9th Asia-Pacific Conference on Wind Engineering
Auckland, New Zealand
3-7 December 2017

Turbulence effect on the flow around a circular cylinder with the diameter of 0.3m

Jianfeng Yao1, Guohui Shen1*, Wenjuan Lou1

[1] Institute of Structural Engineering, College of Civil Engineering & Architecture,
Zhejiang University, Hangzhou 310058, China
(*corresponding to: ghshen@zju.edu.cn)

Abstract

This paper was concerned with the wind flow around a circular cylinder with various wind velocities (*v*) and turbulence intensities (*I*). Wind pressures were measured through wind tunnel tests, by which drag coefficient (C_D) and lift coefficient (C_L) were calculated. The values of drag coefficient varies with the Reynolds numbers (*Re*) and turbulence intensities of incoming flow, and there exists a significant difference between steady flow and turbulent flow in drag coefficient in subcritical Reynolds numbers. An unstable separation bubble appears on one side when flow changes from the steady situation to the turbulent situation. Strong positive relation can be found between tests points that are on the same side on wind pressure under all testing cases. Turbulence intensity affects the spectral density distribution of drag coefficient a lot.

Introduction

Fluid-dynamic loads have a great influence to design of Civil Engineering structures. In particular, in wind engineer, aerodynamics point out that through the definition of an aerodynamic shape factor describing the effects of geometry [1]. That means the geometry of structures influent the stress performance of structures a lot, in practice, especially cross-section is circular.

Flowing around a circular cylinder is a classic problem on aerodynamics as well as on wind resistant engineering, such as towers, bridge pipes, stays and wires. Peculiarities of flowing around a circular cylinder change with the various Reynolds numbers and different kinds of turbulence intensity. Generally, Reynolds numbers could be divided to four kinds of range: subcritical, critical, supercritical and transcritical [2]. Pressure distributions and drag coefficients are different in different range of Reynolds number. The Reynolds numbers in practical engineering are usually bigger than these in wind tunnel tests and the features of flow separation strongly depend on Reynolds number, which will bring many complex problems.

Model description and apparatus

The circular cylinder used in this study is made of plexiglass (highly polished surface), whose dimeter and height is 0.3m and 0.5m respectively. 180 test points were arranged around the surface equably. This model was mounted vertically between end plates in order to create a 2-dimentional flow condition. For the influence of wind tunnel wall, the lower plate was lifted by some blocks.

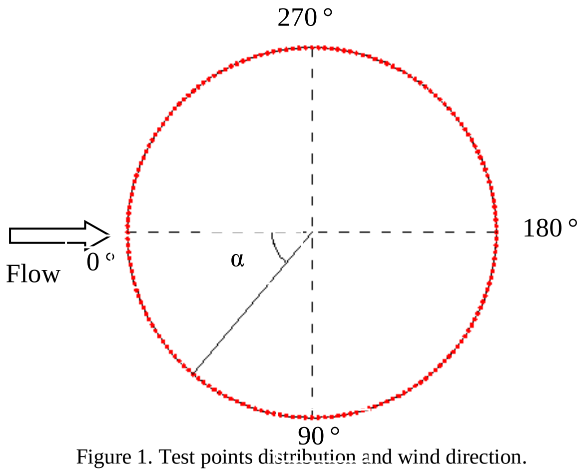


Figure 1. Test points distribution and wind direction.

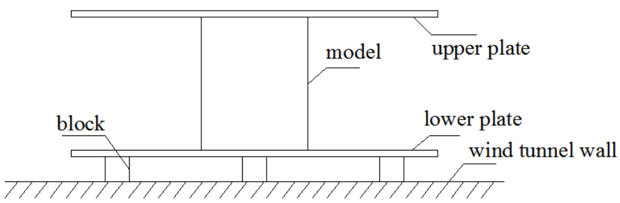


Figure 2. Diagram of test model and apparatus.

This test was conducted in ZD-1 wind tunnel, whose test section is 4m wide and 3m high. The fastest wind velocity can be 55m/s when the wind tunnel is empty. This model was tested with the wind velocity between 4m/s to 36m/s on steady flow condition, and the corresponding Reynolds numbers are 8.3e4 to 7.5e5. Also, tests on turbulent flow were conducted and the I= 4%, 8% and 12% respectively. Because of the limits of test, wind velocity in turbulent flow could not be fast as that in steady flow.

Figure 3. Wind tunnel test.

