (IDB) has a hydraulic diameter of 0.0067 m. The ratio of the distance between the square cylinder and the disturbing object were varied, respectively on M/D=0.00, M/D=0.05, M/D=0.15, M/D=0.25, M/D=0.35, M/D=0.45, and M/D=0.55. The ratio of the disturbing diameter to the diameter of the square cylinder is written as d/D=0.0671. The corresponding Reynolds numbers were at 31,743, 44,441, 57,138, 107,928, and 133,322.

The research was subsequently conducted in laboratory for experimental testing, focusing on collecting flow visualization data to validate the results of numerical computation and drag using a sub-sonic wind tunnel which is equipped with a measuring instrument for the actual resistance force of the test object with the principle of force balance as shown in Figure 2.

FIGURE 2. Sub-sonic wind tunnel

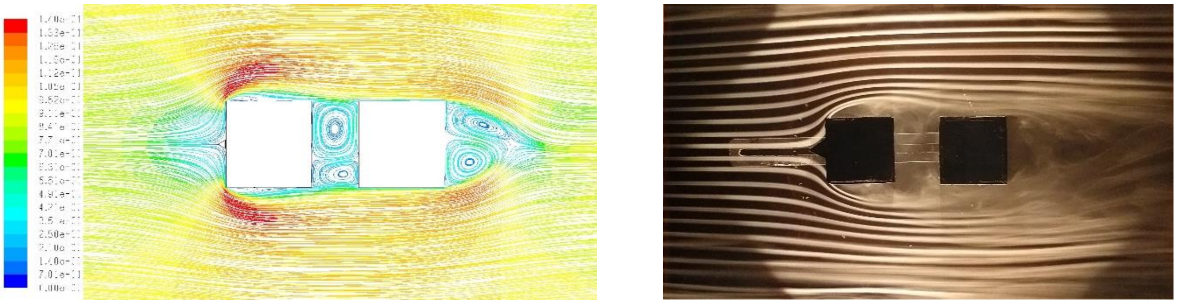
The drag obtained is then written into dimensionless units through the application of Eq. 1

