EFFECTS OF SURFACE ROUGHNESS ON A CIRCULAR CYLINDER IN SUPERCRITICAL TURBULENT FLOW

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ABSTRACT

The effects of surface roughness on pressures and dynamic forces on a circular cylinder were investigated for the Reynolds number range of $6x10^4$ to $1x10^6$ in grid generated turbulent flows. The relative roughness k/d varies from $2.1x10^{-5}$ to $2.3x10^{-3}$ and the turbulence intensity in the flow ranges from 0.4% to 9.1%. Measurements were made with circular cylinders 51mm to 250mm in diameter in wind tunnel working sections 1.5mx1m and 2mx1m and all data presented in this paper were corrected to zero blockage.

INTRODUCTION

While the increase of wind tunnel blockage or turbulence intensity level was shown to have an effect of increasing the Reynolds number in the flow, the surface of the cylinders can also be roughened to develop separated regions and pressure distributions corresponding to a higher equivalent Reynolds number on a smooth cylinder.

Szechenyi (1975) indicated that the high Reynolds number transcritical behaviour can be simulated at Reynolds number well below 10^6 by the proper use of surface roughness to provoke premature boundary layer transition. However, this simulation seems not really exact. Many recent measurements such as Palmer (1994) and Zhang (1993) showed that influence due to surface roughness still exists at very large Reynolds numbers. Achenbach and Heinecke (1981) showed that at transcritical Reynolds number the drag coefficient increases from 0.7 for smooth cylinders to 1.2 for rough cylinders, although the Strouhal number then varies only by 7% from the mean value for all roughnesses. Guven et al (1980) found similar results that the drag and the pressure distribution are affected by surface roughness even in the transcritical regime where Reynolds number independence is achieved. Buresti (1981) also obtained similar results which confirmed that the flow regime cannot be characterised merely by the value of the Reynolds number based on the size of the roughness. Although these measurements exhibited the effect of surface roughness up to the transcritical flow regime, these experimental data were not corrected for wind tunnel blockage effects. This paper presents blockage corrected data on the effect of surface roughness based on investigations on circular cylinders of different sizes in flows of various turbulent intensities for Reynolds number up to $1x10^6$. The objective of this paper is to clarify other concurring effects and to identify the effect mainly due to surface roughness only.

EXPERIMENTAL ARRANGEMENTS

The experimental arrangements for pressure and dynamic force measurements were detailed in previous papers of this Conference series by Cheung and Melbourne in 1980 and 1983 respectively. For the smooth cylinders, the roughness height was taken as three times the centre-line-average (CLA) value measured by a "Talysurf" surface finish instrument. Rough cylinders were obtained by wrapping the cylinders with commercial sandpapers. Double-sided adhesive tape was used

TABLE 1

	Pressure Measurements				Force Measurements			
Cylinder diameter (mm)	φ169		φ250.5		φ120.5		φ225.5	
Grain size	P320	P60	P320	P40	P600	P80	P320	P50
Average particle size k(μm)	44	406	44	608	23	266	44	465
k/d x 10^3	0.26	2.40	0.18	2.43	0.19	2.21	0.20	2.06

to stick the sandpapers onto the surface of the cylinder, with the seam located at the rear of the cylinder. The thickness of the various papers, together with the adhesive tape, was taken into account in evaluating the Reynolds number based on the overall diameter. The sandpaper manufacturer's (Norton Pty Ltd) estimation of the average particle size was used to be the roughness height and the relative roughness are estimated as shown in Table 1.

Thus, essentially three levels of relative roughness with different blockages were used, namely,

smooth cylinder	k/d = 2.1 x 10^{-5}
medium rough cylinder	k/d = 2.1 x 10^{-4}
rough cylinder	k/d = 2.3 x 10^{-3}

PRESSURE MEASUREMENTS

The mean and fluctuating pressure distributions on cylinders of different surface roughness in smooth and turbulent flow are plotted in Figures 1 and 2. The fluctuating pressures for the rough cylinders at different Reynolds numbers are very close to the fluctuating pressures on a smooth cylinder at supercritical Reynolds number. Therefore, the use of roughness on a cylinder surface at subcritical Reynolds number can in effect produce the fluctuating pressures similar to those which occur at supercritical Reynolds number in smooth flow. However, the mean pressure distribution on a rough cylinder depends on Reynolds number. Also, although the base mean pressure on a rough cylinder at subcritical Reynolds number has a similar value as for a smooth cylinder at supercritical Reynolds number, the minimum pressures for these cases are much different. In turbulent flow, the minimum mean pressure increases and the base mean pressure decreases with increase in surface roughness. Also, the position of the maximum fluctuating pressure shifts toward the stagnation of the cylinder as the roughness on the cylinder surface increases. In turbulent flow, the pressure distributions for the rough cylinders do not vary with Reynolds number and thus the base pressures and drag coefficients are independent of Reynolds number in turbulent flow. Although the fluctuating pressure of a smooth cylinder at supercritical Reynolds number can be produced by a rough cylinder at subcritical Reynolds number, other parameters cannot be simulated particularly in turbulent flow. Therefore, supercritical Reynolds number characteristics of a cylinder cannot be simulated by simply roughening the surface finish of the cylinder in a flow at lower Reynolds number.

