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Experimental Measurements of Mean and Turbulence Quantities behind the Circular Cylinder by Attaching Different Number of Tripping Wires

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Abstract**—**For a bluff body, roughness elements in simulating a turbulent boundary layer, leading to delayed flow separation, a smaller wake, and lower form drag. In the present work, flow past a circular cylinder with using tripping wires is studied experimentally. The wind tunnel used for modeling free stream is open blow circuit (maximum speed = 30m/s and maximum turbulence of free stream = 0.1%). The selected Reynolds number for all tests was constant (Re = 25000). The circular cylinder selected for this experiment is 20 and 400mm in diameter and length, respectively. The aim of this research is to find the optimal operation mode. In this study installed some tripping wires 1mm in diameter, with a different number of wires on the circular cylinder and the wake characteristics of the circular cylinder is studied. Results showed that by increasing number of tripping wires attached to the circular cylinder (6, 8, and 10, respectively), The optimal angle for the tripping wires with 1mm in diameter to be installed on the cylinder is 60° (or 6 wires required at angle difference of 60°). Strouhal number for the cylinder with tripping wires 1mm in diameter at angular position 60° showed the maximum value.

Keywords**—**Wake of a circular cylinder, trip wire, velocity defect, Strouhal number.

I. INTRODUCTION

THE aerodynamics is a branch of the dynamics of gasses and more generally the dynamics of fluids that examines the behavior of the flow of air and its effects on moving and fixed objects. The flow of an incompressible fluid with drag around the circular cylinder is one of the classical issues of the mechanics of the fluids. Despite the simple geometry of the cylinder, the flow created behind it is very complex especially at high Reynolds numbers where the equations of motion cannot be simply obtained using numerical methods. For this reason, experimental study of the wake behind the circular cylinder is a basic and dynamic problem in fluid mechanics. Various factors affect the characteristics of the wake behind circular cylinders. From amongst them, one can refer to the effect of Reynolds number [1], [2], the amount of turbulence of free stream, aspect ratio [3], [4], surface roughness [5]-[7], dimensions of the holding plates at the ends of the cylinder [8] and blockage. In this research, the effect of surface roughness is studied by installing trip wires with the dimensional scale of 0.05 (referring to the ratio of the diameter of the tripping wire to the diameter of the circular cylinder). This phenomenon causes smaller wakes area (i.e. reverse flow region) behind the cylinder thus reducing the total drag [9]. The trip wires have been installed at various angles (60, 45, and 36 degrees, i.e. 6, 8, or 10 trip wires symmetrically were used.) then mean velocity and turbulence intensities profiles of the circular cylinder have been studied. Bluff bodies, especially circular cylinders are used in turbo machines, high-rise buildings, aerodynamic design of airplanes, heat exchangers, industrial chimneys, etc. Fluid forces are important factors in the design of building facilities and other engineering structures. Using of tripping wires highly affects the patterns of fluid flow behind the cylinder and also causes a considerable change in the constant and fluctuating forces that act on the cylinder.

There are many studies that have been focused on circular cylinders equipped with tripping wires. By placing a small cylinder near the main cylinder, the authors [10] controlled streams around the main cylinder and found that a decrease in the wake width will lower the drag coefficient. Hover et al. [11] installed two tripping wires on the circular cylinder with low Reynolds number, learned that the installation of a tripping wire on a stable cylinder would significantly decrease lift coefficient, drag force, and increase Strouhal number. Later on, Ekmekci and Rockwell [12] studied the influence of installing tripping wire on the circular cylinder and demonstrated that Strouhal number shows crater-like changes (a gradual decrease and then increase) by changing its angular position across the limits of critical angles.

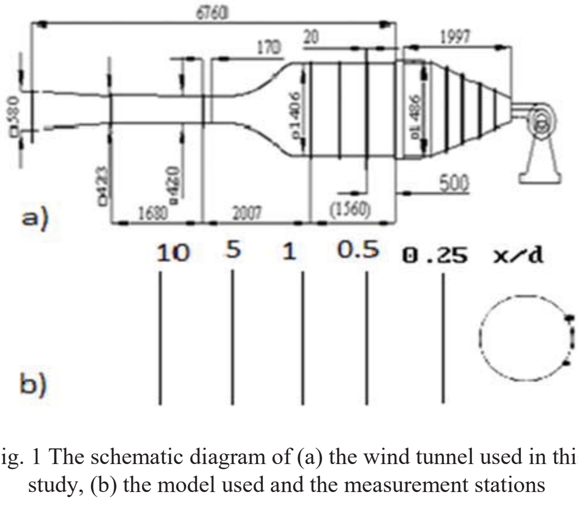

Fig. 1 The schematic diagram of (a) the wind tunnel used in this study, (b) the model used and the measurement stations