I	Range of wind velocity(m/s)	Range of Re
0%	4-36	8.3e4-7.5e5
4%	7-29	1.45e5-6e5
8%	7-19	1.45e5-3.9e5
12%	7-15	1.45e5-3.1e5

Table 1. Different cases of wind tunnel tests.

The influence of turbulence intensity

Drag coefficients and lift coefficient (C_L)are calculated as follows:

$$C_D = \frac{\pi}{N}\sum_{i=1}^{N} C_{pi}\cos\alpha_i \qquad (1)$$

$$C_L = \frac{\pi}{N}\sum_{i=1}^{N} C_{pi}\sin\alpha_i \qquad (2)$$

Where C_D is drag coefficient and C_L is lift coefficient. C_{pi} is wind pressure coefficient. α_i is the angle between test point and wind direction (going clockwise). N is the number of test points. C_D and C_L for the circular cylinder on different turbulence intensity conditions are presented in figure 4.

In steady flow (I=0%), the values of drag coefficient for subcritical Reynolds numbers are about 1.0. When it becomes to critical Reynolds numbers, the values of drag coefficient reduce to 0.4 approximately. Then it becomes to supercritical Reynolds numbers, the value increase to about 0.5, and then it is essentially unchanged. It is almost the same with the results tested by Delany N K [3] when Re<2e5 and I=0%, however, it is bigger than the result presented by NACA.

In turbulent flow, the values of drag coefficient are obviously less than these in steady flow in the range of subcritical Reynolds numbers (Re<2e5). On the other hand, they are almost the same in the range of supercritical Reynolds numbers (Re>3e5). On every condition of turbulence intensity, the values of drag coefficient are between 0.4 to 0.5. It also can be seen that turbulence intensity affect drag coefficient a little except I=0%.

The values of lift coefficient are all around 0 for subcritical Reynolds numbers, however, it fluctuates for supercritical Reynolds numbers when I=0%.

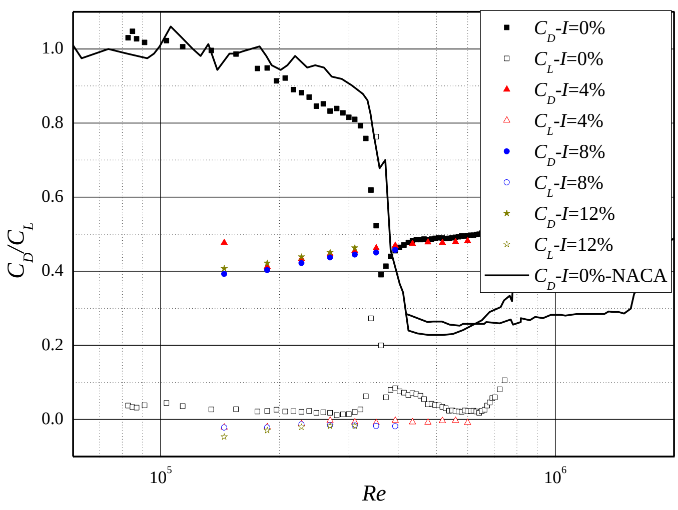


Figure 4. C_D and C_L changed with virous Reynolds numbers.

From figure 4, it can be seen that the value of lift coefficient is approach to 0.8 when Re=3.5e5 (v=17m/s) in steady flow, which is much bigger than that under other Reynolds numbers. In order to know why this phenomenon occurs, the mean wind pressure coefficient distributions measured at the midspan of the circular cylinder with different wind velocities were drawn in figure 5, and the fluctuating quantities of C_D and C_L, C'_D and C'_L were drawn in figure 6.

In figure 5, it can be seen that, when v=10m/s and v=15m/s, the mean wind pressure coefficient distributions are significantly different from others, which are typical laminar separation, and separation occurs at the point of α=60° approximately. When v=17m/s, the boundary layer becomes turbulent at the separation point, only on one side of the cylinder. This is the critical flow regime, in which separation is characterized by an unstable separation bubble, featuring a laminar separation and a turbulent reattachment. The flow asymmetry causes a non-zero value C_L. The separation bubble leads to a delay of the flow separation, causing a substantial reduction in the size of the wake and in the drag coefficient. The separation occurs at the point of α=120° approximately. When v>17m/s, separation bubbles form on both sides of the cylinder, and further reducing the value of C_D. The critical Reynolds number is defined as that value at which C_D. reaches a minimum. Increasing v, with flow becoming supercritical, the value of C_D. increases. Meanwhile, due to the separation bubbles occur both sides and the symmetry of mean wind pressure coefficients, C_L should be back to zero.

