Active Generation of Large Scale Turbulence in a Boundary Layer Wind Tunnel

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Summary

The effect of turbulence on bluff body aerodynamics and response in wind flow has been increasingly studied for a wide range of turbulence integral scale. The generation of large turbulence scale using passive methods with vorticity generators (turbulence grid or trip board) is usually limited by the height and width of the wind tunnel. It is therefore essential to actively supply additional energy to the flow to generate large fluctuations in the wind. Among few active modeling techniques, this paper describes a simple actively controlled method by oscillating a large trip board in the upstream section of the wind tunnel to generate large turbulence length scales of magnitudes up to almost 6 times the maximum length scale obtainable by passive methods in the same wind tunnel. By using this active generation technique, a large longitudinal turbulence length scale up to 0.8m has been achieved at the height of 53mm above the tunnel floor in the 12m wide by 4m high working section of the 1MW Boundary Layer Wind Tunnel at Monash University, which can be used to model more realistically the atmospheric turbulence effects on large structures and air pollutant dispersion studies.

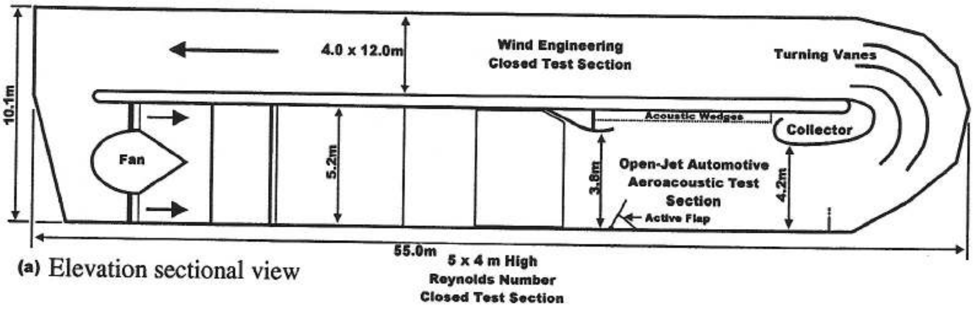
Introduction

Measurements of wind effects on large structures, such as high towers and long bridges, and on air pollutant dispersion studies have often been carried out in boundary layer wind tunnels. In Monash University boundary layer wind tunnels, a relatively simple conventional method has been used for over twenty years to generate turbulence using vorticity generators and floor roughness with an addition of a large trip board of various height installed in an upstream large tunnel section or the return circuit of the tunnel. This additional large trip board can achieve the generation of turbulence length scales in the working test section large enough to be equivalent to full scale values for the 1/400 scale model measurements, as described previously by Cheung and Melbourne [1].

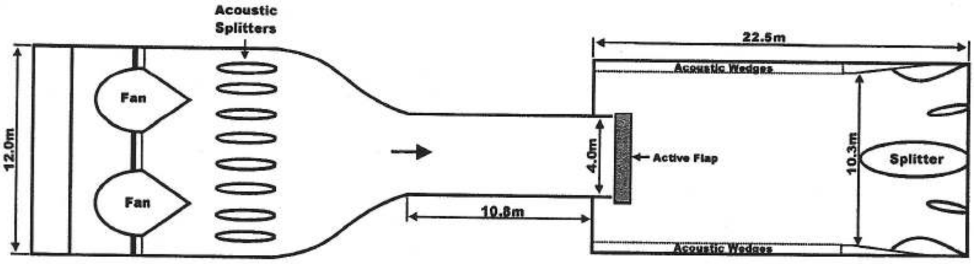
However as the model geometric length scale becomes relatively larger, the turbulence length scale to be modeled is also required to be larger. As the passive generation of the large turbulence scale is limited by the size of the tunnel, the atmospheric turbulence length scale becomes not possible to be properly modeled in the constraint of the working section of the wind tunnel. Also in a number of recent studies of the effect of turbulence on bluff bodies in separated and reattaching flows by Li and Melbourne [2] and by Cheung and Melbourne [3], the size of the wind tunnel working section has often restricted the maximum range of turbulence length scale of the investigations. To increase the maximum possible turbulence length scale in these studies and to enable simulation of atmospheric boundary layer in larger model scale wind tunnel testing, additional energy is required to be input into the mean wind flow to increase the low frequency spectral energy in the wind spectrum and thus increasing the turbulence integral length scale. This additional input of spectral energy can be achieved by active control turbulence generators such as a pulsating grid as outlined by Bienkiewicz, Cermak and Peterka [4] in a relatively small 0.91m square test section wind tunnel. Actively controlled multiple fans (66 in total) and airfoils have also been used by Nishi, Kikugawa, Matsuda and Tashiro [5] to generate large turbulence integral scale in a 1m square test section wind tunnel. These methods become relatively impractical and expensive to generate turbulence in a large test section 12m wide by 4m high. The present paper describes a more cost effective technique by oscillating or flapping the large trip board, which on its own already increases the turbulence length scale by 30%, to further generate additional low frequency large scale turbulence. The longitudinal turbulence length scale generated by the oscillating trip board increases by another six folds and is suitable to simulate full scale boundary layer characteristics for testing large models in the 12m wide by 4 m high working section wind tunnel.