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Nishi et al. [13], demonstrated that considering the angular position in 20 degrees to 52.5 degrees or more than 97.5 degrees, the forces would decrease. Particularly at 75 degrees of angle, the lift and drag coefficient have been increased, and at the 112.5 degrees angular position this ratio has been reduced.

II. METHODOLOGY

A. Wind Tunnel

The (low speed) wind tunnel used in this study is of the open blow circuit type manufactured by Farasanjesh Saba's company. It has an experimental chamber made from plexiglass (in which the model is seen clearly); the chamber is 168 cm long, 40 cm wide and 40 cm tall. The schematic diagram of the wind tunnel and the model are shown (Fig. 1). The velocity in the wind tunnel can be varied from 0 to 30 m/s using motor speed control. The speed of 20 m/s has been used in the experiments in this study. The maximum rated free stream turbulence in the experiment chamber is 0.1% for this equipment.

The anemometer used in this experiment is the constant temperature hot-wire type, made by the Farasanjesh Saba company. It is capable of measuring the average velocity, turbulence intensities, and frequency of Vortices trail behind the cylinder. The one-dimensional probe used in this experiment has a wire 1.25 millimeters long and 5 micrometers in diameter. The circular cylinder used is made of plexiglass (since it has a smooth finished surface). Tripping wires with d/D=0.05 were used at three angles of 60, 45, and 36 degrees on the surface of the cylinder in order to produce surface roughness.

Therefore, the experiments were conducted in four stages. At first, the smooth cylinder was placed inside the experiment chamber, and the characteristics of the resulting wake were examined. Then, in the next three stages, the cylinder with 6, 8 and 10 tripping wires installed on the cylinder was placed in the experiment chamber, and the experiment was repeated.

The flow patterns, mean velocity profiles and the turbulence intensities of the wake were studied in stations (x/d) 0.25, 0.5, 1, 5, and 10.Then the obtained results were compared with each other and with the smooth cylinder in order to find the optimum conditions for the circular cylinder having a wire to cylinder diameter ratio of 0.05.

B. Smooth Circular Cylinder

Normalized diagrams of mean velocity profile and turbulence versus the sampling interval have been plotted for all stations for the smooth cylinder and the cylinder with a various number of tripping wires as shown in Figs. 2-4. In the case of the smooth cylinder (Fig. 2 (a)), the wake behind the cylinder is symmetrical, and two peaks can be seen inside the wake near the cylinder in the central line of the wake. These peaks fall off as we get farther away from the cylinder and at x/d=1 we see a symmetrical peak. The existence of 2 peaks in the diagrams (in the stations near the cylinder), indicate bigger vortices behind the cylinder and by going to the next stations (and getting farther away from the cylinder in the direction of its length) diminishing process occurs and the vortices change to eddy then the area shows a more uniform wake. Also, as we get farther away from the back of the cylinder, the difference between the speed of free stream and the velocity of the flow inside the wake, gradually decreases and as a result it causes the diminishing of the bigger vortices behind the cylinder. In the smooth cylinder or the cylinder without any trip wires (Fig. 2 (a)), it is seen that the velocity defect decreases as we progress towards the front stations and a decreasing condition are observed. As shown in Fig. 2 (a), in station 0, 0.25 and 0.5 (near the circular cylinder), two peaks are observed. These peaks shown velocity is more than mean velocity. This phenomenon is due to the vortex shedding behind the circular cylinder. This vortex shedding is caused by severe reduction pressure, then increase velocity. These peaks gradually disappeared in stations far away from the body. In addition, considering the mean velocity profile of the smooth cylinder (Fig. 2 (a)), it is noticed that outside the wake, all the points nearly progress to the same value. That means the experimental carried out under the same conditions. All profiles of mean velocity show which intersection in one point. At this point, the vortex in the wake is formed. In profiles of turbulence intensities, the maximum turbulence is seen at (Fig. 2 (b)) it is the same point with mentioned earlier (Fig. 2 (a)).

