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A TECHNIQUE FOR THE MEASUREMENT OF THE CROSS WIND JOINT ACCEPTANCE FUNCTION

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ABSTRACT

This paper describes a technique that enables the cross-wind joint acceptance function of two-dimensional rectangular cylinders to be directly measured. Results are presented for a 10:1 rectangular section cylinder for various span lengths of the section and the incident turbulent scale. These results show that the joint acceptance of the rectangular cylinder section decreases with either an increase in the width of the section or a decrease in the turbulence scale.

INTRODUCTION

The spectral approach developed by Davenport (1961, 1962a, 1962b), on the basis of earlier studies (Sears 1941, Liepmann 1952, 1955), remains the most widely used and accepted method for describing the process of incident turbulence excitation or cross-wind buffetting. This approach is shown diagrammatically in Figure 1 and mathematically in Equation 1. It should ne noted that Equation 1 represents a two-fold simplification of the complete equation. Firstly, only one mode of structural response has been assumed. Secondly, the contribution associated with the longitudinal velocity spectrum has been assumed to be negligible (which is a perfectly valid assumption for the symmetrical section described in this paper and, indeed, for majority of all structures).

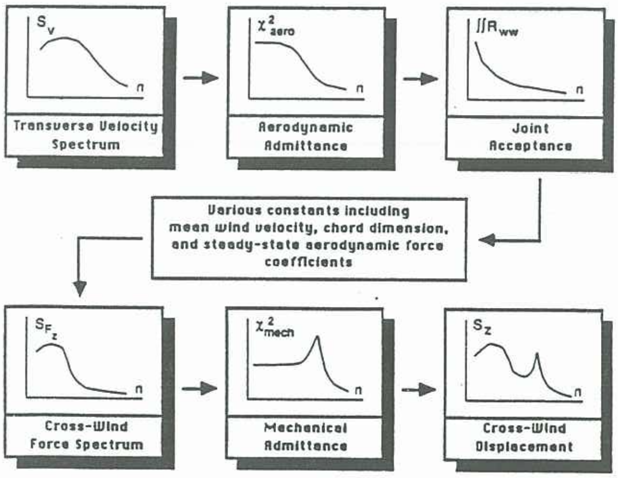

Figure 1. Davenport's Spectral Approach

$$S_{F_z}(n) = \frac{1}{4}\rho^2\,\overline{u}^2\,c^2\left(\frac{dC_{F_z}}{d\alpha}\right)^2 S_w(n)\;\chi^2_{aero}(n)$$
$$\int_{-\frac{b}{2}}^{\frac{b}{2}}\int_{-\frac{b}{2}}^{\frac{b}{2}} R_{ww}(n, y_1, y_2)\,Z_1(y_1)\,Z_1(y_2)\,dy_1\,dy_2 \quad (1)$$

where

$\overline{u}$ = mean longitudinal air velocity
ρ = air density
c = chord dimension of structure
b = span dimension of structure
$\frac{dC_{F_z}}{d\alpha}$ = slope of transverse force characteristic at 0° angle of attack
n = frequency
$S_{F_z}(n)$ = transverse aerodynamic force spectrum
$S_w(n)$ = spectrum of transverse velocity fluctuations
$\chi^2_{aero}(n)$ = aerodynamic admittance
$R_{ww}(n, y_1, y_2)$ = cross-correlation spectrum of transverse velocity fluctuations at two points y_1 and y_2 on spanwise model axis
$Z_1(y)$ = mode shape for the first mode of response (normalised to unity at the centre span of the structure)

The input to the process is the transverse component of turbulence, as quantified by the transverse velocity spectrum. The output from the process is the cross-wind displacement of the structure, as quantified by the cross-wind displacement spectrum. Relating these spectra are various parameters (mean velocity, chord dimension of the structure, etc.) and three transfer functions, namely the aerodynamic admittance, the joint acceptance, and the mechanical admittance.

The mechanical admittance is a familiar transfer function from vibration theory which takes account of the resonant characteristics of the structure and presents us with no difficulty. However, the other two transfer functions (aerodynamic admittance and joint acceptance) which define the ability of a particular turbulent flow to generate aerodynamic force have proven to be much more complex and difficult to unravel. The aerodynamic admittance function takes account of the frequency (or wave length) of the transverse velocity fluctuations in relation to the chord dimension of the structure, while the joint acceptance function takes account of the fact that the turbulent fluctuations are not perfectly correlated across the span of the structure.