$$C_D = \frac{Fd}{\frac{1}{2}\rho U^2 A} \quad (1)$$

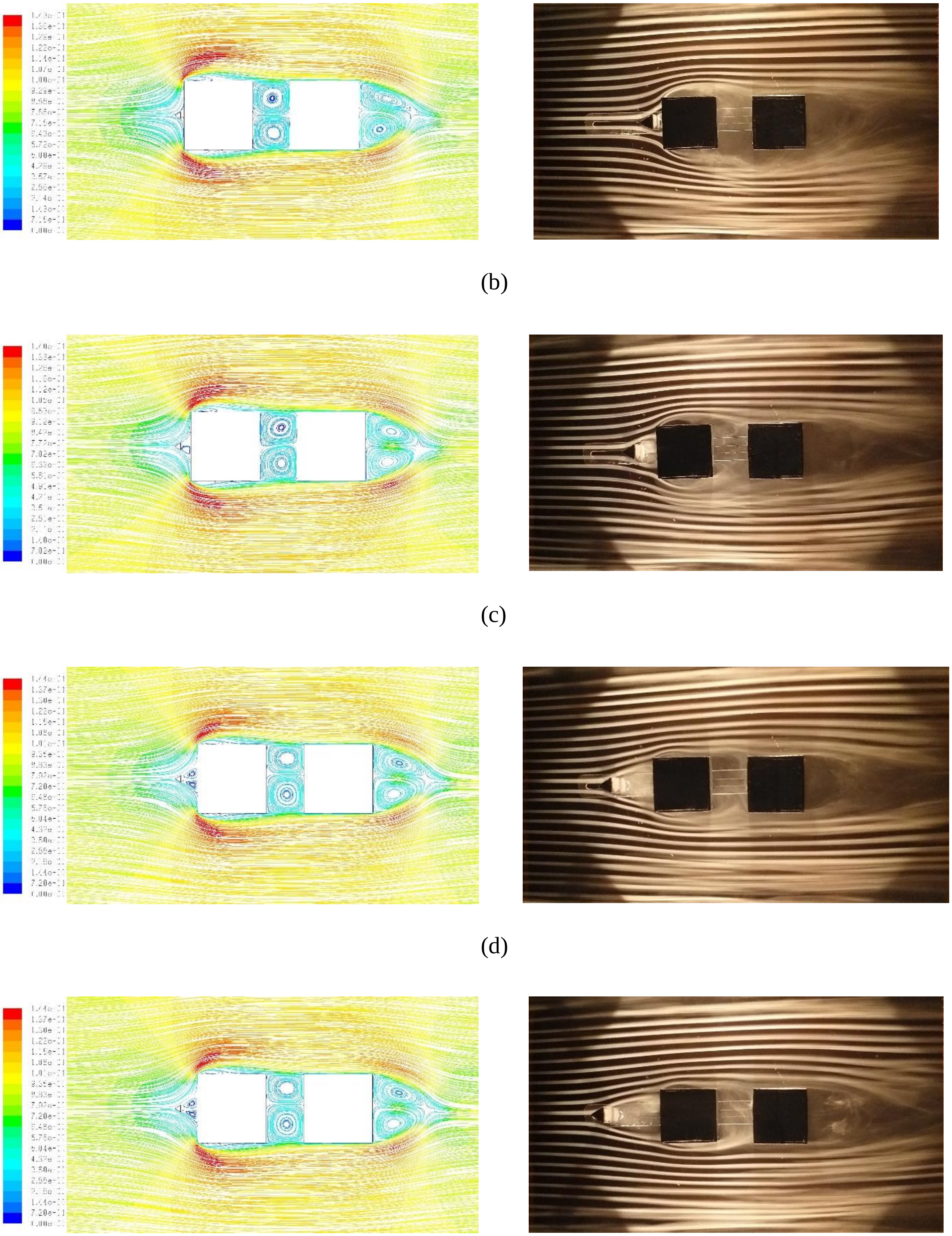
RESULTS AND DISCUSSION

Flow Field

The effect of the application of IDB on the characteristics of the flow pattern through the numerical simulation approach and visualization of the flow of square cylinders arranged in tandem with variations of M/Ds, respectively at M/D=0.00, M/D=0.05, M/D=0.15, M/D=0.25, M/D=0.35, M/D=0.45, and M/D=0.55, are shown in figure 3. In all comparisons, the M/D distance shows a significant increase in flow velocity when the fluid reaches the side part of the test objects. This is because there is a reduction in the intensity of the direct impact against the front side of the cylinder which causes the minimization of the loss of flow momentum to move towards the boundary layer. The thicker the boundary layer, the greater the effect on drags. It can be seen that the model at M/D=0.00 has a thick boundary layer which tends to be larger than the other models. Meanwhile, the smallest boundary layer thickness was obtained at M/D=0.35.



(a)