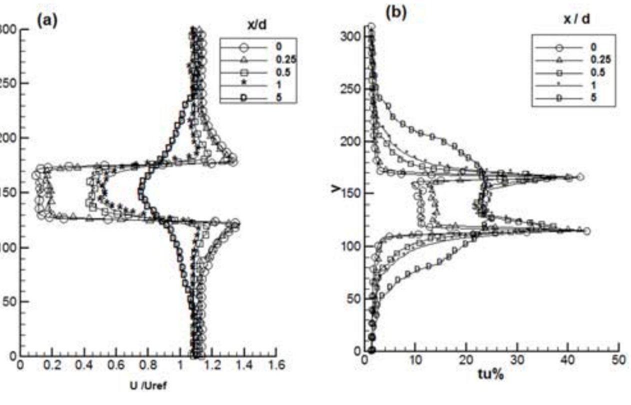


Fig. 2 Normalized diagrams of (a) mean velocity profile and (b) turbulence versus the sampling interval for the smooth circular cylinder for all stations

As it seen in Fig. 2 (b), along with the center line of the circular cylinder, turbulence intensities are lower for closer stations. This phenomenon is due to small vorticities in the center line of the body. As we are going far away from the circular cylinder, the turbulence intensities decreased, and two peaks of the turbulence profiles vanished.

III. RESULTS AND DISCUSSIONS

The plot of the variations of the mean velocity profile versus the number of tripping wires (d/D=0.05) on a circular cylinder in successive stations are shown in Figs. 2 and3. As it can be seen, with the increase in the number of trip wires on the cylinder the wake behind the cylinder becomes wider (Fig. 3). In other words, the magnitude of the shear layer has decreased, and the velocity defect has been lowered. Of course, it is seen that the width of the wake is nearly the same for 8 or 10 trip wires, and it can even be said that the width of the wake is wider for the case with 8 trip wires, and the velocity defect is the least in that case. Therefore, the magnitude of the shear layer in the case of 8 trip wires is the smallest of all. In this part, it can be concluded that with the increase of the width of the wake, the velocity defect will be decreased. With an increase in the number of tripping wires mounted on the cylinder, the highest peak of velocity (the point at which the pressure has drastically dropped) at the border of the wake has increased when compared with the smooth cylinder as shown in Figs. 2 and 3. Of course, once again we see a similar behavior for the case with 8 and 10 tripping wires as shown in Figs 3 (b) and (c).It can be seen that the maximum peak of velocity at the border of the wake must be considered for the case of 8 tripping wires. Thus, in cylinders with 8 tripping wires, we see a more serious drop in the pressure and increase in velocity.

In general, it can be said that the largeness of magnitude of the vortices in cylinders with 8 or 10 tripping wires is more than that of the cylinder with 6 tripping wires (Fig. 3 (a)), and the behavior of the former is different from that of the latter. Moreover, as you get farther away from the central line of the body (i.e. the circular cylinder) in the direction out of the wake, all the diagrams end at the same range of mean velocity (similar to the smooth cylinder).

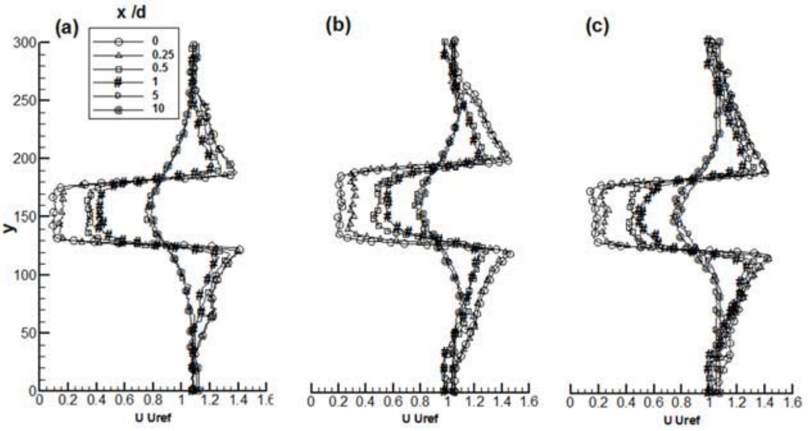


Fig. 3 Normalized diagrams of mean velocity profile and versus the sampling interval for all stations (d/D=0.05): circular cylinder by attaching (a) 6, (b) 8, and (c) 10 trip wire