The current project is part of an ongoing study whose ultimate objective is to develop an empirical model of the complete incident turbulence excitation mechanism for bluff bodies in turbulent flows. In order to accomplish this, it is necessary to isolate and measure each of the two transfer functions (aerodynamic admittance and joint acceptance) independently. Earlier experiments of Jancauskas (1983) and Jancauskas and Melbourne, 1985 and 1986, using a novel experimental technique to directly measure the aerodynamic admittance of bluff cylinders, established a clear trend for the behaviour of the aerodynamic admittance function. In these experiments, a gust generator was used to generate discrete-frequency transverse velocity fluctuations which in turn excited two-dimensional models mounted in a wind tunnel. As the gusts were fully correlated across the span of the model, the joint acceptance function was unity, effectively removing it from the process, and leaving the aerodynamic admittance as the only unknown.

In the first stage of the present project, the authors used a different approach for isolating and measuring the aerodynamic admittance function (Sankaran & Jancauskas, 1991). Using a pneumatic averaging technique, pressure measurements were made on a very narrow chordwise slice of several rectangular section models of different thickness-to-chord ratios. Because of the small spanwise dimension of the slice (typically, about 1.0 mm which is the diameter of the pressure taps), the grid turbulence was, in effect, fully correlated over the span of the slice. The joint acceptance of the slice was therefore equal to unity, leaving the aerodynamic admittance as the only unknown and enabling it to be evaluated. The results of this study were in excellent agreement with those obtained by Jancauskas & Melbourne (1986) despite the fact that the two techniques were entirely different. This agreement established the universality of the aerodynamic admittance for rectangular section cylinders in turbulent flows.

Having measured the aerodynamic admittance for a particular section in a particular turbulent flow, it is now possible, in the second stage of the project, to measure the joint acceptance for any given span of that section. This approach is based on the assumption that the coherence characteristics of the turbulence and the aerodynamic admittance of a particular section remain unchanged as the span is varied.

A technique which enables the direct measurement of cross-wind joint acceptance function is presented here. Measurements made using this approach, on a 10:1 rectangular cylinder for a variety of turbulence configurations are also included in this paper.

EXPERIMENTAL ARRANGEMENT & STRATEGY

The measurements were made using a two-dimensional test facility installed in the 45 kW open circuit wind tunnel at James Cook University of North Queensland. The wind tunnel has a test section measuring 17.5 m (L) x 2.5 m (W) x 2 m (H). The two-dimensional test facility, specifically developed for this project, allows 800 mm span models to be installed horizontally across the working section between floor-to-ceiling end plates. The model is held at each end in a supporting frame which is isolated from the wind tunnel and fixed to the laboratory floor via rubber pads to ensure that tunnel vibrations are not transmitted to the model. Small gaps between each end of the model and the end plates are sealed with sponge rubber to prevent air flow through gaps while still providing vibration isolation from the endplates.

The measurements presented in this paper were made on a 10:1 rectangular cylinder having a chord of 300 mm and a depth of 30 mm. A photo of the 10:1 model in the two-dimensional test facility is shown in Figure 2.

The model could be inclined at any angle of attack to the flow (for measurement of the steady state transverse force characteristic) but was set at an angle of attack of zero during the joint acceptance measurements.

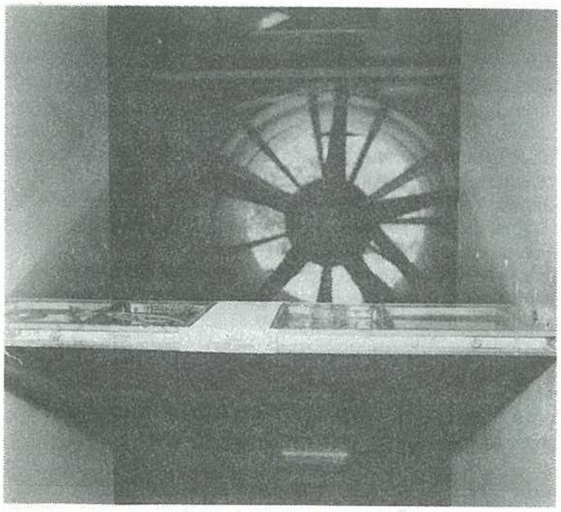

Figure 2. Photo showing the 10:1 rectangular section in the two-dimensional test facility

The actual force measurements were made on a chordwise slice of the model, the spanwise width of which was varied between 15 mm (5% of the chord dimension) and 300 mm (100% of the chord dimension). This slice, or *active section*, was suspended on a specially designed force measuring balance which was fully contained within the body of the model. The active section was constructed as a sandwich using lightweight materials (balsa wood and polystyrene foam).

