16th Australasian Wind Engineering Society Workshop
Brisbane, Australia
18-19 July, 2013

Embedded Turbulence in the Wake of Buildings Affecting Aircraft Operations

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Abstract

To study the magnitude of high, short distance shear flows in embedded turbulence events in the wake of a Building, three component velocity measurements have been made in the wake of a 1/200 scale wind tunnel model of a 240m wide by 60m deep by 35m high rectangular Building. The measurements were made using four velocity measuring probes located downstream of the Building. The time series velocity data were analysed to determine the magnitude of short distance wind shears in embedded turbulence events in the wake of the Building. Short distance wind shears have been presented in this report in full scale dimensions and scaled to relate to approaching wind conditions having a maximum gust wind speed of $10ms^{-1}$ in an hour at a height of 10m in Terrain Category 2.

Introduction

Relatively coherent vortices are developed in the wakes of buildings and these can develop shear flows with the ability to cause adverse effects on aircraft flying through these wakes, particularly in the landing phase. Longitudinal and vertical shear flows over distances between 20m and 200m along and across the path of an aircraft are of most significance, depending on the aircraft size.

The more extreme vortex or turbulence events are to be found intermittently embedded in building wakes and until the availability of multi-component velocity probes and/or diagnostic measurements have been difficult to measure using wind tunnel models. More specifically, using several such instruments (Turbulent Flow Instrumentation 'Cobra Probe') to measure three component velocity time series at locations a distance apart, it is now possible to capture and define these embedded turbulence events which generate the short distance shear flows of most importance to aircraft response.

Criteria to define when buildings wakes are likely to cause adverse effects on aircraft operations have been developed internationally which are based on mean wind speed shear properties and turbulence intensities, both of which describe only mean properties in the wake flow. Whilst in some of these studies some account has been taken of turbulence events in the wake of a building is has been shown that strong, short distance shear flows, can persist as turbulence intensities and mean shear flows decrease. Hence, in only relating to the mean properties in the wake behind a building, the short distance shear flows in embedded turbulence events that are likely to have the most impact on an aircraft in the critical stages of landing and take-off are likely to be missed.

To provide information on the properties of embedded turbulence events within the wake of a rectangular Building a short programme of wind tunnel measurements and data reduction have been undertaken. These measurements were made in the MEL Consultants 400kW Boundary Layer Wind Tunnel, using a 1/200 scale model.

Model and Experimental Techniques

A photograph of the 1/200 scale model of a 240m wide by 60m deep by 35m high rectangular Building is shown in Figure 1. A plan of the Building is given in Figure 2, along with the location of the four, three component, velocity measuring probes and the velocity measurement definitions. The measurements were made in a model boundary layer of flow over open country terrain (Terrain Category 2 as defined by the Australian Wind Loading Standard AS/NZS 1170.2:2011) and the velocity profiles and turbulence intensities for the incident flow are given in Figures 3 and 4.

Figure 1. Photograph of 1/200 scale building model in the wind tunnel.

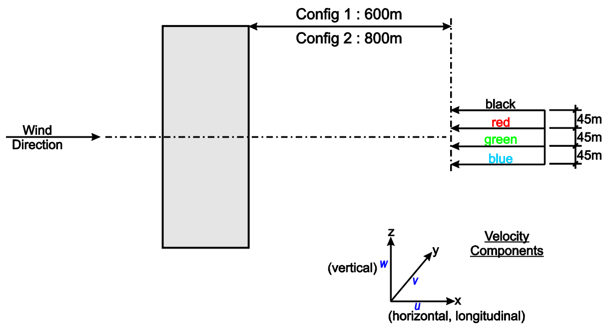

Figure 2. Plan of the rectangular building and location of the velocity probes and velocity measurement definitions.

The three component velocity measurements that will be presented in this report had a minimum resolvable frequency of 2.5Hz, in full scale. All the short distance wind shears evaluated and presented in this report will be based on data with this frequency response and are hence all comparable. However, it is noted that if the analysis had been done with data filtered with a 3 second moving average the wind shear values would have been lower. The velocity measurements were recorded over a time span of 4 hours in full scale time.