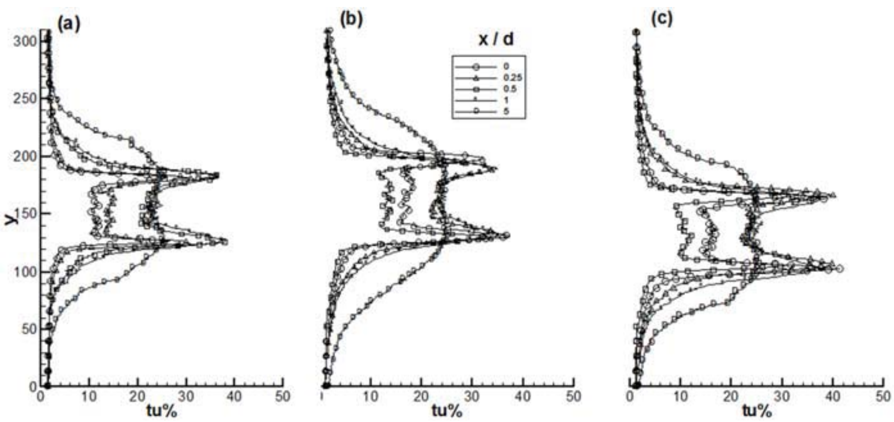


Fig. 4 Normalized diagrams of turbulence profile and versus the sampling interval for all stations (d/D=0.05): circular cylinder by attaching (a) 6, (b) 8, and (c) 10 trip wire

Studying the plots of turbulence intensities (Fig. 4), it can be seen the maximum turbulence of the cylinder with 6 tripping wires is less than that of the other cases, while the intensity of turbulence (the width of the turbulence diagrams) in that case is more than that of all other cases (Fig. 4 (a)). Moreover, it can be seen from the diagrams, that the turbulence of the case with 6 tripping wires in the last few stations is flatter and there is a drastic drop in the turbulence. In other words, whenever the magnitude of turbulence is more, the maximum turbulence shows more decrease.

Next, we will review and compare the graphs of the profiles of mean velocity versus the sampling range for the smooth cylinder versus the ones with a various number of tripping wires at fixed stations as shown in Figs. 5-8. At the station x/d=0.25 (Fig. 5), the minimum peak of average velocity inside the wake is related to the cylinder with 6 tripping wires, and it is very much like that of the smooth cylinder. Again we can see that the behavior of the cylinder with 10 tripping wires is somewhere in between that of the cases with 6 and 8 tripping wires, and the one with 8 tripping wires has the highest velocity defect. Considering Fig. 5, it can be seen that the highest peak of velocity at the border of the wake is related to the cylinder with 8 tripping wires. then as the number of tripping wires changes (10, 6, and 0 respectively), the highest peak in velocity is reduced. Of course, once again the behavior of the cylinder with 10 and 8 tripping wires is almost similar, and the cylinder with 6 tripping wires shows a better behavior. The span of the wake also shows a similar behavior regarding the highest peak of velocity, while that of the cylinder with 8 tripping wires is bigger and then with a change in the number of tripping wires (10, 6, 0, respectively) it becomes lower as the number of tripper wires decreases.

Thus it can be said that the gradient of velocity in the cylinder with 8 tripping wires is less than that of the other three graphs. Therefore, its (dU /dy) is less since according to Τ = μ(dU/dy) the rate of shear stress is lower in this case. In cases of (10, 6, 0 tripping wires, respectively) the rate of shear stress increases as the number of tripping wires decreases. Thus, considering Fig. 5 the highest amount of shear stress is related to the smooth cylinder, and after it, it is observable in the cylinder with 6 tripping wires. Concerning what was stated, whenever the rate of shear stress is less, it can be said that the velocity defect is less. Of course, considering the fact that the data collecting station is very close to the object, the results obtained from this station are less valid due to the presence of separation phenomenon, accidental flows, and the existence of three-dimensional flows behind the cylinder.

