IN-VENTO 2026
International Conference of the Italian Association for Wind Engineering
Bari, September 13th – 16th, 2026

Physical modelling of the Reynolds-number transcritical regime of a smooth circular cylinder

Claudio Mannini[a], Tommaso Massai[a], Niccolò Barni[a]

[a]*Department of Civil and Environmental Engineering, University of Florence, Florence, Italy, claudio.mannini@unifi.it, tommaso.massai@unifi.it, niccolo.barni@unifi.it*

SUMMARY:
The simulation in the wind tunnel of the high Reynolds number (transcritical) regime for a circular cylinder is of great interest for many civil engineering structures, but it is still a challenging task. The problem is further complicated by the free-stream turbulence investing the structures and by the need in some practical applications to adopt strategies that work independently of the wind direction. Having this in mind, a solution with staggered discontinuous ribs has previously been proposed by the authors and is refined and carefully studied in the present work with specific experiments. The results reveal that very small ribs are effective in triggering the transcritical regime at relatively low Reynolds number, in terms of mean pressure coefficient distribution, mean drag coefficient, root-mean-square of the lift coefficient, and Strouhal number.

Keywords: Circular cylinder, Reynolds number, wind tunnel, roughness, smooth flow, turbulent flow

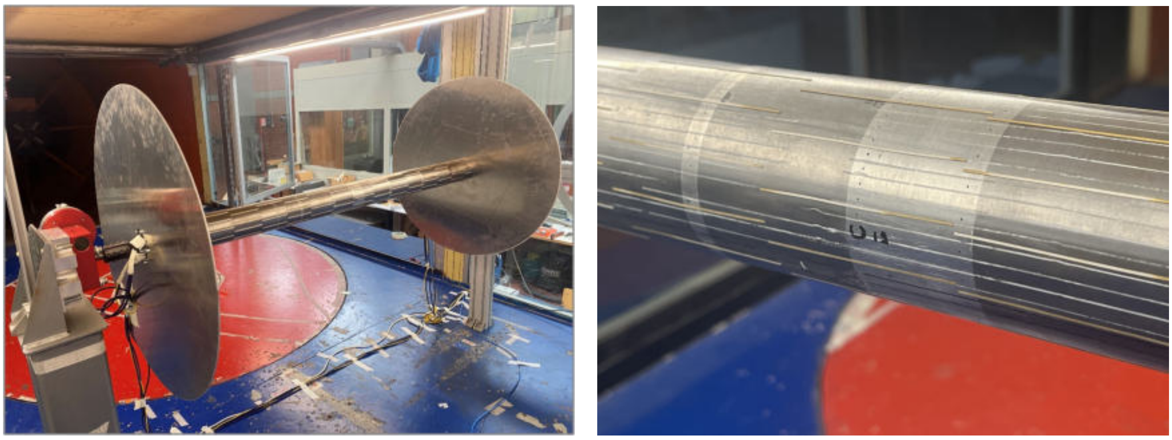
1. INTRODUCTION

Despite the long track of research, simulating the high Reynolds number behaviour of a circular cylinder in a wind tunnel, particularly in the so-called transcritical (or postcritical) regime, remains an open issue, although it is crucial for load and vibration assessment of large structures such as chimneys and wind turbine towers. This task is further complicated by the considerable uncertainty in the target statistics of force and pressure coefficients, as evidenced by the wide scatter of results reported in the literature. Wind tunnel tests have shown that diffused surface roughness can promote a transcritical regime, but with earlier separation and significantly higher drag compared to a smooth cylinder, owing to excessive momentum subtraction from the attached turbulent boundary layers (e.g., Buresti, 1981; Nakamura and Tomonari, 1982). In contrast, localized spanwise ribs or trip wires are more effective in triggering the laminar-to-turbulent transition of the boundary layers and in reproducing the behaviour of smooth cylinders at high Reynolds number (e.g., Nakamura and Tomonari, 1982). A further complicating factor is free-stream turbulence, which is always present in practical wind engineering applications and is known to strongly affect Reynolds number transitions.