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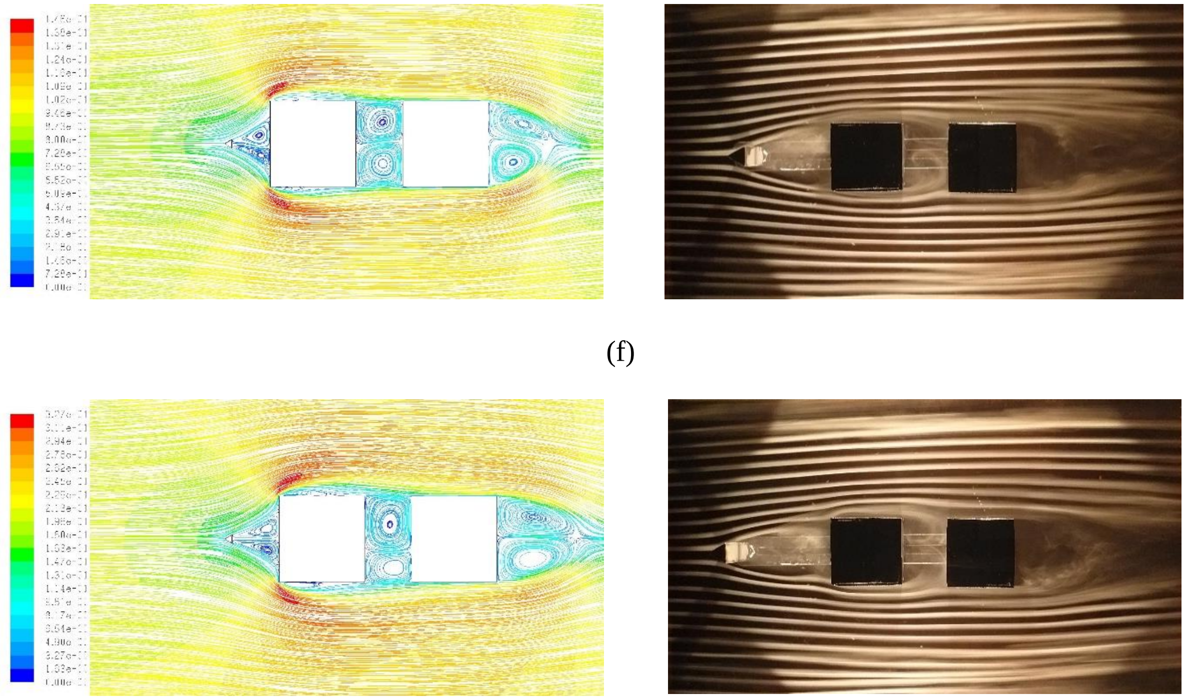
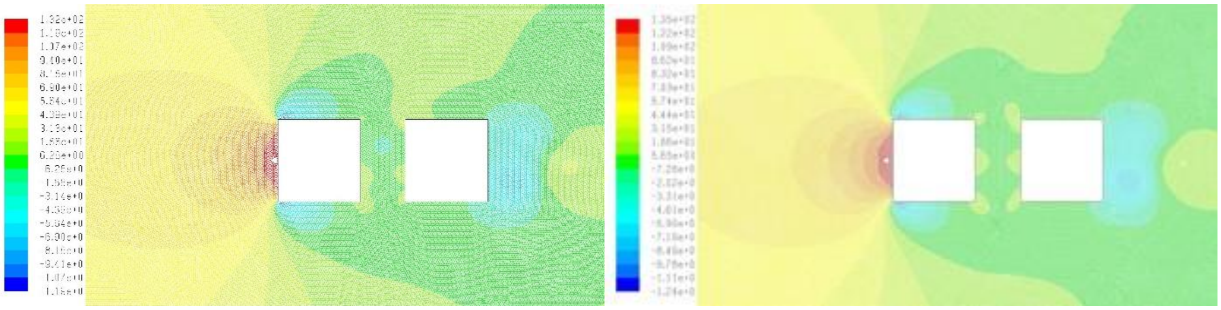

(f)

