A Reliability Study of Wind Tunnel Results for Cladding Pressures

By

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1. INTRODUCTION

In undertaking wind tunnel pressure tests, decisions have to be made regarding the length of sampling time, the sampling frequency, the low pass filtering frequency and the probability level associated with peak pressures. This paper presents a purely statistical analysis of the effects of these parameters on the determination of peak pressures. The significance of some of these parameters varies with the method of analysis. Five types of analyses are compared in relation to these parameters. These are the Direct Extreme Value Analysis (DEVA), the Largest Peak method[1,2], the Upcrossing method[3] (both the standard Upcrossing method and an alternative semi-empirical Upcrossing method), Peterka's method[2] and Monash University's method developed recently by Melbourne and Cheung[1].

The Largest Peak Method is where one simply treats the largest peak occurring over a sampling time of one hour as the mean hourly peak pressure. Melbourne[1] has devised a method of detecting peaks which may in fact be spikes set up by the pressure measurement system.

The DEVA, which is the most commonly used method, was investigated using Gumbel's method as well as Lieblein's and Gringorten's methods of correction for bias due to the ranking process. An alternative DEVA, developed by the authors was also compared. This alternative DEVA directly analyses the distribution of consecutive extremes instead of using order statistics (hence not requiring correction for bias).

The Upcrossing method (or Normalised Crossing method) is another commonly used method. The standard Upcrossing method in which Type I parameters are derived from a Poisson distribution was investigated. In the Standard Upcrossing method, the mode is obtained by finding the peak factor that corresponds to a single crossing per time, T and the dispersion can be obtained from the slope of the line of best fit. The Alternative Upcrossing method differs from the Standard Upcrossing method in that the peak is obtained by finding the level corresponding to a crossing rate of an empirically determined fraction of the crossing rate at the mean of the fluctuating pressure signal.

In Monash University's method, the parent distribution of the peaks (defined differently to Peterka's peaks) is analysed. The range from the mean is divided into ten intervals and a probability distribution is obtained by dividing the number of peaks in each interval by the total number of peaks in the "positive" direction and the peak is related to an empirically determined probability level.

The effects of the different probability distributions such as the Gaussian, Weibull, Poisson and Gumbel distribution functions on the peak pressure results and their sensitivity to the above parameters were also investigated. Load factors were computed for the various methods of analysis, based on the method reported by Davenport[5]. These are designed to be used with pressure results obtained from wind tunnel tests.

2. EXPERIMENTAL SETUP

2.1 Model of Building and Wind

A perspex CAARC model of 1:500 scale was tested in a terrain category type 3 (Suburban) wind environment. The test was conducted at the University of Sydney N⁰.1 Boundary Layer Wind Tunnel. It is of an open circuit type and is 2.4 x 2.0 x 20 m in size. An augmented growth method was used to generate the required wind model by means of triangular vorticity generators and floor-mounted roughness elements.

2.2 Pressure Measurement System

Pressure signals were obtained from pressure taps on each of the windward face, leeward face, windward edge of side face and leeward edge of side face. These were considered to be sufficiently representative of the various types of pressure signals. PVC tubes were connected from the tapping positions to a pressure scanning switch. These PVC tubes had a calibrated length of 1 m and an internal diameter of 1.3 mm. A leak tube of 0.3 mm internal diameter and 10 mm in length was placed between each set of pressure scanning switch and pressure transducer. The function of the leak tubes was to attenuate peaks in the frequency response in the system. The system was calibrated by using the method reported by Holmes and Lewis[4]. The frequency response was close to linear upto ~300 Hz and had no resonant peaks to about 1000 Hz.

2.3 Data Acquision System

The signal output was initially recorded on magnetic tape using a frequency modulated data recorder which has a frequency response of upto 1250 Hz. The recording of the signal on tape allows one to vary the sampling parameters and methods of analysis of the peaks without changing the actual signal. The signal was low pass filtered at 1000 Hz prior to being recorded. The same recorded signal was used to investigate the effect of different low pass filtering frequencies of upto 1000 Hz. The digitisation was performed using a 12-bit analogue to digital converter which was powered by an IBM AT compatible microcomputer. The same computer was used for the data reduction.