The study of groups of cylinders, such as offshore wind turbine towers without rotor and nacelle during the pre-assembly phase at the port quayside, additionally highlights the need for an omnidirectional roughness response of wind tunnel models. Building on this motivation, Mannini et al. (2023) proposed a promising solution based on staggered discontinuous ribs. The present work refines this approach and explores it in depth through dedicated wind tunnel tests.

2. METHODOLOGY

The experimental tests are carried out in the CRIACIV wind tunnel, featuring a test section of 2.4 m $\times$ 1.6 m and a maximum flow speed of about 30 m/s. The cylinder model is made of stainless steel and is mounted horizontally in the wind tunnel (Fig. 1(a)). It is 1.22 m long and



(a) (b)

Figure 1. Setup for aerodynamic force measurement: overall view of the model mounted in the wind tunnel (a); close-up view of the model surface showing pressure taps and paper strips (b).

has a diameter D of 0.08 m. Circular end-plates with a diameter of 0.66 m are placed at both ends of the model to confine the flow. The blockage ratio is 5%.

The model is equipped with 190 pressure taps, distributed between seven arrays (48 taps in the midspan array), and the measurements are carried with the PSI DTC Initium system at a sampling rate of 650 Hz. The sensor accuracy is ± 1.24 Pa. 0.5 m-long Teflon tubes with an internal diameter of $0.8 \cdot 10^{-3}$ m are employed to connect the pressure taps with the miniaturized sensors. Measurement results are corrected to account for the transfer function of the tubes. Several rough cylinder configurations have been tested, changing the thickness, the width and the circumferential arrangement of the ribs. The final solution has been obtained by covering the model surface with paper strips having a thickness k of $0.17 \cdot 10^{-3}$ m ($k/D = 2.1 \cdot 10^{-3}$), a length of 0.08 m (D) and a width of $1 \cdot 10^{-3}$ m ($0.0125D$). The strips are spaced 30 deg apart and present a staggered arrangement, as shown in Fig. 1(b).

Tests are performed in both smooth and turbulent flows. In the first case, the turbulence intensity is below 1%. In contrast, homogeneous isotropic turbulence is generated through a grid made of 0.14 m-wide slats assembled according to a 0.55 m square mesh. For turbulent flow 1 (TF#1 in short) the grid is placed 5.65 m upstream of the model, producing a longitudinal turbulence intensity I_u in the range 11.5% to 13.2% and a longitudinal integral length scale L_u^x between 0.175 m and 0.24 m, depending on the mean wind speed. Instead, the grid is located 7.56 m upstream of the model for turbulent flow 2 (TF#2 in short), and I_u is between 8.3% and 11%, while $0.22 \text{ m} \leq L_u^x \leq 0.28$ m. The grid also reduces the maximum wind tunnel mean flow speed.

3. RESULTS

Without ribs, the cylinder is always in the subcritical regime in the wind tunnel range of wind speed in smooth flow, while the drag crisis is reached in turbulent flow. In contrast, a summary of the experimental results for the rough cylinder is shown in Fig. 2. The Reynolds number is defined as $\text{Re} = UD/\nu$, where U is the mean wind speed and ν the air kinematic viscosity. Fig. 2(a) shows the mean pressure coefficient distribution C_p for the midspan section for the highest nominal Reynolds number attained ($\text{Re} = 1.56 \cdot 10^5$ in smooth flow, and

