Measurement of the Cross-Wind Joint Acceptance Function in a Low Turbulence Flow

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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. As shown diagrammatically in Figure 1,

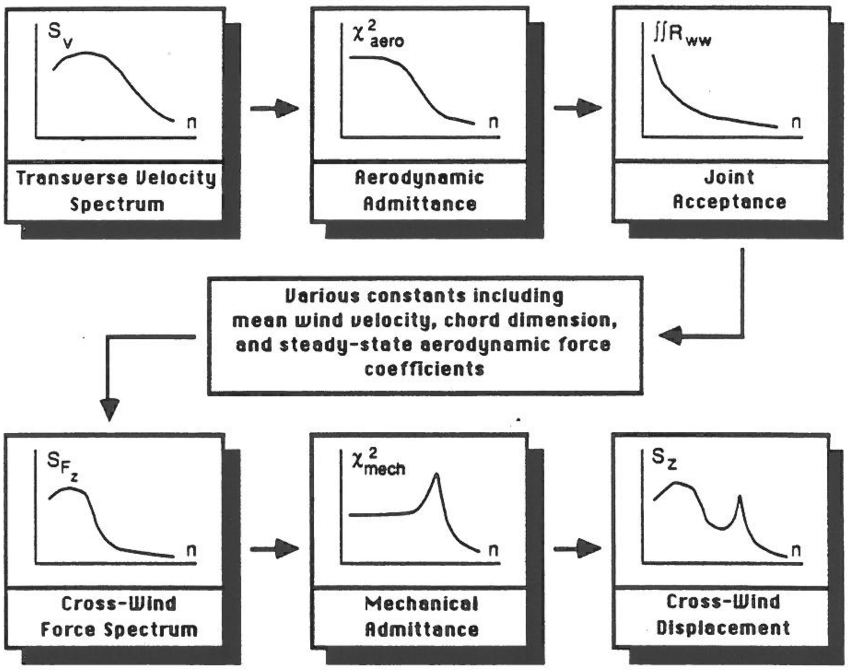

Figure 1. Davenport's Spectral Approach

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 takes account of the resonant characteristics of the structure and presents us with no difficulty. However, the other two transfer functions which define the ability of a particular turbulent flow to generate aerodynamic force have proven to be much more complex. 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 ultimate objective of the current project 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 was necessary to isolate and measure each of the two transfer functions (aerodynamic admittance and joint acceptance) independently.

In the first stage of the project, the aerodynamic admittance was measured for a range of two-dimensional rectangular cylinders in a variety of grid-generated turbulent flows (Sankaran & Jancauskas, 1991). Using a pneumatic averaging technique, these measurements were made on a very narrow chordwise slice of each model. Because of the small spanwise dimension of the slice, 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) using an entirely different experimental technique.

Having measured the aerodynamic admittance for a particular section in a particular turbulent flow, it was then 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 he section remain unchanged as the span is varied.

This paper presents preliminary joint acceptance measurements made using this approach on a 10:1 rectangular cylinder in low turbulence flow.

EXPERIMENTAL ARRANGEMENT

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 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 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. 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.

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 100 mm (33% 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). As shown in Figure 2, 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 latex membrane.

Figure 2. Front view of the model showing the active section

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 a low turbulence flow with a longitudinal turbulence intensity (Iu) of 1.5%. The flow had an integral length scale of approximately 0.023 m and all tests were conducted at a mean wind velocity of approximately 15 m/s.

JOINT ACCEPTANCE RESULTS

Figure 3 shows joint acceptance functions measured for the 1.5% low turbulence flow using the 10:1 rectangular section with three different spans of 15 mm, 30 mm and 100 mm.

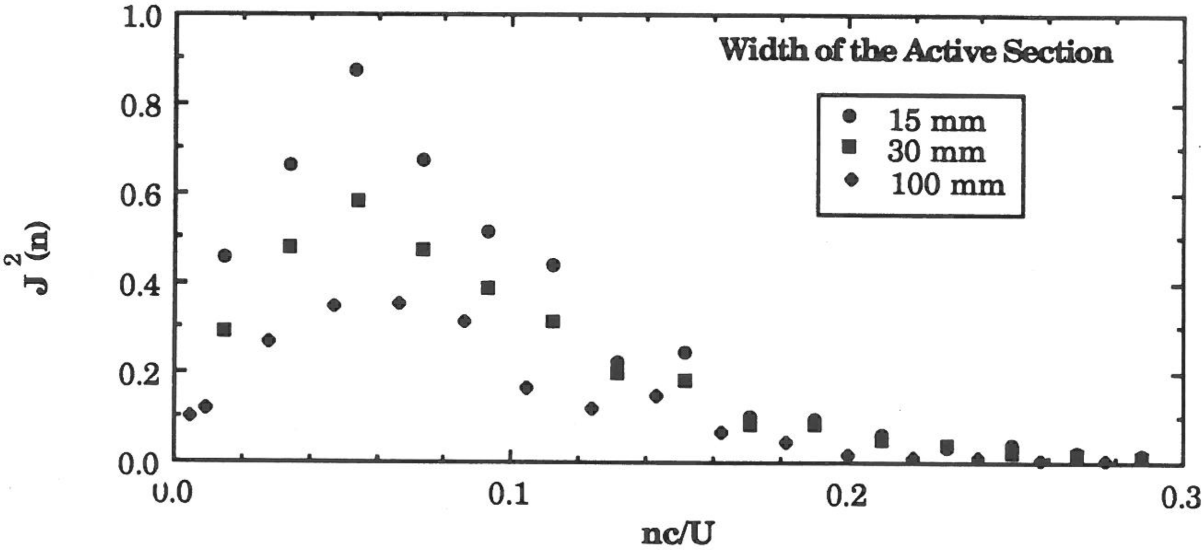

Figure 3. Measured joint acceptance for various widths of active section.

It can be seen that the three sets of data exhibit a clear trend; as the model span 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 fluctuations (as represented by the rms) **per unit span** of the model, correspondingly decreased as the span increased.

However, the data in Figure 3 demonstrates behaviour at low reduced frequencies that is counter-intuitive. It should be obvious that the higher the frequency (that is, the smaller the scale), the poorer the spanwise correlation for a given span. Hence, one would expect to see the joint acceptance function decreasing monotonically from a value of one at a frequency of zero. It can be seen in Figure 3 that all three joint acceptance functions reach a maximum value at a reduced frequency of approximately 0.05, and approach zero (rather than one) as the frequency approaches zero. The authors are unsure as to the reason for this behaviour but suspect it may be associated with the response of instrumentation at these low frequencies (below 2 Hz).

CONCLUDING REMARKS

1. A procedure has been developed that enables the joint acceptance function for bluff bodies to be isolated and measured. Preliminary measurements made using this technique exhibit trends that are intuitively correct with the joint acceptance decreasing as the span of the structure increases.

   However, the fact that the measured joint acceptance functions approach a value of zero, rather than one, at low frequencies is of concern to the authors and is currently being investigated.

2. The Davenport theory indicates that, for a given model span, the joint acceptance is a function only of the turbulence characteristics. This assertion will be checked by future measurements which will investigate the effects of varying model geometry and turbulence characteristics.

   An attempt will also be made to verify the measured joint acceptance functions by measuring and double-integrating the cross correlation spectra of the turbulent flows.

ACKNOWLEDGEMENTS

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