The data given in this report are in full scale dimensions and are all scaled to relate to approaching wind conditions having a mean wind speed of $6ms^{-1}$ and an approximate maximum gust wind speed of $10ms^{-1}$ in the hour at a height of 10m in open country terrain as defined by Terrain Category 2. Measurements were

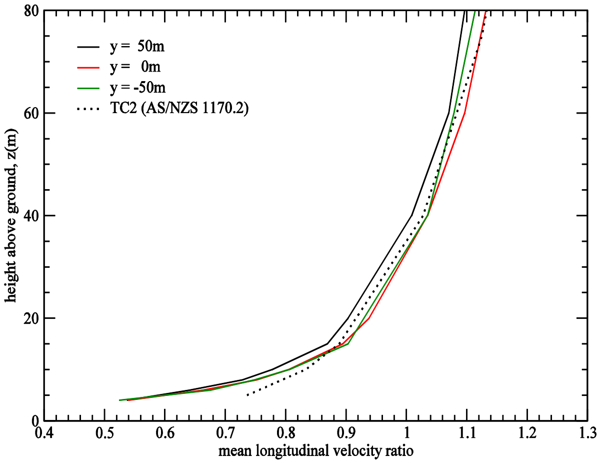

Figure 3. Mean longitudinal velocity profile of the wind tunnel model flow over open country terrain.

made for the wind flow normal to the long axis of the Building and downstream at distances of 600m and 800 m from the centre downstream side of the Building as shown in Figure 2. These two configuration have been designated Configuration 1 and 2 respectively.

The scaling of the model to full scale parameters was determined by using the non-dimensional Reduced Velocity parameter,

i.e. $\frac{V_r}{N_r L_r} = Constant,$

where the subscripted parameters, V_r, N_r and L_r are the velocity, frequency and length ratios of model over full scale.

Overview of Turbulence Intensities

An initial overview of the effect of the Building on the downstream conditions can be seen in the turbulence intensities for the three components, longitudinal (u), lateral (v) and vertical (w) for the configurations measured. The turbulence intensity profiles are given for the incident flow and in the wake at 600m and 800m downstream of the Building in Figure 4. The turbulence intensities are defined as the standard deviation of the velocity components normalised by the mean longitudinal wind velocity, for the full data record.

It can be seen that at the height of the Building (35m) the turbulence intensities in the incident flow are between 60% and 80% of the turbulence intensities measured in the wake of the building and the characteristic is quite different in that the turbulence intensities in the wake do not diminish so rapidly with height. These turbulence intensities are not necessarily an indication of the severity of embedded turbulence events (as the turbulence in the freestream and in a single building wake are generated by essentially different mechanisms); and these records will be analysed for embedded events in the same way as those measurements in the wake of the Building to provide background comparisons.

The highest longitudinal and vertical turbulence intensities can be seen to occur between heights of 30m to 60m. For convenience the detailed analysis of the embedded turbulence events will be done in this report for the building height of 35m.