3. RESULTS AND CONCLUSIONS

The uncertainty due to the digitisation technique which results in randomly clipping the peaks, and the non-stationarity of the signal is quite significant for pressure tests. The coefficients of variation due to the combined effects of digitisation and non-stationarity on peak pressures were significantly higher than those for the mean and standard deviation pressures.

The selection of a probability distribution function is important in correctly representing the characteristics of the pressure signals obtained in the wind tunnel tests. While a Gumbel distribution has its advantages in the DEVA, a Poisson Distribution function proves to be well suited for the Upcrossing Analyses. A Weibull distribution function is by its nature well suited for the Monash University's method.

For the pressure measuring system used, low pass filtering frequencies lower than 100 Hz cause excessive attenuation of peaks resulting in unacceptable results. It was also found that the higher the sampling frequency the lesser the effect of the filtering frequency, provided that the filtering frequency is not less than 100 Hz. In general, sampling frequencies should not be less than 100 Hz. However, Monash University's method was sensitive to sampling frequencies above 1000 Hz due to the method of selection of peaks.

The Standard Upcrossing method and the Alternative Upcrossing method have a distinct advantage in terms of sampling time requirements because they use more of the data and because the Poisson function provides an excellent fit to the data. For the same precision, Monash University's method and Peterka's method require a sampling time of 1 hour (prototype) compared with 30 min. using the Upcrossing methods. An Alternative DEVA developed by the authors required half the number of data values as Gumbel's DEVA. The effects of the various linear unbiased estimators was found to be negligible.

The different methods of analysis had little effect on the estimation of the mean hourly peak pressures provided that certain probability levels are used. The various DEVAs (using $\hat{P} = U + 1.4/a$), the Upcrossing methods (at $\hat{P} = U + 1.4/a$ for the Standard Upcrossing method and a crossing rate of 1/360 for the Alternative Upcrossing method), Peterka's method, and Monash University's method (using a probability level of 0.002) all gave results within ±7 percent from averages of four values obtained from four consecutive one hour records using the Largest Peak method, for the various signals. However, it is important to note that some methods are more sensitive to the adjustment of the sampling parameters than others.

Load factors applicable to results obtained from wind tunnel tests for cladding pressures were derived using the method reported by Davenport[5]. These factors take into account uncertainties in the prototype and model reference wind velocities, non-stationarity, the digitisation process, sampling and filtering frequencies as well as changes in the upstream terrain and in the internal pressures. The load factors are plotted against sampling and filtering frequencies since they are the most varied parameters. Examples of these can be seen in Figure 1, based on 95% confidence intervals for the various coefficients of variation. The Alternative Upcrossing method attracted the lowest load factors while the Largest Peak method required the highest.

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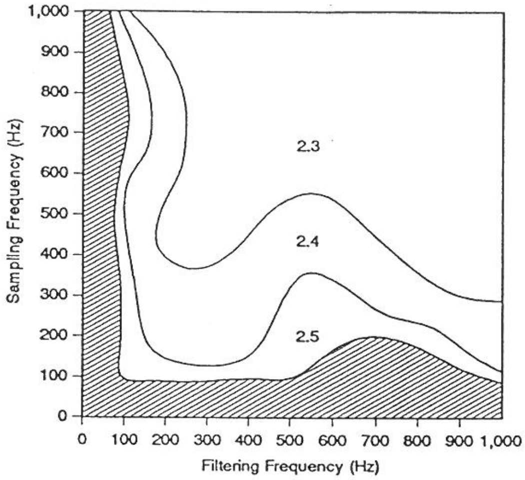
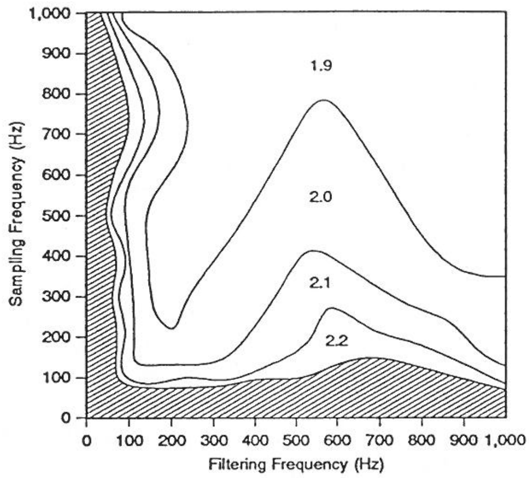
Figure 1: Plots of Load Factors for Wind Tunnel Cladding Pressure Results