Experimental Technique

A boundary layer model of the natural wind, typically 1/1500 scale for suburban terrain, was generated by flow over carpets and roughness elements augmented by vorticity generators installed in the return circuit of the 1MW Boundary Layer Wind Tunnel at Monash University. An additional large trip board or flap, 600mm high, was also installed in the return circuit at the beginning of the 4m wide by 3.8m high air jet open test section as shown in Figure 1. This large trip board or flap, hinged about the floor, was activated by a pneumatic cylinder to oscillate or flap in the wind, with adjustable oscillation stroke and frequency.



(a) Elevation sectional view



(b) Plan sectional view

Figure 1 Sectional elevation view of the 1MW Boundary Layer Wind Tunnel at Monash University, showing the setting up of active control system of trip board for the generation of large turbulence integral length scale in wind flow.

Three component wind velocity time series measured by a multi-hole dynamic pressure probe (the Cobra Probe) were recorded at 2500Hz for sampling periods of 300 seconds at various heights above ground. Averaged power spectral densities of the time series were obtained using MATLAB for FFT lengths of 4096 samples with Hanning windows. In order to minimize the experimental uncertainties associated with the determination of integral length scale from the measured wind spectra, a smoothing procedure of the spectral data as suggested by Iyengar and Farell [6] was adopted. This procedure consisted of extrapolating the spectral measurements at low frequencies using a parabola fitted through the first few points of the sample spectrum. A Von-Karman spectrum was then shifted along the horizontal inverse wavelength axis by varying the length scale L_x variable until it became tangential to the fitted parabolic curve. The Von-Karman form of longitudinal wind velocity spectrum is related to the Harris form of wind spectrum commonly used in wind engineering such that $L_z \approx 11.88\, L_x$ as follows:

$$\frac{nS_u(n)}{\sigma_u^2} = \frac{4\left(\frac{nL_x}{U}\right)}{\left[1+70.7\left(\frac{nL_x}{U}\right)^2\right]^{\frac{5}{6}}}$$

Von-Karman Spectrum

$$\frac{nS_u(n)}{\sigma_u^2} = \frac{0.6\left(\frac{nL_z}{U}\right)}{\left[2+\left(\frac{nL_z}{U}\right)^2\right]^{\frac{5}{6}}}$$

Harris Spectrum

Results and Discussion

The longitudinal velocity power spectrum for the wind flow, $U \approx 8ms^{-1}$, measured at 53mm above the tunnel floor without the additional oscillatory trip board is plotted as a function of inverse wavelength as shown in Figure 2. This longitudinal turbulence length scale L_x, which is the highest obtainable in this wind tunnel without using active generation of turbulence, is evaluated to be 140mm. For a model geometric scale of 1/1500, this integral length scale becomes $L_x = 1500 \bullet 0.14 = 210m$ (i.e. $L_z \approx 2500m$) which adequately simulates the high length scale values of the atmospheric turbulence at a height of $h = 1500 \bullet 0.053 \approx 80m$.