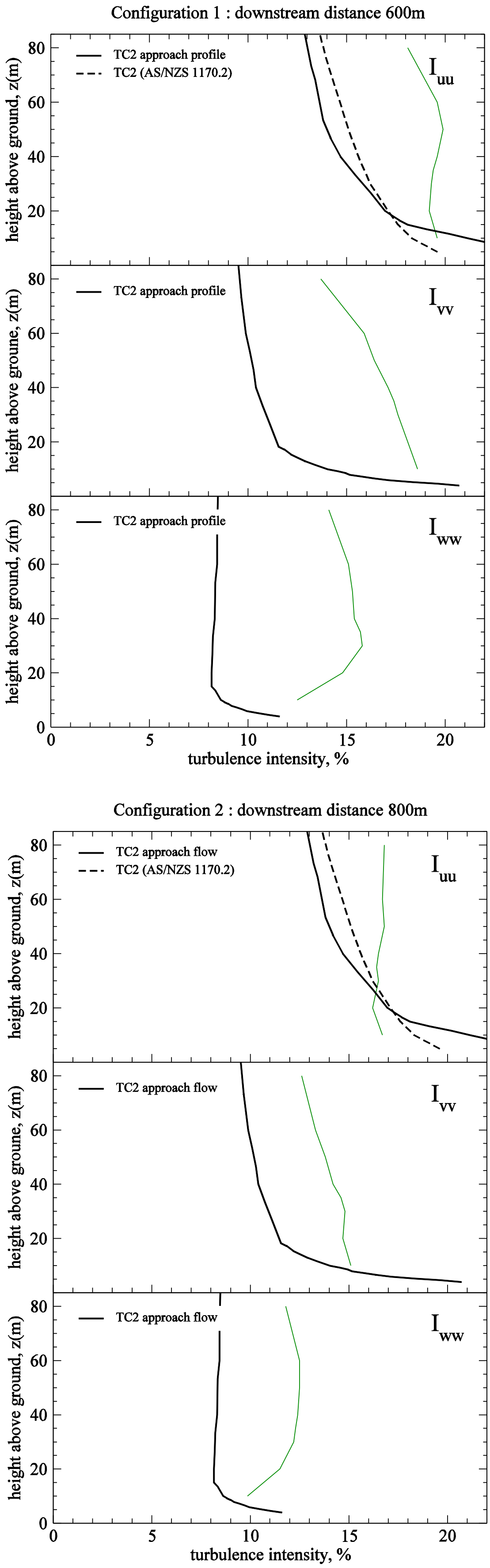

Figure 4. Turbulence intensity profiles for Configurations 1 and 2 at a distance of 600m and 800m downstream of the centre of the downstream side of the building. Terrain Category 2 incident turbulence profiles are also included in each plot.

Detailed Analysis

The detailed analysis was undertaken to characterise the various, short distance wind shears present in embedded turbulence events within the wake flows behind the Building. The process commenced with a visual inspection of the full velocity time series to select one or more 5 minute (300 second) segments including typically high velocity variations in longitudinal and vertical components (u and w). Examples of 300 second segments for the u and v components are given for Test Configuration 1 in Figures 5 and 6. From the 300 second segments, one or more 50 second segments were selected from which to determine typically high, short distance, wind shear values. It is emphasised that whilst typically high wind shear values have been sought, the process to date is manual and higher values may have occurred. Some examples of 50 second segments for Test Configurations 1 and 2 are given in Figures 7 and 8.

Example of detailed analysis for Test Configuration 1

From the 300 second segment in Figure 5 a 50 second segment of the longitudinal velocity component from the four probes for Test Configuration 1 is given in Figure 7. Examples of the analysis to obtain the short distance wind shears from this Figure are given as follows:

- At a time near 11486 seconds it can be seen that the black trace is at 10.5ms^{-1} whilst the green trace is at 3.3ms^{-1}. The difference is 7.2ms^{-1} between two longitudinal velocity measurements 90m apart. This is interpreted as a crosswind wind shear of 7ms^{-1} over 90m normal to the wind direction.

- At a time near 11462 seconds it can be seen that the blue trace falls from 11.2ms^{-1} to 4.4ms^{-1} over a time of 9 seconds, or from 9.6ms^{-1} to 4.4ms^{-1} in 7 seconds. The difference is 6.8ms^{-1} and 5.2ms^{-1} respectively. Given that for a maximum gust wind speed of 10ms^{-1}at 10m in Terrain Category 2, the mean convective longitudinal velocity at 35m would be approximately 7ms^{-1}, the time of 9 and 7 seconds is equivalent to a distance of approximately 65m and 50m respectively. This is interpreted as an alongwind shear of 5ms^{-1} over 50m.

In Table 1 the results of the analysis of the 50 second segments for Configuration 1 and 2 are given as wind shears over short distances scaled to relate to approaching wind conditions having a maximum gust wind speed of 10ms^{-1} in an hour at a height of 10m in Terrain Category 2. The data in Table 1 have been analysed in the same way as described above. As the analysis to date has been done manually there may be higher shear rates than are being given in Table 1.