In figure 6, although C'_L is bigger than C'_D in all range of Re, C'_L changes resembled to C'_D. It also can be seen that when Re=3.5e5 (v=17m/s) in steady flow, there is a saltation especially C'_L. That means, when Re reaches a certain value, the unstable separation bubble on one side of a cylinder could cause bigger C_L and C'_L.

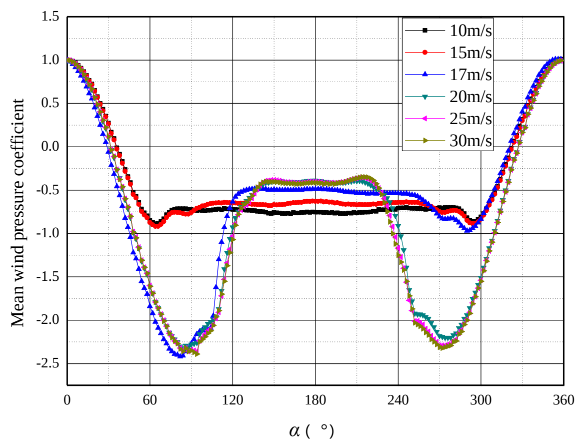


Figure 5. Mean wind pressure coefficient distributions measured at the midspan of the circular cylinder with different wind velocities.

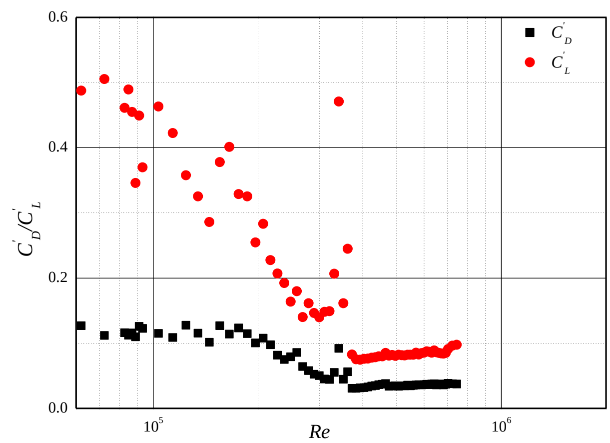
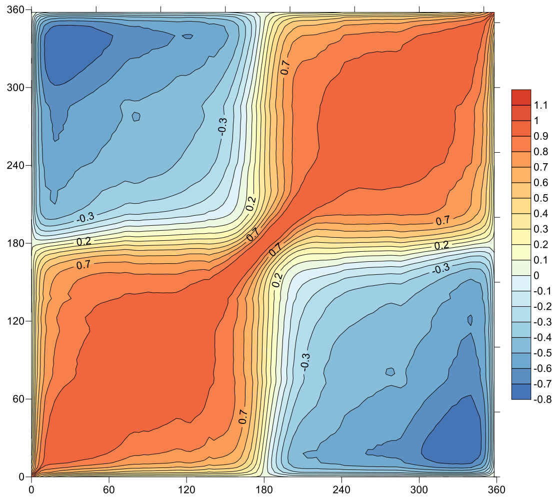


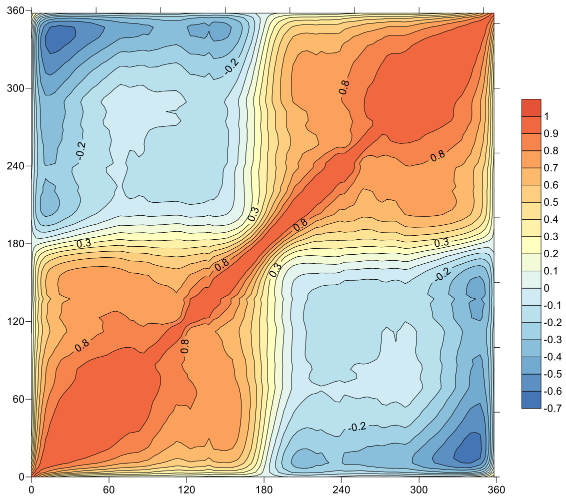
Figure 5. Fluctuating quantities of C_D and C_L when I=0%, C'_D and C'_L