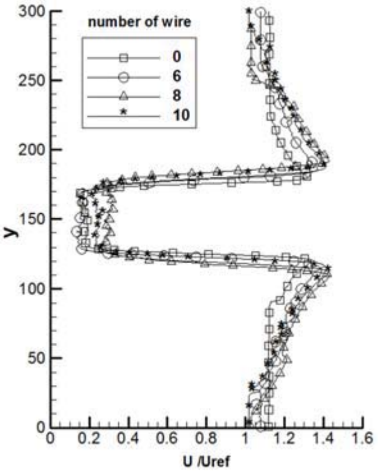


Fig. 5 Normalized diagrams of mean velocity profile and versus the sampling interval (d/D=0.05): circular cylinder by attaching 6, 8, and 10 trip wires in the first station (x/d=0.25)

In station x/d=0.5 (Fig. 6), nearly all the results obtained from the first station (Fig. 5) have been verified with the only difference being that the inner span of the wake in the cylinder with 6 tripping wires is the narrowest of all. Thus, it has a higher velocity gradient and a higher rate of shear stress. We can conclude that the cylinder with 6 tripping wires satisfies the desired requirements and its behavior is completely different from that of the other three cases.

In the station x/d=1 (Fig. 7), all of the results obtained from the 2nd station have been verified. Thus, considering these results, it can be said that an optimum state has been found with the cylinder with 6 tripping wires and d/D=0.05. In other words, for the cylinder with wires with the ratio d/D=0.05, the cylinder with 6 tripping wires shows a better behavior than the cylinder with 10 or 8 tripping wires as well as the smooth level cylinder. Although a desirable result has been obtained, drag coefficient must also be examined and compared in the stations far away from the cylinder.

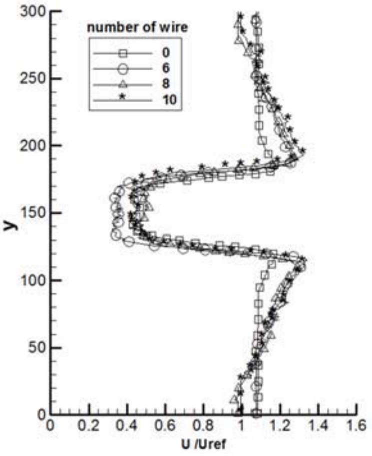


Fig. 6 Normalized diagrams of mean velocity profile and versus the sampling interval (d/D=0.05): circular cylinder by attaching 6, 8, and 10 trip wires in the second station (x/d=0.5)

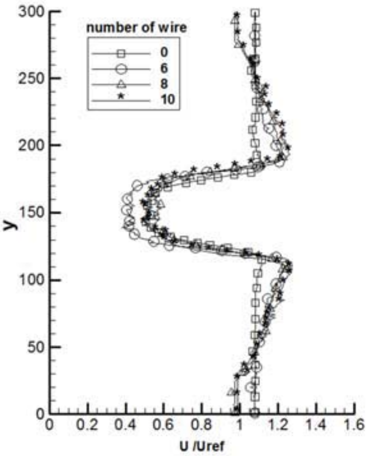


Fig. 7 Normalized diagrams of mean velocity profile and versus the sampling interval (d/D=0.05): circular cylinder by attaching 6, 8, and 10 trip wires in the third station (x/d=1)

In the station x/d=5 (Fig. 8), the results obtained from the two previous stations (x/d=0.5, 1) are verified. It is noteworthy that in the last stations, the velocity inside the wake slowly becomes equal to that of the free stream. Thus, in the domain of the wake similar to what is shown in Fig. 8, gradually decreases and does not give any clear indication of the behavior of the tripping wires and their diameter.

Fig. 9 shows the graph of the velocity defect and the maximum turbulence intensities. In other words, it verifies the results of the other plots (Figs. 5-8). In Fig. 9 (a), it can be seen that the highest velocity defect and minimum turbulence intensities (Fig. 9 (b)) are related to the cylinder with 6 tripping wires (with an inter-wire angle of 60 degrees).