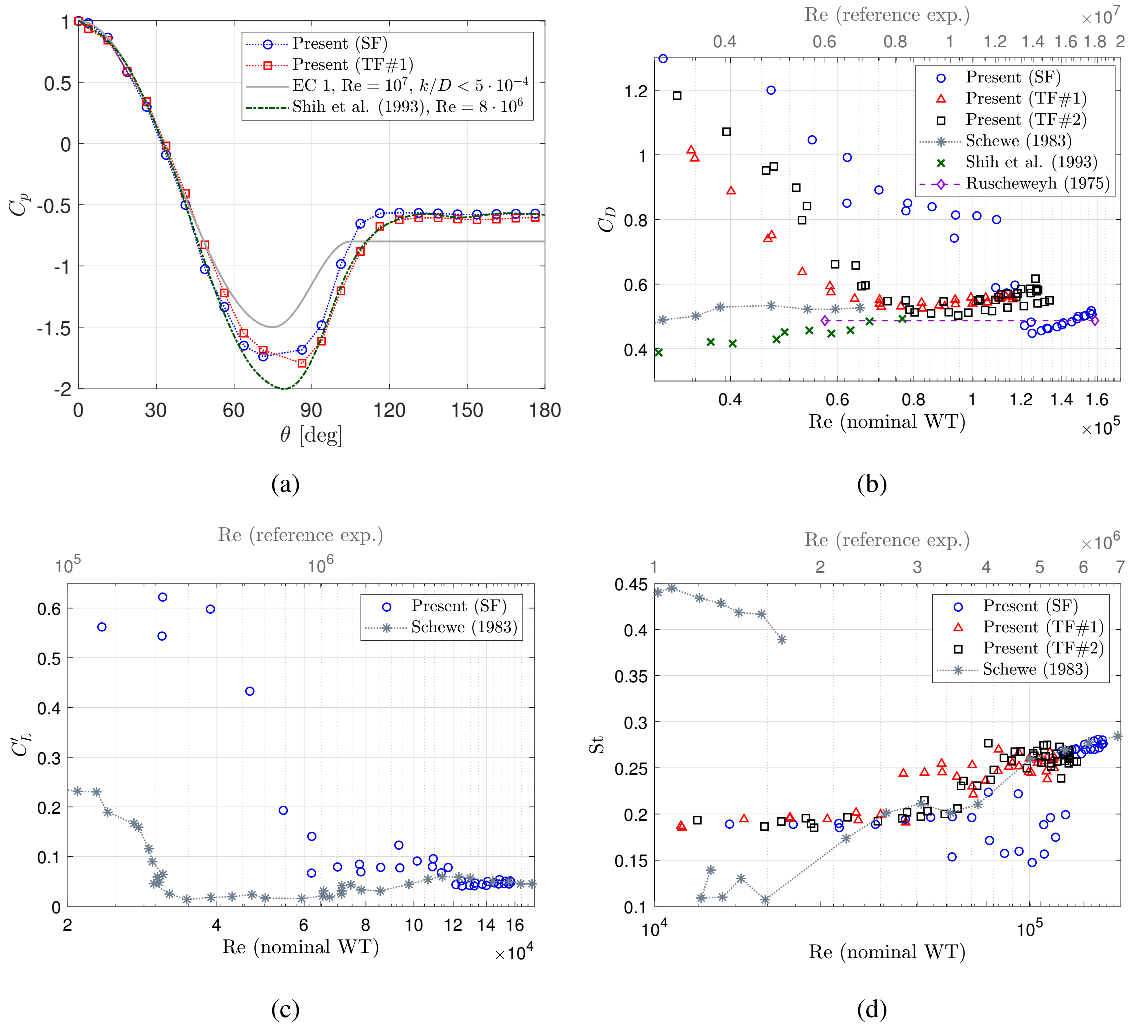


Figure 2. Mean pressure coefficient distribution at the maximum wind-tunnel flow velocity (a); mean drag coefficient (b), standard deviation of the lift coefficient (c), and Strouhal number (d) as a function of the Reynolds number. *SF* stands for "smooth flow", while EC 1 indicates the Eurocode 1.