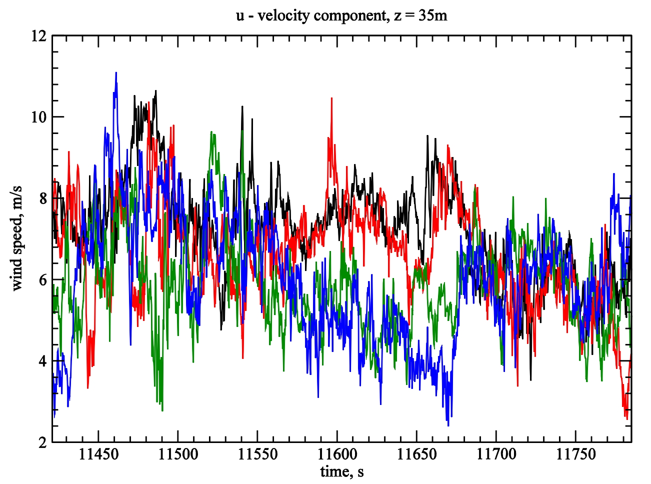

Figure 5. Longitudinal velocity component for Test Configuration 1 for the four probes at a height of 35m above ground and 600m downstream as a function of time over 300 seconds for a reference wind speed with a minimum gust wind speed of 10ms^{-1} at 10m over open terrain.

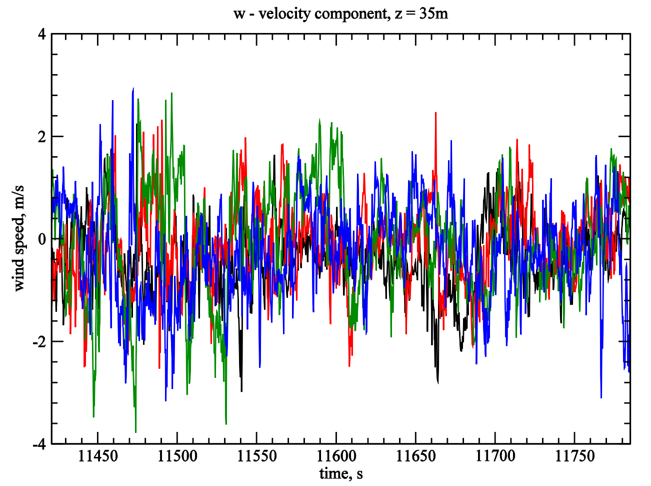

Figure 6. Vertical velocity component for Test Configuration 1 for the four probes at a height of 35m above ground and 600m downstream as a function of time over 300 seconds for a reference wind speed with a minimum gust wind speed of 10ms^{-1} at 10m over open terrain.

Test Configuration	Wind Direction	Height and Distance from Building	u-component		w-component	
			Cross-wind	*Along-wind*	*Cross-wind*	*Along-wind*
Incident Flow Open Country	N/A	z = 35m	5ms^{-1} in 135m 3.5ms^{-1} in 90m 3.5ms^{-1} in 45m	4ms^{-1} in 100m 3ms^{-1} in 50m	2.5ms^{-1} in 135m 2ms^{-1} in 90m 2ms^{-1} in 45m	2ms^{-1} in 100m 2.5ms^{-1} in 50m
Configuration 1	Normal to building long axis	z = 35m x = 600m	7ms^{-1} in 135m 7ms^{-1} in 90m 5.5ms^{-1} in 45m	6ms^{-1} in 150m 7ms^{-1} in 100m 5.5ms^{-1} in 50m 5ms^{-1} in 25m	4.5ms^{-1} in 135m 4.5ms^{-1} in 90m 6ms^{-1} in 45m	5.5ms^{-1} in 150m 5ms^{-1} in 100m 5ms^{-1} in 50m 6.5ms^{-1} in 25m
Configuration 2	Normal to building long axis	z = 35m x = 800m	7ms^{-1} in 135m 7.5ms^{-1} in 90m 6.5ms^{-1} in 45m	7ms^{-1} in 150m 5.5ms^{-1} in 100m 5ms^{-1} in 50m	5ms^{-1} in 135m 4.5ms^{-1} in 90m 6ms^{-1} in 45m	5ms^{-1} in 150m 5.5ms^{-1} in 100m 5ms^{-1} in 50m

Table 1. High value, short distance wind shears in the Incident Flow and in the wake of the Building (35m high, 60m wide, 240m long) for approach wind conditions in which the maximum gust wind speed within an hour at 10m in Open Country Terrain is 10ms^{-1} (as defined by AS/NZS 1170.2).