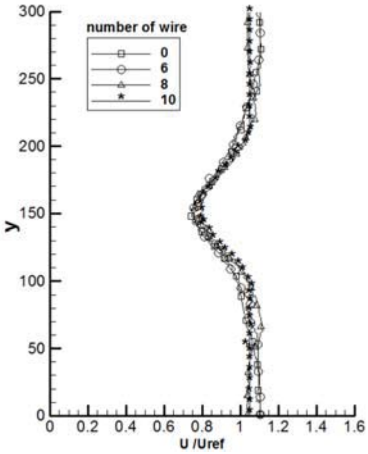


Fig. 8 Normalized diagrams of mean velocity profile and versus the sampling interval (d/D=0.05): circular cylinder by attaching 6, 8, and 10 trip wires in the fourth station (x/d=5)

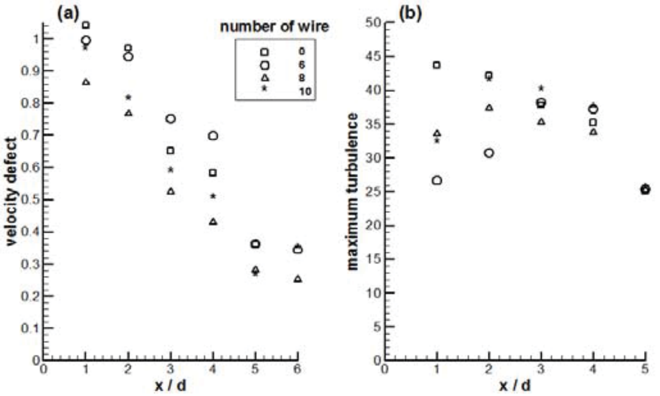


Fig. 9 Graph of (a) velocity defect and (b) maximum turbulence (d/D=0.05): smooth circular cylinder and it by attaching 6, 8, and 10 trip wires

The plot of Strouhal number is shown (Fig. 10). Here, the results obtained from the previous figures (Figs. 1-9) are verified, and the maximum Strouhal number in different stations is associated with the cylinder with six tripping wires. This is in line with the findings of other researchers who concluded that Strouhal number increases considerably with a reduction of drag coefficient [10].

IV. VALIDATION

The results of the mean velocities obtained from this experiment are in good agreement with the results of the research done by Karaman [14] (the flow around the circular cylinder). In both cases, the conditions were incompressible flow at low Reynolds numbers. The mean velocity profile obtained in this study is compared with that obtained by Karaman in 2000 (Fig. 11 (a)). Both have been measured at nearly the same distance from the circular cylinder. The Strouhal number obtained from the smooth cylinder shown in Fig. 11 (b) is validated well [6], [15].

V. CONCLUSION

Considering the profiles related to the wake behind the circular cylinder, we can summarize the results of this study as follows:

- In cylinders with 8 or 10 wires (with d/D=0.05), the wake has nearly the same response while it is different from the response of a smooth cylinder and one with 6 trip wires (d/D=0.05). The span of the wake and the velocity at the border of the wake in a cylinder with 8 wires or more is greater than that of other cases, and the rate of the shear layer, in this case, is less than that of the other cases. The behavior of cylinders with 6 trip wires (with the widest wake span and shear layer) and one with 10 trip wires were reported.
- What is most important is that the optimal conditions for the cylinder with tripping wire at the scale of d/D=0.05 have been stated to be when the angle between the wires is sixty degrees, and six wires are symmetrically mounted. In other words, the best situation for a circular cylinder with tipping wires at the scale of d/D=0.05 occurs when there are six wires mounted at sixty degrees relative to each other on the cylinder.