Re $= 1.16 \cdot 10^5$ for TF#1). Results in smooth and turbulent flow are in good agreement except for a small discrepancy in pressure recovery trend after reaching the minimum pressure. Moreover, they follow the C_p measured at high Reynolds number by Shih et al. (1993), except for a slight overestimation of pressure around the minimum. These patterns are different from that provided by Eurocode 1 for a Reynolds number Re $= 10^7$, which is indeed associated with a significantly higher mean drag coefficient. The experiments reveal that the data provided by Eurocode 1 mimic in fact the behaviour of a rough cylinder at high Reynolds number (see for details Mannini et al. 2023). Fig. 2(b) shows the cylinder mean drag coefficient obtained by pressure integration as a function of the nominal Reynolds number. A nearly constant value slightly higher than 0.5 is measured in smooth flow for the highest wind speeds achievable in the wind tunnel, which is in line with the high Reynolds number measurements by Ruscheweyh (1975), Shih et al. (1993) and Schewe (1983). In turbulent flow, the saturation of the mean drag coefficient pattern is reached at a lower mean wind speed, and the results are still in line with the reference high Reynolds number experiments, though slightly higher and more dispersed than in smooth flow. The standard deviation of the lift coefficient in smooth flow changes from about 0.55 in the subcritical regime (not reported in the figure) to about 0.05 in the transcritical regime simulated with the ribs (Fig. 2(c)), a result that complies very well with those reported in Schewe (1983). Turbulent flow data are not reported in this case because the external forcing of turbulence makes the results not comparable. The Strouhal number is equal to about 0.19 in the subcritical regime and increases up to 0.27-0.28 in the transcritical regime (Fig. 2(d)), in perfect agreement with the measurements by Schewe (1983) in a high-pressure wind tunnel. Though clearly more scattered, these results are also confirmed in the two turbulent flows tested. The difference between subcritical and transcritical regime is studied in terms of spanwise correlation too. Results are not reported here in the interest of brevity.

Finally, it is important to notice that the data presented do not substantially change when the model is rotated by an angle comprised between 0 and 30 deg, thus modifying the relative position of the ribs with respect to the stagnation line. This confirms the required independence of the wind direction of the proposed surface roughness solution.

4. CONCLUSIONS AND PROSPECTS

Staggered discontinuous small ribs represent a promising strategy for simulating the transcritical flow regime past a smooth circular cylinder under both smooth and turbulent wind, independently of the flow direction. The study reveals the key role played above all by the rib thickness, considering that it is fairly easy to reproduce the behaviour of a rough cylinder at high Reynolds number. Indeed, the thickness of the ribs must be the minimum necessary to reach a plateau in the pattern of the force coefficients with the Reynolds number, and the separation position must comply with that of a smooth cylinder in the transcritical regime.

The campaign is still in progress, and the results of wake masurements via hot-wire anemometry and particle image velocimetry (PIV) techniques will be available at the conference.

REFERENCES

Buresti, G. (1981). The effect of surface roughness on the flow regime around circular cylinders. Journal of Wind Engineering and Industrial Aerodynamics 8, 105–114.

Mannini, C., T. Massai, A. Giachetti, and A. Giusti (2023). Aerodynamic loads on groups of offshore wind turbine towers stored on quaysides during the pre-assembly phase. Journal of Wind Engineering and Industrial Aerodynamics 242, 105569.

Nakamura, Y. and Y. Tomonari (1982). The effects of surface roughness on the flow past circular cylinders at high Reynolds numbers. Journal of Fluid Mechanics 123, 363–378.

Ruscheweyh, H. (1975). Wind loadings on the television tower, Hamburg, Germany. Journal of Wind Engineering and Industrial Aerodynamics 1, 315–333.

Schewe, G. (1983). On the force fluctuations acting on a circular cylinder in crossflow from subcritical up to transcritical Reynolds numbers. Journal of Fluid Mechanics 133, 265–285.

Shih, W. C. L., C. Wang, D. Coles, and A. Roshko (1993). Experiments on flow past rough circular cylinders at large Reynolds numbers. Journal of Wind Engineering and Industrial Aerodynamics 49, 351–368.