ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Influence of flow turbulence on circular cylinder aerodynamics

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SUMMARY:
A 2.5 m high circular cylinder with a diameter of 0.16 m was built to study the influence of turbulence on the surface pressures. Two circular 2.4 mm diameter rods were placed symmetrically on either side parallel to the stagnation line of the circular cylinder to promote transition of the boundary layer from laminar to turbulent. The circular cylinder was tested at a Reynolds number of 9 x 10^4, two turbulence intensities and two integral length scales. The trip wires forced the flow into the supercritical flow regime, and it separated at $\theta = 115°$ for all the test conditions, instead of at $\theta = 85°$ expected for a smooth cylinder at this Reynolds number. Drag force correlations dropped to zero after 4 diameters, whereas the lift correlations were still slightly positive at the highest separation of 5.5 diameters. There was less scatter in the correlations at the higher turbulence intensity of 6.5%.

Keywords: Circular cylinder, Turbulence, Correlation length

1. INTRODUCTION

The circular cylinder is a widely used structural shape in engineering, such as in cables, electric transmission lines, bridge piers, chimneys. Due to its wide application, many researchers have studied its different flow states in laminar and turbulent flows from the 1960s to the present day (Maryami et al., 2020; Vickery and Watkins, 1964). The flow characteristics around bluff bodies and methods for reducing the associated noise and vibrations are also of great interest to academia and industry (Flay and Vickery, 1995; Gabbai and Benaroya , 2005). Flow around the simple circular cylinder is very sensitive to the characteristic parameters of the incoming flow, including Reynolds number (Re), turbulence intensity, etc. Lienhard (1966) summarised the results of many experimental studies and gave a law for the variation of the wake shape of a cylinder with Reynolds number. While many experimental studies have been performed on the flow around circular cylinders, high-quality measurements are still needed to better understand the impact of free-stream turbulence characteristics on their aerodynamic performance, including the unsteady forces acting on the cylinder. These measurements were made as part of a larger investigation into wind tunnel modelling of extremely slender tower-like structures.

2. EXPERIMENTAL MODEL AND SETUP

In this study, the surface pressures on a 2.5 m high circular cylinder with a diameter (*D*) of 0.16 m were sampled simultaneously in the Boundary Layer Wind Tunnel (BLWT) at the University of Auckland. Two circular 2.4 mm diameter rods were placed symmetrically ($\beta = 50°$) on either side parallel to the front stagnation line, as shown in Fig. 1 (a), to promote the transition of the boundary layers from laminar to turbulent (Lgarashi, 1986). There were 16 equally-spaced pressure taps at each level at 22.5° intervals, as shown in Fig. 1 (b), resulting in a total of 496 pressure taps on the model surface. A Pitot-static tube mounted 0.91 m in front of the model and 1.2 m above the floor was used to measure the free-stream dynamic pressure and velocity (u_0). The 496 pressure taps and the Pitot-static tube were sampled simultaneously for two minutes at 400 Hz. The distorted pressure signals from the pressure tubes were corrected using a digital filter (Kay et al., 2020). Three different passive grids were employed to generate the onset turbulence. The circular cylinder model was tested for a range of Reynolds numbers, turbulence intensities and integral length scales, but only two sets of results are discussed herein as shown in Table 1.

The pressure, drag and lift coefficients C_p, C_d C_l were calculated using Eq. (1) – (3), respectively.

$$C_p = \frac{p}{0.5 \cdot \rho \cdot u_0^2} \tag{1}$$

$$C_d = \frac{\pi}{16} \sum_{i=1}^{16} C_{pi} \cos[22.5°(i-1)] \tag{2}$$

$$C_l = \frac{\pi}{16} \sum_{i=1}^{16} C_{pi} \sin[22.5°(i-1)] \tag{3}$$

where p is pressure difference in Pa between the surface pressure measured at each pressure tap location and the reference wind tunnel static pressure. i is the pressure tap number, and number 1 faces directly upstream.