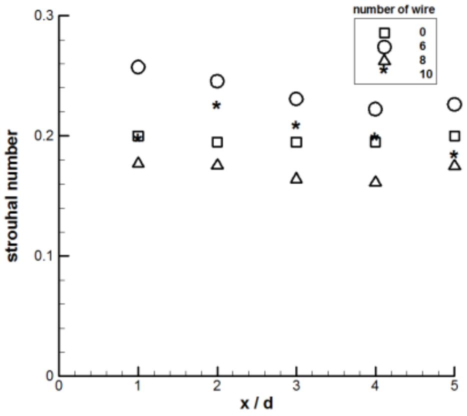
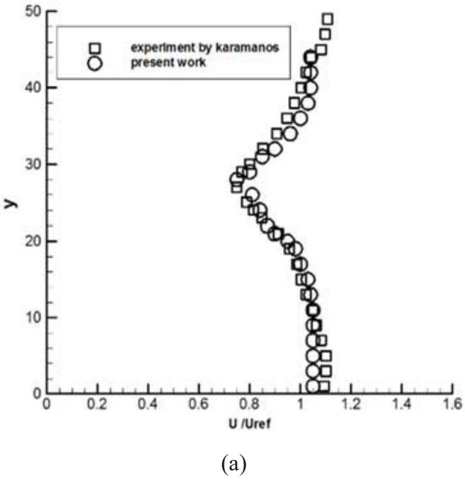
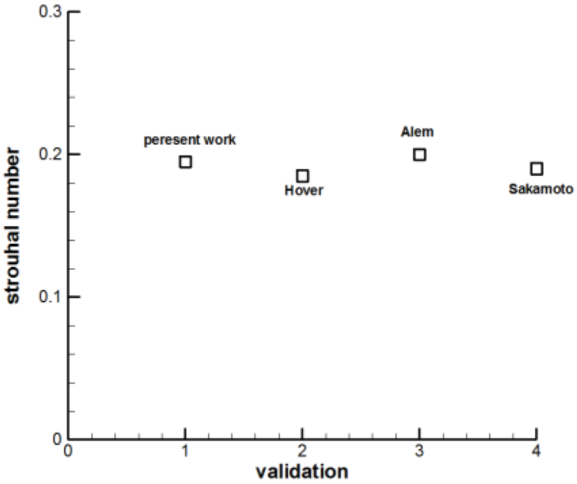


Fig. 10 Graph of strouhal number (d/D=0.05): smooth circular cylinder and it by attaching 6, 8, and 10 trip wires



(a)



(b)

Fig. 11 (a) Diagram of mean velocity [14], and (b) graph of Strouhal number [6], [15], for smooth circular cylinder validated by other researchers

REFERENCES

[1] A, P. P., & *P. Paranthoën, L. B. (1999). Characteristics of the near wake of a cylinder at low Reynolds numbers. Eur. J. Mech. B/Fluids, 659–674.

[2] C.-H. Kuo, L.-C. C.-C. (2007). Wake flow pattern modified by small control cylinders at low Reynolds number. Journal of Fluids and Structures, 938–956.

[3] F. Rehimi, F. A. (2008). Experimental investigation of a confined flow downstream of a circular cylinder centered between two parallel walls. Journal of Fluids and Structures 24, 855–882.

[4] Tiago B. Araújo, C. S. (2012). Influence of obstacle aspect ratio on tripped cylinder wakes. International Journal of Heat and Fluid Flow, 109–118.

[5] Fumiaki Nagao, M. N. (2012). properties of wake excitation in tandem circular cylinders with several kinds of surface roughness . BBAA7.

[6] T.B.Aydin, A. (2014). Critical effects of a spanwise surface wire on flow past a circular cylinder and the significance of the wire size and Reynolds number. Journal of Fluids and Structures, 132–147.

[7] Bragg, J. M. (2013). Study of a Swept Wing with Leading-Edge Ice Using a Wake Survey Technique. AIAA.

[8] X.K. Wang, S. T. (2008). Comparison of flow patterns in the near wake of a circular cylinder and a square cylinder placed near a plane wall. Ocean Engineering 35, 458–472.

[9] C. K. Chear, S. S. (2015). Vehicle Aerodynamics: Drag Reduction by Surface Dimples. International Journal of Mechanical, Aerospace, Industrial, and Mechatronics Engineering.

[10] Tsutsui, T. I. (1992). flow control around a circular cylinder by a small cylinder. Australasian fluid mechanics conference .

[11] By F. S. HOVER, H. T. (2001). Vortex-induced vibrations of a cylinder with tripping wires. J. Fluid Mech., 175-195.

[12] Alis Ekmekci, D. O. (2010). Control of Flow past a Circular Cylinder via a Spanwise Surface Wire: Effect of the Scale of the Wire. AIAA.

[13] Luis Antonio Rodrigues Quadrant, YoshikiNishi (2014). Amplification/suppression of flow-induced motions of an elastically mounted circular cylinder by attaching tripping wires. Journal of Fluids and Structures, 93–102.

[14] By X. M A, G.-S. Karamanos and G. E. Karniadakis. (2000). Dynamics and low-dimensionality of a turbulent near wake. J. Fluid Mech, 29–65.

[15] Md. Mahbub Alam, H. S. (2003). Reduction of fluid forces acting on a single circular cylinder and two circular cylinders by using tripping rods. Journal of Fluids and Structures 18, 347–366.