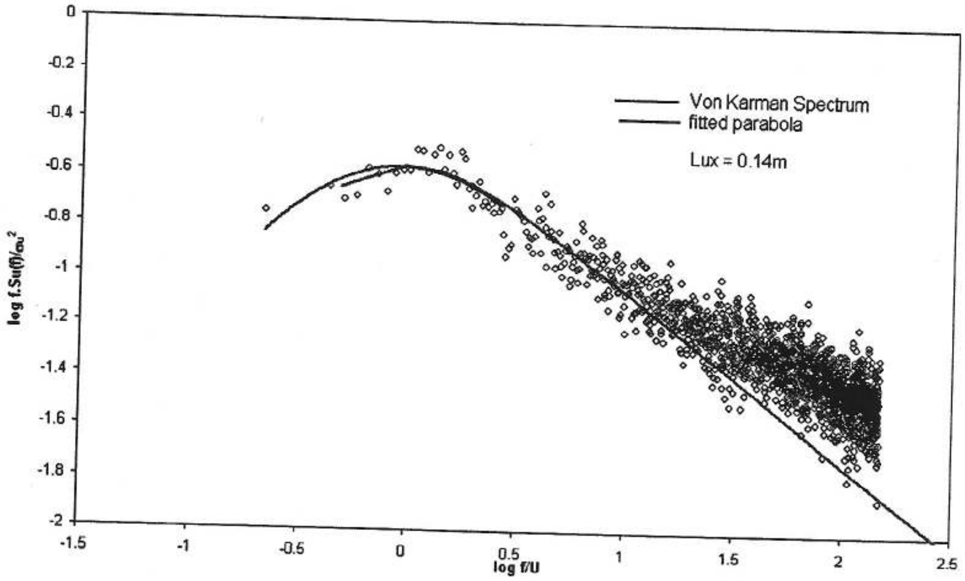


Figure 2 Longitudinal velocity spectrum measured without active generation of turbulence in the wind tunnel.

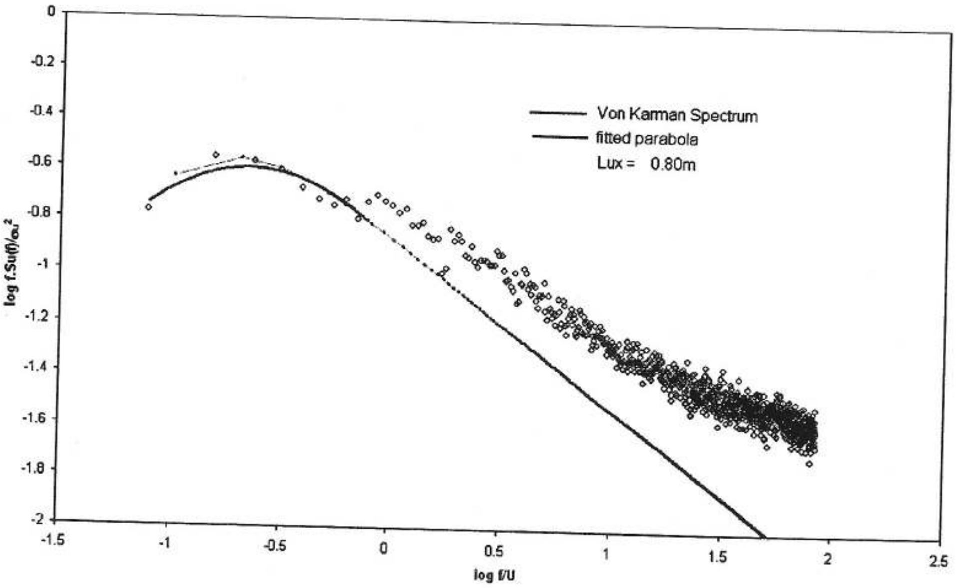


Figure 3 Longitudinal velocity spectrum measured with active generation of turbulence in the wind tunnel.

When the wind tunnel is used for testing in a model geometric scale of 1/200, the largest longitudinal integral length scale of 140mm obtainable by the passive method would only be equivalent to a full scale value of $L_x = 200 \bullet 0.14 = 28$m (i.e. $L_z \approx 330$m) which is too small relative to the realistic value found in the atmospheric boundary layer. By the active generation of turbulence method, however, higher turbulence length scale can be achieved. With the additional trip board activated to oscillate from approximately -5° to 35° from vertical at an oscillatory frequency of about 0.08Hz, the longitudinal length scale measured from the wind spectrum as shown in Figure 3, is 800mm. Thus, the equivalent full scale value of the longitudinal length scale becomes $L_x = 200 \bullet 0.80 = 160$m (i.e. $L_z \approx 1900$m) at a height of $h = 200 \bullet 0.053 \approx 10$m, which satisfactorily simulates the macro-scale low frequency turbulence in atmosphere.

Conclusions

An active control of generation of large scale turbulence has been installed in the boundary layer wind tunnel for testing large structures and dispersion studies as well as facilitating a wide range of length scale variations in the test working section for fundamental investigations on separated and reattaching flows. The maximum longitudinal integral length scale of 140mm obtainable in the 12m wide by 4m high section by passive method has been increased to 800mm by actively controlling an oscillatory trip board turbulence generator in the return circuit of the 1MW wind tunnel. These longitudinal turbulence length scales were shown to provide proper modeling of atmospheric turbulence in testing with geometric scale ranging from 1/200 to 1/1500 in the boundary layer simulation.

Reference

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