Correlation analysis

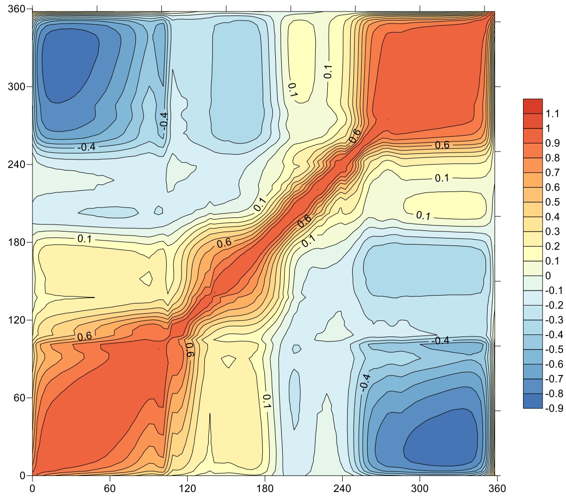
Correlation coefficients of wind pressure around the circular cylinder were showed in Figure 6. It can be seen that the values of some adjacent points are approaching to 1.0, that means wind pressure of these points is strongly correlated. On the contrary, correlation weakens with the increasing gap in angle (α). When $v \leq 17$m/s, there almost exists positive correlation on both sides. With the increasing of v, the regions of strong positive correlation (correlation coefficient >0.5) reduce and the regions of negative correlation (correlation coefficient <-0.5) increases oppositely, especially the regions of correlation coefficient <-0.7. There exists weak correlation in the range of 120° to 240° when v>17m/s. Also, the unstable separation bubble when v=17m/s can be seen in Figure 6(c), correlation coefficient is not symmetrical between the range of 120° to 180° and 180° to 240°.



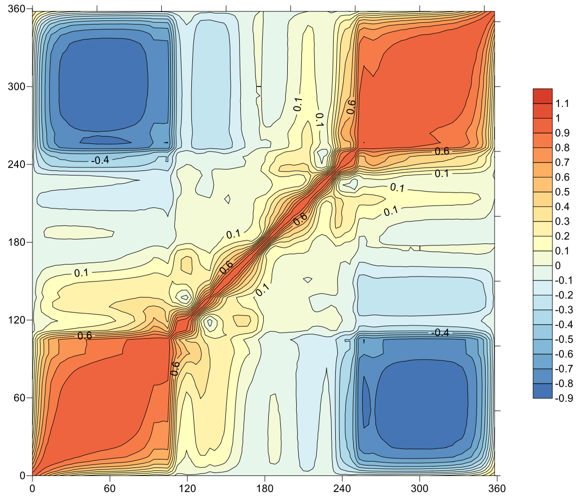
(a)v=10m/s



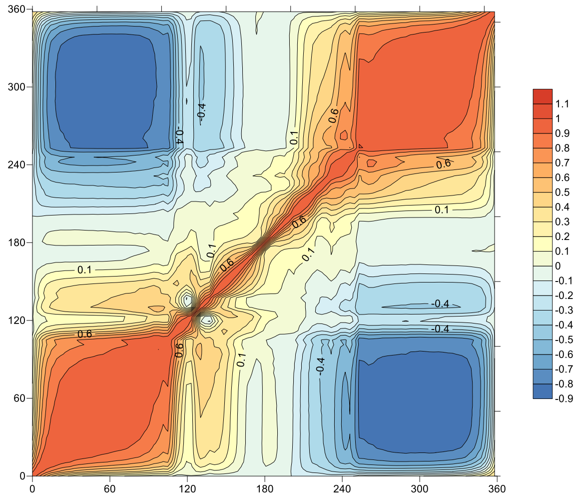
(b) v=15m/s



(c) v=17m/s

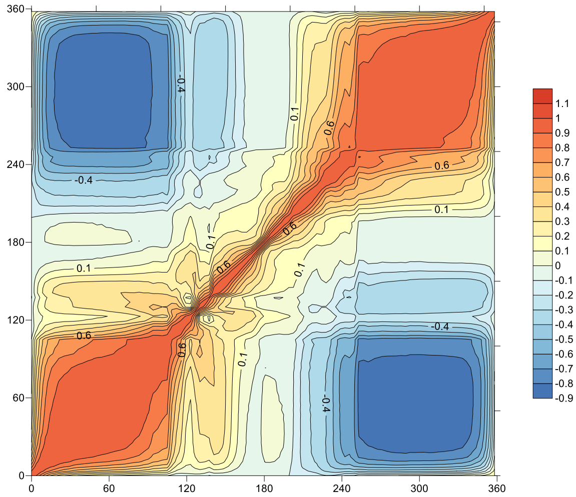


(d) v=20m/s



(e) v=25m/s

Figure 6. Correlation coefficients of wind pressure around the circular cylinder.