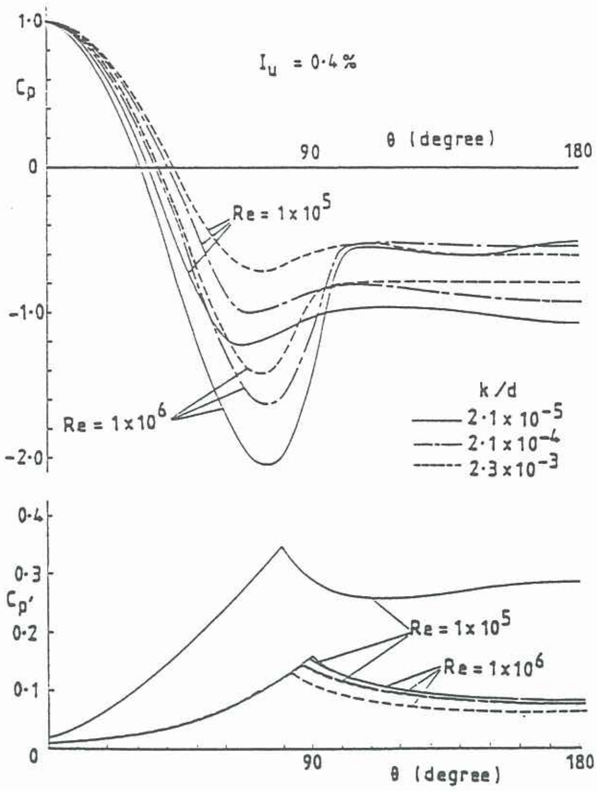

Figure.1: MEAN AND FLUCTUATING PRESSURE DISTRIBUTION ON CYLINDERS OF DIFFERENT SURFACE ROUGHNESS FOR FLOWS OF TURBULENCE INTENSITY OF 0.4%.

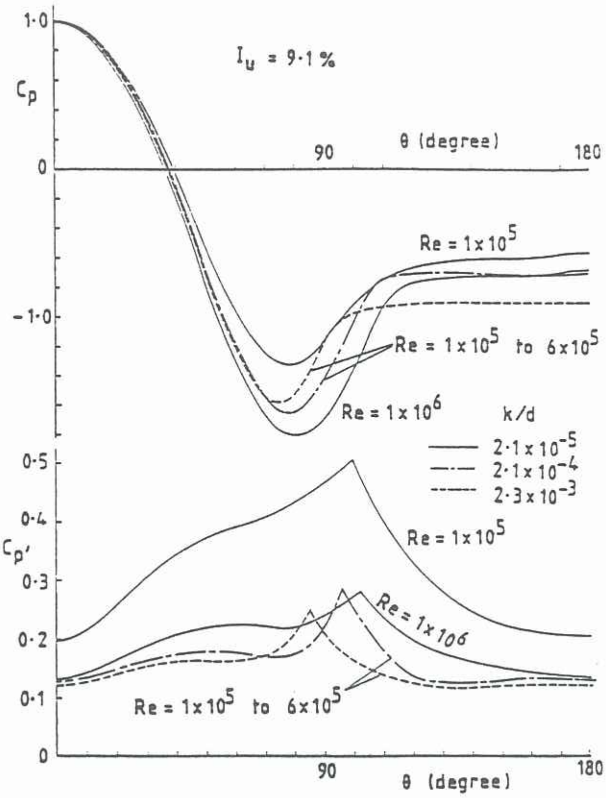

Figure 2: MEAN AND FLUCTUATING PRESSURE DISTRIBUTION ON CYLINDERS OF DIFFERENT SURFACE ROUGHNESS FOR FLOWS OF TURBULENCE INTENSITY OF 9.1%

