AMPLITUDE EFFECTS ON AERODYNAMIC RESPONSE OF A CIRCULAR CYLINDER IN TURBULENT FLOW

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1. Introduction

The prediction of critical cross-wind response of circular cylinders driven by vortex excitation in turbulent flow has been a goal for many researchers. The prediction of cylinder response to wind action is complicated by the many aerodynamic variables involved in addition to the dynamic variables of mass, damping and stiffness. The most relevant of these aerodynamically related variables are as follows:

Reynolds number
Surface roughness
Turbulence intensity
Turbulence scale
Aspect ratio and taper
Displacement and rate of displacement dependence

The relationship of the first five of these to the development of fluctuating lift forces has become progressively better understood in recent times (e.g. Szechenyi (1975), Cheung (1983), Vickery (1984), Melbourne (1997), Eaddy (unpublished)). However the effect of the cylinder motion on the development of these fluctuating lift forces is not well understood and much of that known is restricted to knowledge of the lock-in phenomenon at sub-critical Reynolds numbers in smooth flow. With the advent of modern pressure measuring techniques it is now possible to explore these motion dependence effects without having to rely on the measurement of forces on dynamic models which have been severely limited in Reynolds number range by the difficulty in building models light enough and stiff enough to reach critical wind speeds at sufficiently high oscillation frequencies. This study is aimed at overcoming these difficulties and extending our knowledge of the development of fluctuating lift on oscillating circular cylinders in turbulent wind flow.

2. Review

In a paper by Melbourne (1997) [1], an overview was given of some current knowledge into the relationship between the mass-damping parameter, K_s, and critical response (Table 1). The mass-damping parameter can be defined by either the Scruton number, $S_c = \frac{2\,m\delta}{\rho d^2}$, as developed by Scruton [2] in the 1950s, or by a parameter used by Vickery [3] in relation to chimneys $K_s = \frac{m\zeta}{\rho d^2}$ (the two parameters are related by the equation $S_c = 4\,\Pi K_s$), where m is the mass per unit length, ρ the fluid density, d the cross-wind width, δ the logarithmic decrement of damping and ζ the fraction of critical damping.

Author	Type of cylinder	Flow Regime	K_s
Scruton [2]	Circular cantilevered	Smooth flow, low turbulence	>1.5
Vickery [3]	Circular chimney	Turbulent transcritical	>2
ESDU			>2.5
Melbourne [1]	model and full scale masts with roughness or longitudinal attachments	Various	>4
Scruton [2]	Rectangular cantilevered	Smooth flow, low turbulence	>6

Table 1. Suggested values of the mass-damping parameter above which there was little likelihood of critical cross-wind response.

With the results outlined in Table 1, coupled with the work done by Szechenyi [4] and Cheung [5], , showing a relationship between the cross-wind fluctuating lift coefficient and surface roughness and turbulence intensity (for Re 3 X 10^5 to 2 X 10^6) (Eaddy [6] has also shown this in more recent unpublished work), Melbourne concluded that the mass-damping parameter does not completely determine or predict the onset of critical response of a cylinder and that an analytical model would need to cover not only the Reynolds number, turbulence and roughness effects as developed by Vickery and Basu [3] but also "amplitude dependent aerodynamic damping and amplitude dependence on end fixity and mode shape".

It is this amplitude dependence that leads to the topic of research in furthering the knowledge of amplitude dependence of the cross-wind fluctuating lift on a oscillating cylinder. Work by Novak and Tanaka (1975) [7] demonstrated the relationship between amplitude of oscillation of a cylinder in flow and cross-wind fluctuating lift (Fig. 1.); this research was conducted for subcritical Reynolds numbers only and the oscillation of the cylinder tested was driven at prescribed frequencies and amplitudes.

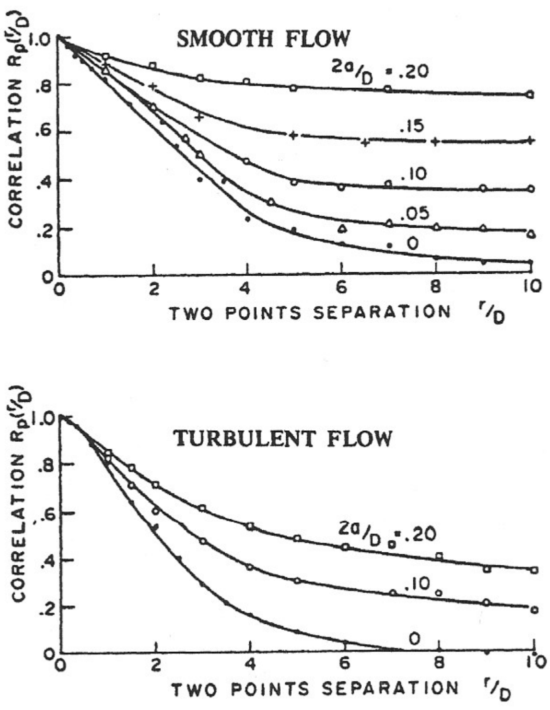

Fig. 1. Variations of Spanwise Pressure Correlation with Turbulence and Amplitude of Vibration (2a = double amplitude, *r* distance between pressure taps, *D* diameter of cylinder, *R* correlation coefficient) (after Ref. [7]).