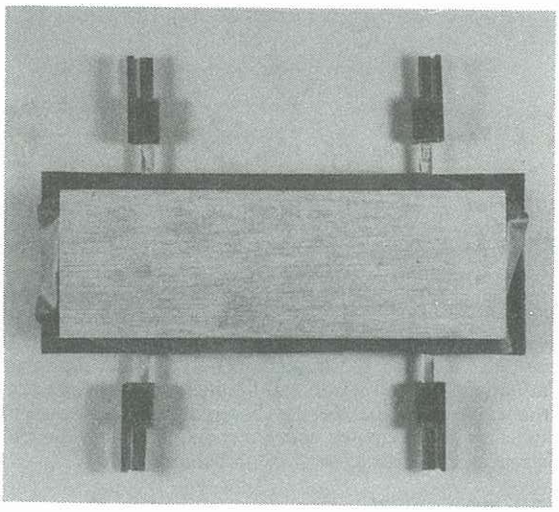

Figure 3. Close-up view of the active section

As shown in Figure 3, only the top and bottom surfaces of the active section were exposed to the flow. The gaps between the active section and the body of the model were sealed with a membrane.

The force balance consisted of four strain-gauged cantilevers. The active section was attached to the cantilevers using taut wires; this connection method virtually eliminated twisting of the cantilevers due to rotation of the active section. Semiconductor strain gauges, with a gauge factor approximately 100 times that of conventional metal strain gauges, were used. The gauges were connected into a Wheatstone bridge circuit which was designed to respond only to cross-wind forcing of the active section.

The force balance system (complete with active section) had a frequency response of at least 80 Hz and was linear over the entire measurement range. Cross-coupling (or the contribution from forces and moments other than cross-wind force) was less than 5%.

The measurements were made in three different background turbulence levels (Iu =1.6%, 6% and 16%). The flows had integral length scales (based on longitudinal velocity measurements) of approximately 0.255, 0.163, 0.111 m respectively. The spanwise lengthscales are yet to be measured.

All velocity measurements were made using a X-configuration hot-film probe and a TSI IFA-100 constant temperature anemometer. The hot-film voltages were linearised using TSI Model 1072 linearisers before sampled by a DATA 6100 waveform analyser which was also used to obtain the transverse velocity spectra.

The steady stste transverse force characteristic for each active section was measured using the force balance. This enabled the slope of the transverse force characteristic at 0° angle of attack to be determined. The cross-wind force spectrum was obtained by processing the signal from the force balance using the waveform analyser.

The transverse velocity spectrum, cross-wind force spectrum and the aerodynamic admittance function for each particular section/turbulence configuration (as previously measured in stage I of the project by Sankaran & Jancauskas, 1991) were used in equation 1 to directly obtain the joint acceptance function.

JOINT ACCEPTANCE RESULTS

Figure 4 shows the measured joint acceptance functions for the 1.6% low turbulence flow (of integral scale 0.255 m) using the 10:1 rectangular section for five different active section widths (b) of 15 mm, 30 mm, 50mm, 75 mm and 300 mm.

It can be seen that the five sets of data exhibit a clear trend; as the width of active section is increased, the joint acceptance decreases. This behaviour is intuitively correct. The incident turbulence contains energy over a range of frequencies, and hence scales. If the span of the model was infinitesimally small, then **all** scales would appear large relative to the span and would consequently be well correlated over the span; the joint acceptance function would be unity for all frequencies. However, as the span of the structure is increased, then all scales of turbulence would appear less large relative to the span and their correlation (and hence, joint acceptance) would be correspondingly decreased.

It should be noted at this point that the integral of the cross-wind force spectrum (as represented by the rms) **per unit span** of the model, correspondingly decreased as the span increased.

Figures 5 and 6 show the behaviour of joint acceptance function for a range of active section widths as the incident turbulence intensity is increased to 6% and 16% respectively (with a corresponding decrease in integral scales to 0.163 m and 0.111 m respectively).

Once again, it can be seen that the joint acceptance function decreases as the span of the active section increases.

Moreover, by comparing Figures 4, 5 and 6, it can be seen that the joint acceptance function decreases as the turbulence intensity increases and the integral scale decreases. This is more obvious in Figure 7 which shows the results for one particular span of the section (0.015 m) plotted as a function of turbulent intensity/scale.

Onceagain, the explanation provided for Figure 4 applies to Figure 7 as well and the behaviour is consistent.

Future measurements will focus on investigating the effects of varying model geometry (i.e. aspect ratio of the rectangular sections) and on separating the effects of turbulence intensity and length scale. An attempt will also be made to verify the measured joint acceptance functions by double-integrating the cross correlation spectra of the turbulent flows.

CONCLUDING REMARKS

1. A procedure has been developed that enables the joint acceptance function for bluff bodies to be isolated and measured.
2. Measurements made using this technique exhibit trends that are intuitively correct with the joint acceptance decreasing as either the span of the active section increases or the scale of the freestream turbulence decreases.