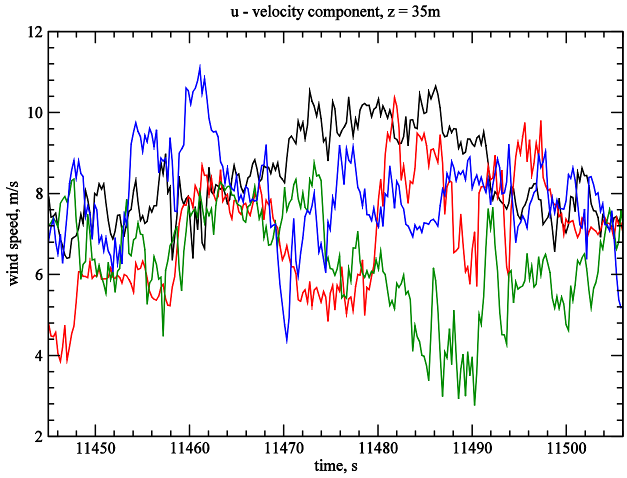

Figure 7. Longitudinal velocity component for Test Configuration 1 for the four probes at a height of 35m above ground and 600m downstream as a function of time over 50 seconds for a reference wind speed with a maximum gust wind speed of $10ms^{-1}$ at 10m over open terrain.

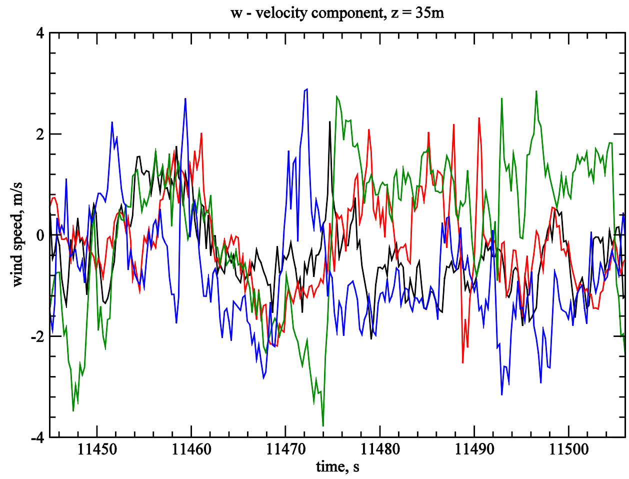

Figure 8. Vertical velocity component for Test Configuration 1 for the four probes at a height of 35m above ground and 600m downstream as a function of time over 50 seconds for a reference wind speed with a maximum gust wind speed of $10ms^{-1}$ at 10m over open terrain.

Conclusions

Three component velocity measurements have been made in the wake of a 1/200 scale wind tunnel model of a 240m wide by 60m deep by 35m high rectangular Building. The measurements were made using four velocity measuring probes located across a line through the centre of the Building for a wind direction normal to the long axis of the Building. These data were analysed to determine the magnitude of short distance wind shears in embedded turbulence events in the wake of the Building. Short distance wind shears have been presented in this report in full scale dimensions and scaled to relate to approaching wind conditions having a maximum gust wind speed of $10ms^{-1}$ in an hour at a height of 10m in Terrain Category 2 as defined by the Australian Wind Loading Standard AS/NZS 1170.2.

Cross-wind, short distance, longitudinal wind shears of approximately $7ms^{-1}$ over distances varying from 45m to 135m have been measured for both 600m and 800m distances downstream of the Building. For an aircraft approaching at $50ms^{-1}$ in $10ms^{-1}$ or $15ms^{-1}$ cross-winds this relates to a 15% or 20% change in wind speed respectively over distances varying from about 50m to 150m. Similarly, along-wind short distance vertical wind shears of approximately $5ms^{-1}$ have been measured over distances varying from 50m to 150m. For an aircraft approaching at $50ms^{-1}$ in $10ms^{-1}$ cross-winds this relates to a differential angle of attack between the two wings of approximately 6^0. Similar scaling of these effects can be done for different approach wind speeds.

References

Australian/New Zealand Standard AS/NZS 1170.2:2011 (Incorporating Amendment Nos 1 and 2), Structural design actions. Part 2: Wind actions