Table 1. Test conditions

Test	u_0 $(m \cdot s^{-1})$	Re	TI (%)	Integral length xLu
1	9.07	9.24×10^4	3.03	0.294
2	9.03	9.20×10^4	6.48	0.354

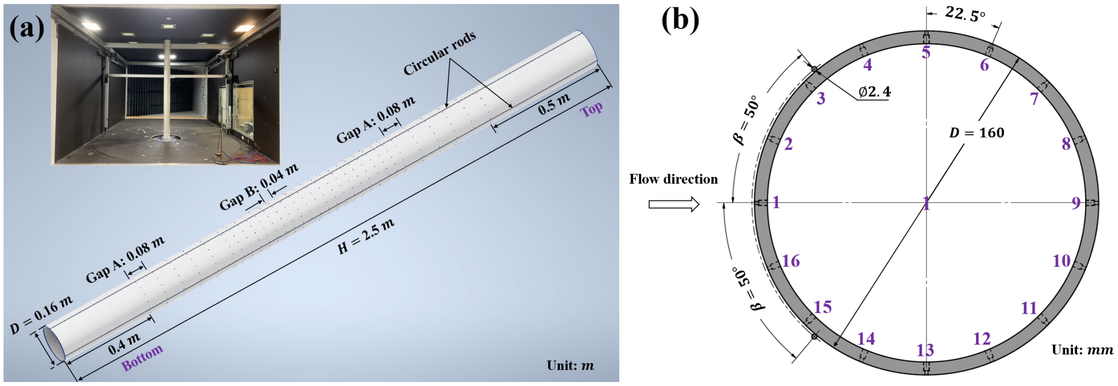

Figure 1. (a). Circular cylinder model and wind tunnel; (b). Section through circular model.

3. RESULTS AND DISCUSSION

3.1. Mean and standard deviation pressure coefficients

Fig. 2 shows the mean pressure coefficient contours of the circular cylinder from levels 1 to 18 for two sets of Reynolds numbers, turbulence intensities and integral length scales. It is evident that the flow separates at $\theta = 115°$ for both cases, indicating that the flow is in the supercritical regime (Morkovin, 1964), whereas the flow around a smooth cylinder is expected to separate at $\theta = 85°$ for this Reynolds number (Morkovin, 1964). Fig. 2 (b) shows that the pressure coefficients become slightly more negative between 50° and 115° for Case 2 with the higher turbulence intensity and Fig. 3 shows that the standard deviations also increase at the higher turbulence intensity.

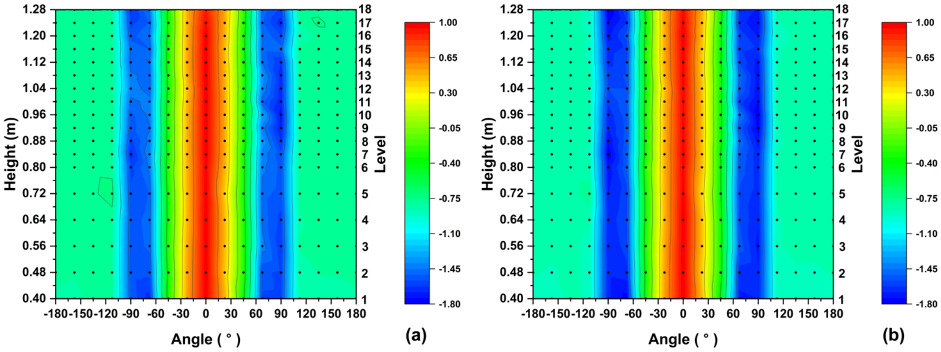

Figure 2. Mean C_p contours at $Re = 9.2 \times 10^4$, $xLu = 0.3$: (a). case 1 TI= 3.0%, (b). case 2: TI= 6.5%.