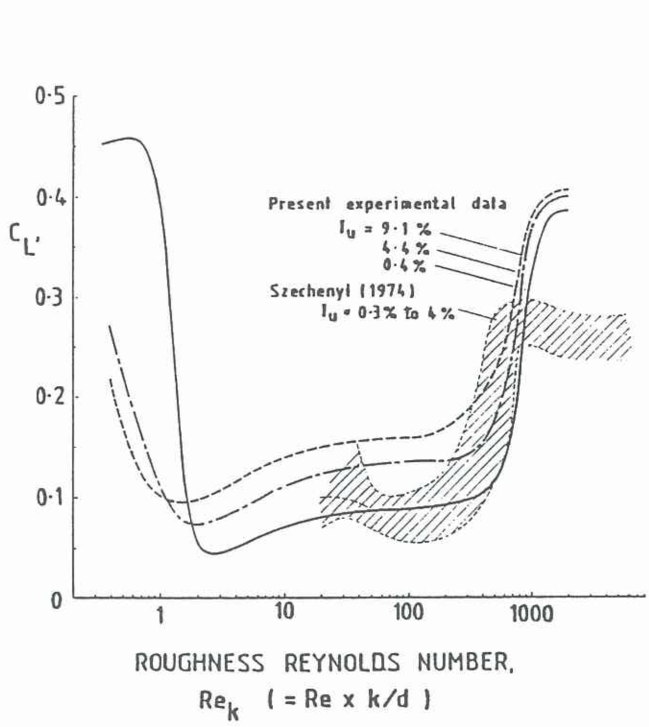

Figure 3: FLUCTUATING LIFT COEFFICIENT AS A FUNCTION OF ROUGHNESS REYNOLDS NUMBER FOR DIFFERENT TURBULENCE INTENSITIES

DYNAMIC FORCE MEASUREMENTS

Dynamic force measurements with the rough cylinders have the same trend as for the smooth cylinders, except that the transition in the critical regime appears to occur earlier at a lower Reynolds number. The swinging of wake is apparent in the presence of turbulence for rough cylinders. The Strouhal number decreases from about 0.35 in the subcritical flow regime (Re = $1x\ 10^5$) to a constant value of about 0.22 for Reynolds number above 3 x 10^5. Also, the Strouhal number increases slightly with turbulence but the effect of turbulence is not prominent. For constant turbulence intensity, the increase in fluctuating lift is observed with increase in roughness. This increase in fluctuating lift becomes more significant at high Reynolds number for the very rough cylinder. By composing the data in terms of the roughness Reynolds number, $Re_k = \frac{\rho u k}{\mu} = Re \bullet \frac{k}{d}$ as shown in Figure 3, it can be seen that there is a drop in fluctuating lift at low roughness Reynolds number followed by a slight increase and then a significant increase again at the high roughness Reynolds number.

The effect of turbulence on rough cylinders have the same trend as those on smooth cylinders. However, the effect of turbulence on very rough cylinders at high Reynolds number is not as pronounced. Thus, the increase in fluctuating lift at roughness Reynolds number of about 500, consistent with Szechenyi (1975) measurement, is mainly caused by the effect of roughness. When the surface of a cylinder has attained to that degree of roughness, the effect of turbulence as well as the effect of Reynolds number are less prominent. Data obtained for high roughness Reynolds number were measured from rough cylinders only. Hence, whether there is such an equivalent increase in fluctuating lift for a smooth cylinder in the transcritical flow regime at that high roughness Reynolds number is still not known. The increase in fluctuating lift may be caused by localised effects of each roughness element on the surface of the cylinder. The effect of surface roughness on fluctuating drag is very similar to that on fluctuating lift. As shown in Figure 4, the fluctuating drag coefficients are generally lower than the fluctuating lift coefficients.

The effect of surface roughness on the aerodynamic damping is similar to the effect of increasing turbulence intensity in the subcritical regime as reported by Cheung and Melbourne (1983). As the Reynolds number is increased to the supercritical regime, the effect of surface roughness on aerodynamic damping becomes small.

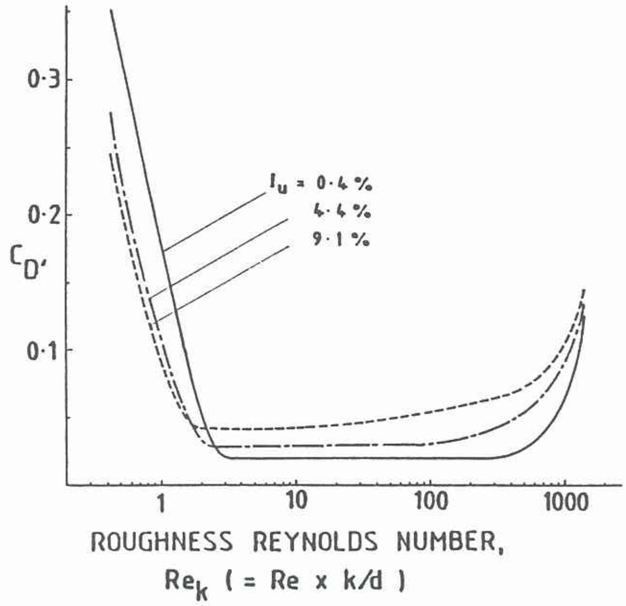

Figure 4: FLUCTUATING DRAG COEFFICIENT AS A FUNCTION OF ROUGHNESS REYNOLDS NUMBER FOR DIFFERENT TURBULENCE INTENSITIES

CONCLUSIONS

Wind tunnel data from pressure and dynamic force measurements on circular cylinders with various uniform surface roughness have been presented. These results provide a data base for further research on rough cylinders for Reynolds number beyond $1x10^6$ and for the effects of roughness size and distribution. Further measurements including correlations on a large rough circular cylinder will be continuing.

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