3. Proposed Experiment

The aim of this work is to gain an understanding of how amplitude of oscillation affects the forces on an oscillating cylinder at different oscillation amplitudes, Reynolds numbers, various turbulence intensities and length scales and surface roughness.

The cylinder is a lightweight, stiff circular cylinder of approximately 1.8m in length and having a diameter of 0.25m (in order to have an aspect ratio > 7 so that, as Fox and West (1990) and later Szepessy and Bearman (1992) determined, the centre of the cylinder will be very close to two-dimensional flow with minimal influence from the walls). The cylinder will be horizontally mounted on a driven yoke supported by springs that can be adjusted to change the natural frequency of the system. The cylinder will be mounted between boundary layer bleed end plates on the walls of the wind tunnel. A diagramatic arrangement of the support structure is shown here is Fig. 2. The cylinder will have approximately 86 pressure taps around it, their locations shown in Fig. 3., based on the work by Eaddy (unpublished). These pressure taps will be connected via PVC tubing running on the inside of the cylinder to two Scanivalve pressure transducer systems, one at either end of the cylinder (Fig. 3.). Corrections for tube response will be made during the data processing stage using the Inverse Transfer Function Technique (ITF) as described by Irwin *et al* (1979) and used by Eaddy (unpublished) for his work on stationary cylinders. Testing of the cylinder will be carried out in the 2 X 2m working section of the 450kW wind tunnel at Monash University.

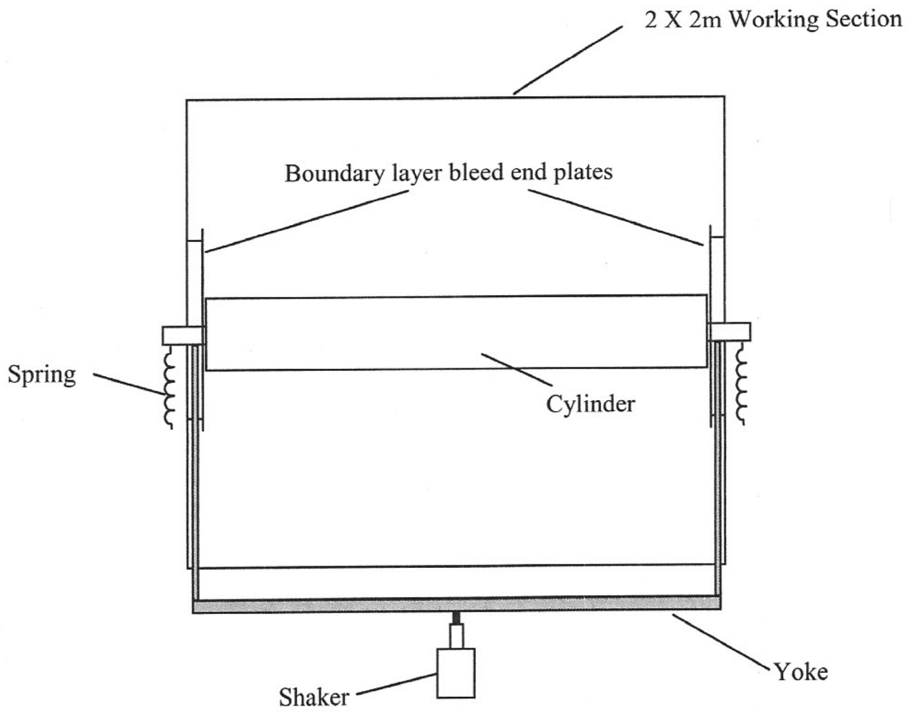

Fig.2. Diagramatic arrangement of cylinder support structure.

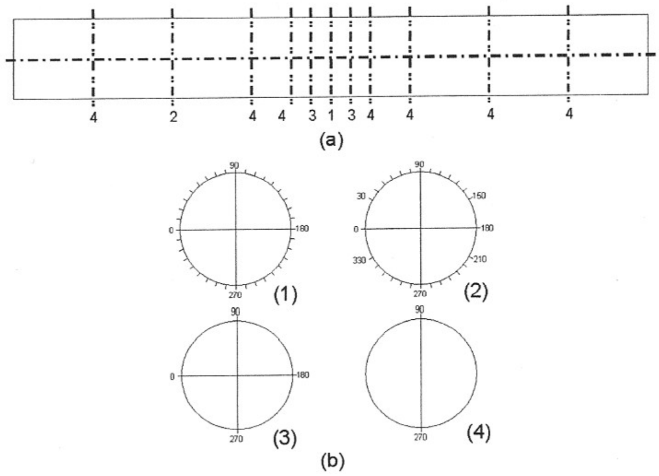

Fig.3. Preliminary design of pressure tap location on cylinder (a) axial, and (b) circumferential.

Instantaneous pressures from the pressure taps around the cylinder and the reference Pitot-static tube will be obtained using two Scanivalve ZOC-16 electronic pressure scanning systems at either end of the cylinder. Data will be recorded and stored on hard disk and processed later using Matlab^{TM}. The processing will include the correction of the data for the amplitude and phase response of the PVC tubing by applying the ITF technique to each channel's time history. The corrected data will then be used to calculate the sectional fluctuating lift coefficient by integrating the pressure distribution of a ring of taps on the cylinder.

References

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