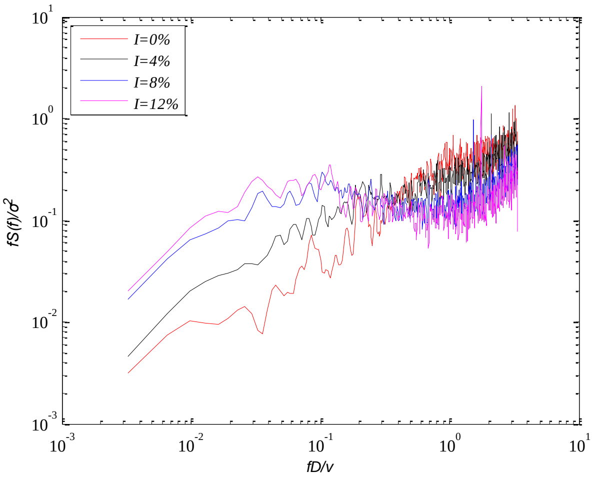
(e) v=30m/s

Figure 6 (cont.). Correlation coefficients of wind pressure around the circular cylinder.

Spectral analysis

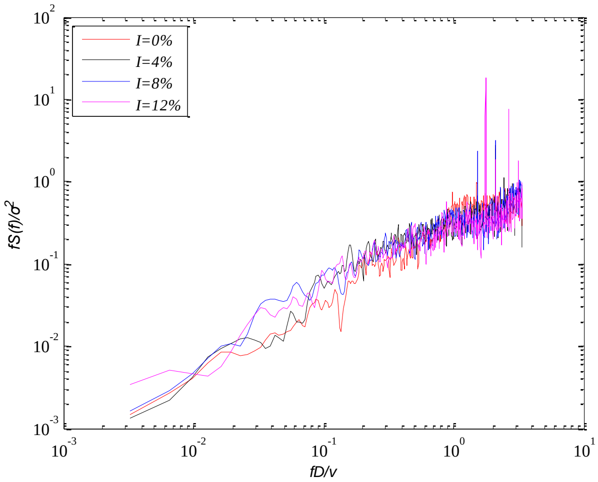
Normalized spectral densities of C_D and C_L was showed in Figure 7. It can be seen that, with the increasing of the value of *fD/v*, energy density of C_D increases when I=0% and 4%. Compared to this, when I=8% and 12%, energy density of C_D decreases in the range of *fD/v*=0.1 to 1. It also can be seen that, with the increasing of turbulence intensity, the value of energy density of C_D in low frequency increases, however, it decreases in high frequency.

For C_L, it can be seen that turbulence intensity is negligible for energy density distribution of C_L. In general, energy density of C_L increases with the increasing value of *fD/v* on the condition of various kinds of turbulence intensity conducted in tests.



(a) normalized spectral densities of C_D

Figure 7. Normalized spectral densities of C_D and in different kinds of turbulence intensity.



(b) normalized spectral densities C_L

Figure 7 (cont.). Normalized spectral densities of C_D and in different kinds of turbulence intensity.

Conclusions

This paper presents the characteristics of flowing around a circular cylinder change with the various Reynolds numbers and different kinds of turbulence intensity. The value of drag coefficient is maintained at about 1.0 in subcritical area, and then it decreases until to about 0.4 (critical Reynolds numbers, *Re* =3.6e5), then it increases to about 0.5. An unstable separation bubble appears on one side when Reynolds numbers from subcritical to critical. The value of drag coefficient decrease a lot due to the turbulent flow in subcritical area, however, lift coefficient is influenced a little. There is a strong positive relation between tests points that are on the same side on wind pressure, of which the area decreases with the increasing wind velocity. The value of energy density of C_D increases in low frequency and decreases in high frequency with the increasing of turbulence intensity. On the contrary, the influence of turbulence intensity can be ignored for spectral density distribution of lift coefficient.

References

[1] Davenport A. Past, present and future of wind engineering. J Wind Eng Indust Aerodynam 2002;90(12):1371–80.

[2] Achenbach E. Influence of surface roughness on the cross-flow around a circular cylinder [J], Journal of Fluid Mechanics, 1971, 46(2):321-335.

[3] Delany N K, Sorensen N E. Low-speed drag of cylinders of various shapes[J]. Technical Report Archive & Image Library, 1953