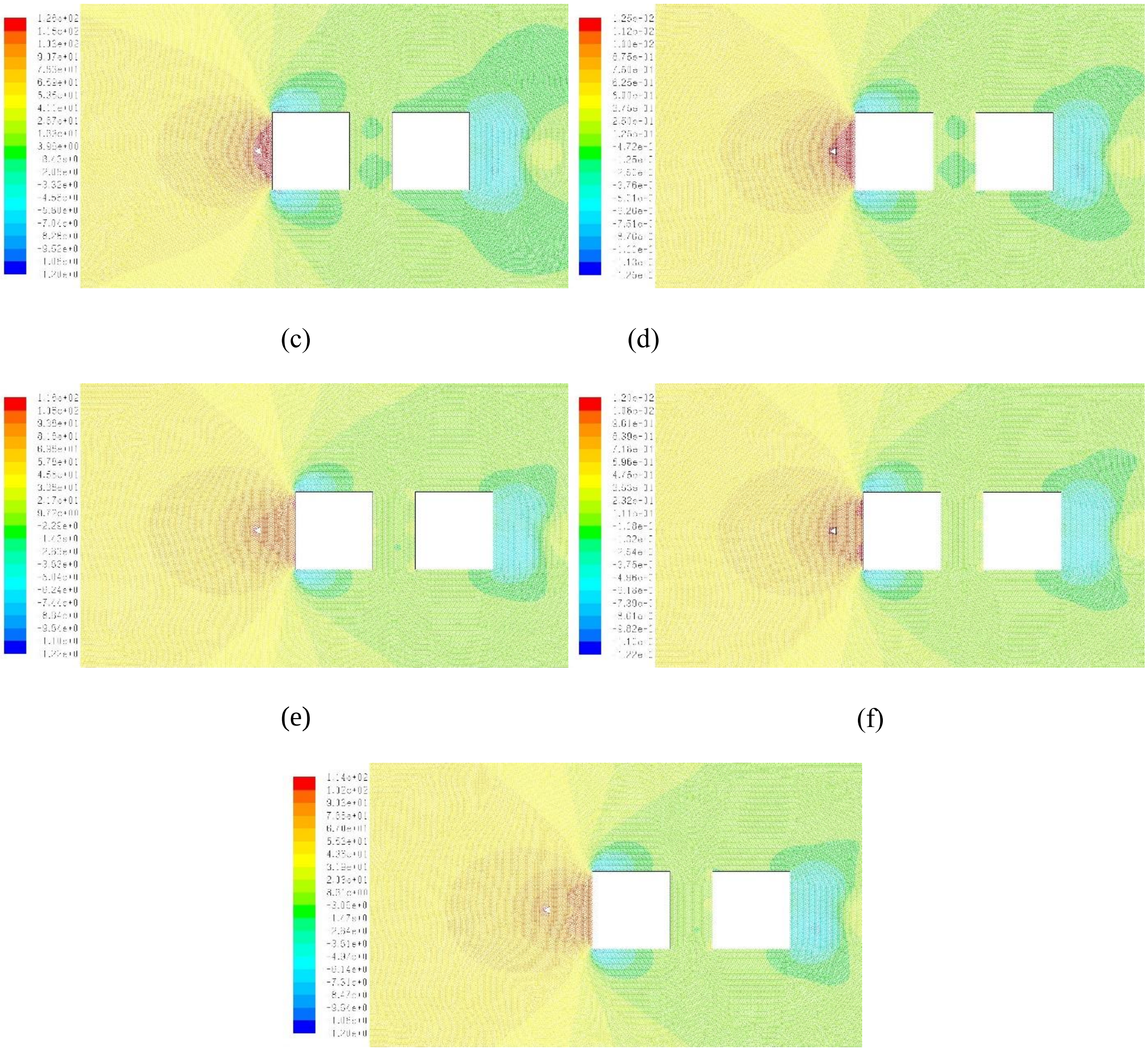
(g)

FIGURE 3. Comparison of computational and experimental velocity pathlines (a) M/D=0.00, (b) M/D=0.05, (c) M/D=0.15, (d) M/D=0.25, (e) M/D = 0.35, (f) M/D=0.45, (g) M/D=0.55

Pressure Field

The effect of adding IDB with distance ratios of M/D=0.00, M/D=0.05, M/D=0.15, M/D=0.25, M/D=0.35, M/D=0.45, and M/D=0.55 to the pressure field are shown in figure 4. The addition of IDB which aims to reduce the direct collision between the fluid flow and the front side of the square cylinder are proved to be able to reduce the positive pressure intensity. It can be seen that the model with the distance ratio M/D=0.35 has the lowest pressure contour when compared to the ones in other models.