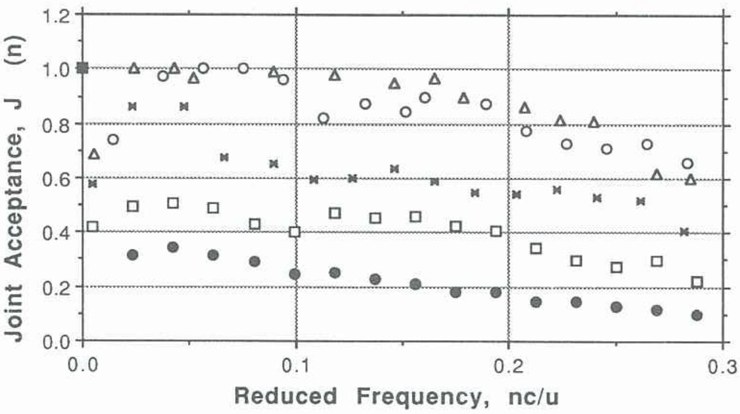

Figure 4. Joint acceptance function for various widths of active sections in a low turbulence flow (of length scale 0.255 m). Δ , 15 mm; O , 30; ⋈ , 50; □ , 75; ● , 300

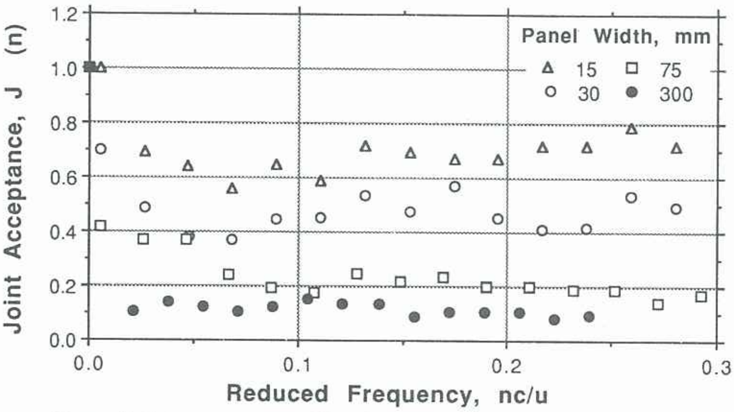

Figure 5. Joint accepatance Function in a moderate turbulent flow (Iu=6% and length scale 0.163 m)

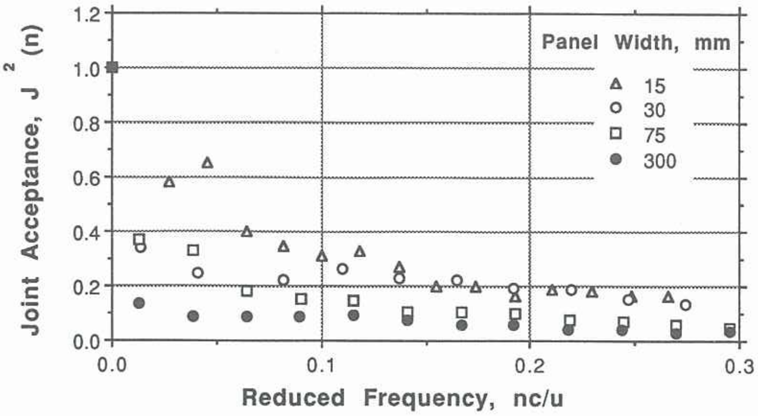

Figure 6. Joint acceptance function in a high turbulent flow (Iu=16% and length scale of 0.111m)

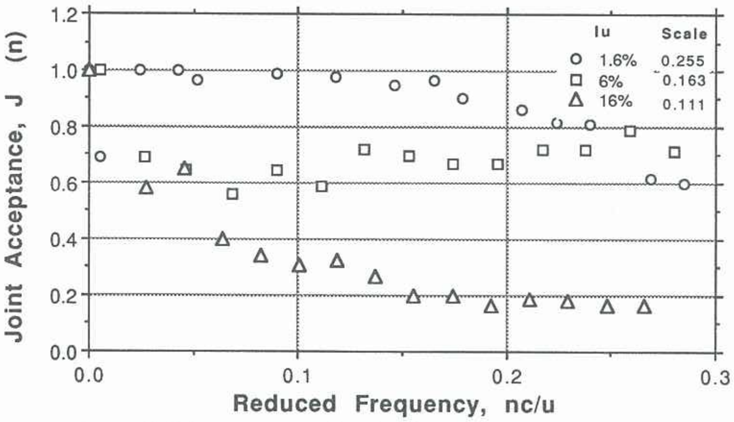

Figure 7. Joint acceptance function for an active section of 15 mm span in various turbulence levels

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