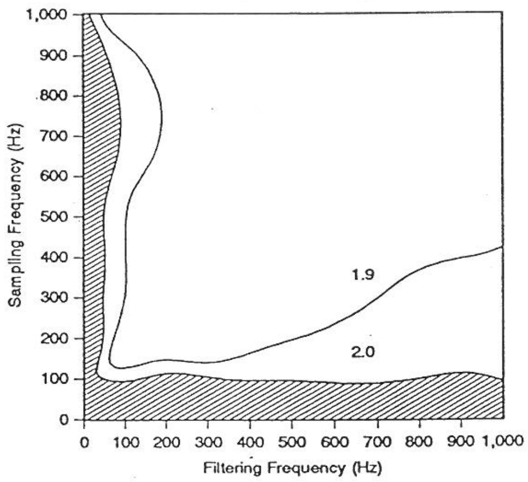
a) Largest Peak Method



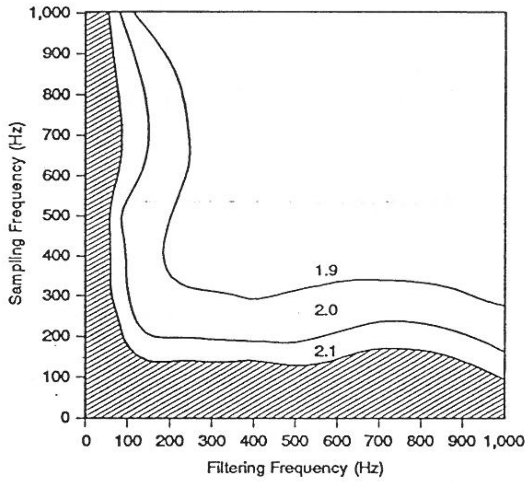
b) Standard Upcrossing Method



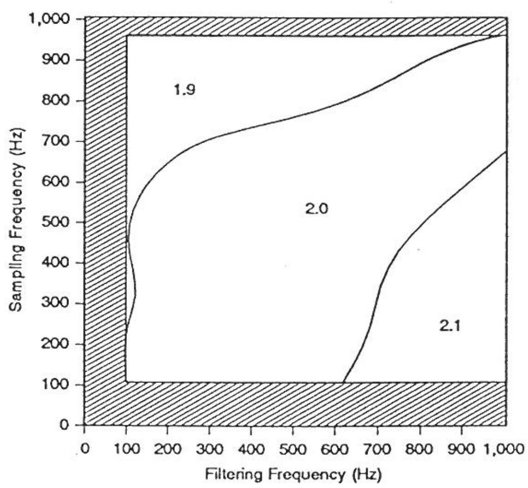
c) Alternative Upcrossing Method



d) Peterka's Method



e) Melbourne's method



ASSUMPTIONS USED IN THE COMPUTATION OF LOAD FACTORS
(For 95 percent confidence intervals)

Factor	Phi	C.O.V.
Changes in upstream conditions	0.9	0.10
Effect of openings in walls and roof on the internal pressure	1.0	0.05
Wind tunnel modelling of the wind and building	1.0	0.10
Repeatability in the predicted pressure difference	1.0	0.25 *
Meteorological estimates of wind velocity	1.0	0.11

Note: These figures are generally based on work reported by A.G. Davenport (1983) and by J.D. Homes (1985).

* Based on experimental work by the author. The corresponding value of the C.O.V. for the Largest peak method is 0.35.