(a) (b)



(c) (d)

(e) (f)

(g)

FIGURE 4. Comparison of pressure contours at various distance ratios (a) M/D=0.00, (b) M/D=0.05, (c) M/D=0.15, (d) M/D=0.25, (e) M/D = 0.35, (f) M/D=0.45, (g) M/D=0.55

Drag Coefficients

The drag coefficient obtained through experimental testing at variations of respective M/D=0.00, M/D=0.05, M/D=0.15, M/D=0.25, M/D=0.35, M/D=0.45, and M/D=0.55 is shown in table 2. For an upstream velocity of 5 m/s, the lowest resistance for M/D=0.05 was of 1.0978 and the highest drag coefficient obtained at the ratio of the distance M/D=0.35, M/D=0.45 and M/D=0.55 was of 1.1664. For a velocity of 7 m/s, the lowest drag coefficient obtained at M/D=0.05 was of 0.7701 and the highest obtained at M/D=0.55 was of 0.8401. Quite differently, for a speed of 9 m/s, the lowest drag coefficient is obtained at M/D=0.35 at Cd=0.6588 and the highest is obtained at M/D=0.45 and M/D= .55 of at Cd=0.7412. For a velocity of 17 m/s, the lowest drag coefficient is obtained at M/D=0.25 at Cd=0.6741, while the highest is obtained at M/D=0.15 at Cd=0.7517. For the upstream velocity of 21 m/s, it was also found that the lowest drag coefficient was obtained at M/D=0.35 at Cd=0.7079 and the highest was obtained at M/D=0.25 at Cd=0.7702.

TABLE 2. The drag coefficient at various distance ratios, M/D

U_0	Re	Cd for M/D						
		0.00	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**	**0.55**
5	31743	1.1614	1.0978	1.1034	1.1034	1.1664	1.1664	1.1664
7	44441	0.8017	0.7701	0.7741	0.7743	0.8051	0.8051	0.8401
9	57138	0.7169	0.6988	0.7024	0.6811	0.6588	0.7412	0.7412
17	107928	0.6855	0.7122	0.7517	0.6741	0.6875	0.7063	0.7122
21	133322	0.7165	0.7118	0.7702	0.7272	0.7079	0.7118	0.7155

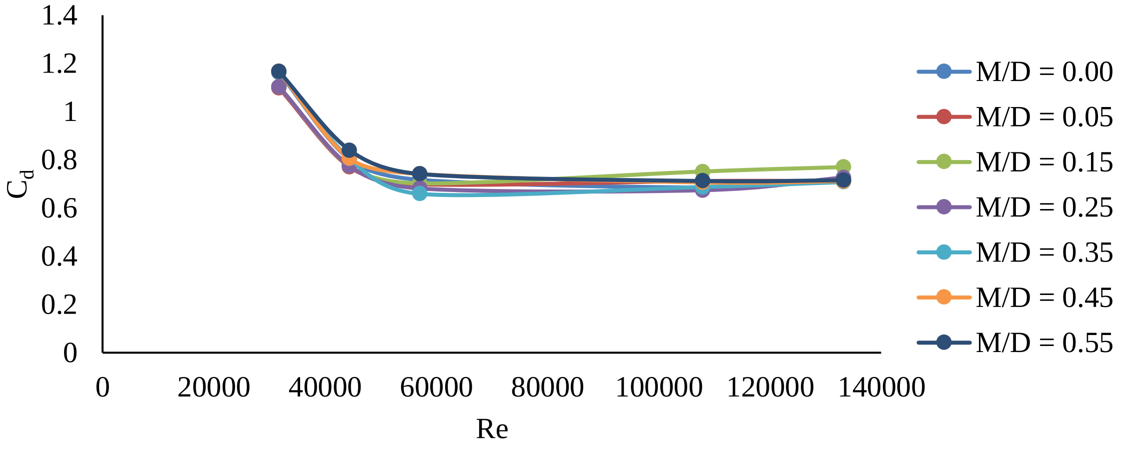


FIGURE 5. Comparison of the drag coefficient against the Reynolds number

CONCLUSION

The addition of the Inlet Disturbance Body has been proven to give significant effects on the characteristics of the flow pattern, pressure field, and drag coefficient. The thickness of the boundary layer, the pressure field intensity, and the lowest drag coefficient are obtained in the model with the distance ratio, M/D=0.35. The lowest drag coefficient is obtained at an upstream velocity of 9 m/s of 0.6588.

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