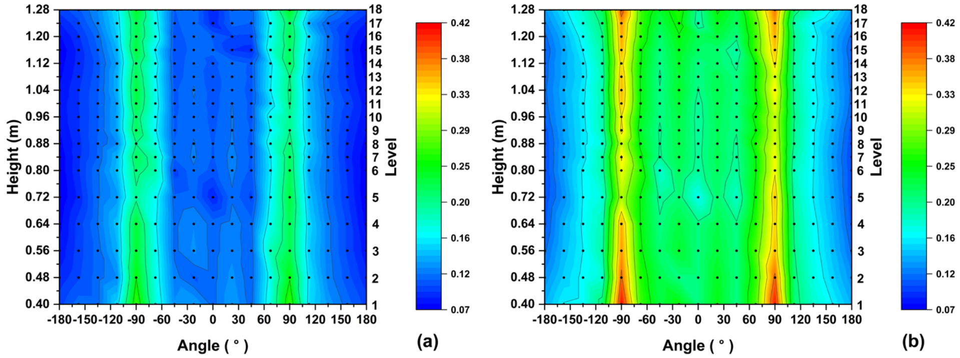

Figure 3. Standard deviation C_p contours at $Re = 9.2 \times 10^4$, $xLu = 0.3$: (a). case 1 TI= 3.0%, (b). case 2: TI= 6.5%.

3.2. Drag and lift correlation coefficients

Fig. 4 and Fig. 5 show the drag and lift coefficient correlations between levels for two flow conditions. The red dot-dash lines are curves fitted to the average values. It is found that the drag force correlations drop to zero when the separation distance exceeds four diameters. The lift force correlations drop more slowly than the drag force with increasing separation distance and there is a greater spread of results, especially for Case 1 with the lower turbulence intensity of 3%.

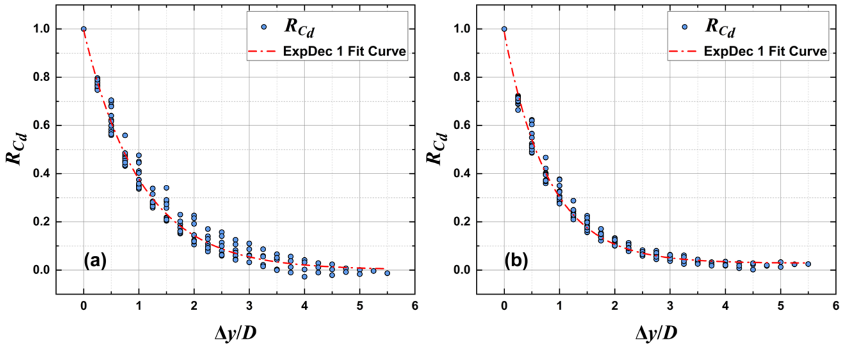

Figure 4. Drag force correlations at $Re = 9.2 \times 10^4$, $xLu = 0.3$: (a). case 1: TI= 3.0%, (b). case 2: TI= 6.5%.

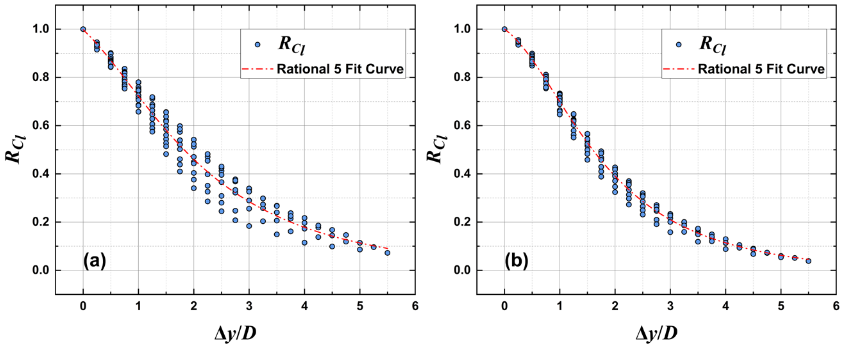

Figure 5. Lift force correlations at $Re = 9.2 \times 10^4$, $xLu = 0.3$: (a). case 1: TI= 3.0%, (b). case 2: TI= 6.5%.

4. CONCLUSIONS

The influence of turbulence intensity and integral length scale on the surface pressures of a circular cylinder have been described in this paper. The study shows that the flow separation angle is at $\theta = 115°$, and the flow is in the supercritical flow regime for all test conditions due to the effect of the tripping rods. The pressure coefficients between 50° and 115° are more negative at the higher turbulence intensity. The drag correlations drop to zero after 4 diameters, whereas the lift correlations are still slightly positive at the highest separation of 5.5 diameters in these measurements. There is less scatter in both drag and lift force correlations results at the lower turbulence intensity.

ACKNOWLEDGEMENTS

The authors would like to thank the China Scholarship Council (NO.201906370045) for providing financial support for this research.

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