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Some Measurements of Roof-Top Atmospheric Turbulence

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ABSTRACT

An ultrasonic anemometer was used to collect roof-top turbulence data. The multistorey building is among a group of buildings of similar heights located in a high-rise urban centre. Probability distribution, power spectra and auto-correlation were reported with applications to roof-top dispersion in mind.

INTRODUCTION

The study of gas dispersion on the roof-top of buildings in the city centre has a lot of applications in the fields of pollution control and building services engineering. For the building service engineer in a crowded high-rise city, the only available place for exhaust vents and air-intake room is always on the roof-top to save space. In modern cities not only buildings but also hospitals, universities and even factories are housed in high-rise buildings and centrally air-conditioned. The recirculation of exhausted gas will reduce the efficiency of the ventilation system. More seriously, if harmful gases or micro-organisms are present in the recirculated gas, major health problems will occur. The low exhaust vents of domestic gas water heaters and restaurant exhaust flues will cause recirculation and pollution problems in the city centre. Halitsky (1962) and Wilson (1976) have derived semi-empirical dispersion formulae based on wind-tunnel studies. Those formulae became guide-lines for building service engineers in designing exhaust and air-intake systems. A field study of roof-top dispersion has been carried out at the University of Hong Kong. The concentration measurements have been reported in two previous papers, Kot & Lam (1985) and Lam et al. (1985).

In order to understand the dispersion problem more fully, the knowledge of the structure of atmospheric turbulence on the roof-top is essential. Also once the spectra of turbulence on the roof-top is known a statistical simulation of diffusion on the roof-top can be carried out on the computer and then compared with the measured concentrations. A representative spectrum of atmospheric turbulence on the roof-top is also very useful for wind engineering of roof-top structure such as microwave dishes for telecommunication. Unfortunately very few atmospheric turbulence spectra above urban centre have been published. The meteorologists measure atmospheric turbulence from high towers in an open field. As far as we know, there is no easily available specially measured turbulence spectra on the roof-top level within a city. The main reason behind the scarcity of this kind of data is that atmospheric turbulence above roof-top is site specific. The measured spectra at one site may not be the same for another. We are planning to do measurements on many different sites to see if there are major differences between sites and whether a representative spectrum can be constructed. In this paper we shall report on the results of the turbulence measurements on the first site.

EXPERIMENT

The apparatus used for measuring the atmospheric turbulence was a Kaijo Denke DA 300 ultrasonic anemometer. The height of the centre of the ultrasonic probe was three metres above the roof. This height was chosen because it was representative of the height of the mean plume of exhaust gas from the vent in the concentration measurement experiments. The building is of twenty-eight metres in height, surrounded by a group of buildings of similar heights. This group of buildings is on the campus of the University of Hong Kong close to high-rise built up urban centre. The interested readers are requested to refer to Kot & Lam (1985) for more details on the location and surrounding complex terrain. The roof-top is surrounded by parapet walls of 1.5 metres in height. There are water tank, lift machinery room and air-intake room for central air-conditioning system. The size of the building is 25 m x 46 m and the roof-top arrangements are fairly representative of buildings in high-rise urban centres.

The ultrasonic anemometer has a sampling rate of 18.8 cycles/sec. The digital outputs were recorded on an eight inch floppy disc. The data were later transferred to the university main frame computer for data analysis. The disc could only store records of several minutes of real time. Fortunately, this was the sampling period of most importance in the study of roof-top short range dispersion.

DATA ANALYSIS

Conventional random data analysis included studies of probability distribution, power spectrum, correlation and randomness test. These topics were well developed and the procedures for their computation were presented in Bendat & Piersol (1971) and Otnes & Enochson (1972) for digital version.

The three orthogonal wind components were measured by the ultrasonic anemometer continously at the fixed location mentioned above. The analyses below were performed on the Eulerian properties of the three wind components. For convenience, A, B, C were denoted as the digital signal outputs from the anemometer. Ua, Va, Wa would denote the east, north and vertically upward winds respectively. X, Y, W would correspond to the Ua, Va, Wa respectively after second order trend removal and normalization. The digital outputs of the anemometer composed of the multiplexed A, B, C. The sampling rate of the anemometer was 18.8 samples per second. Owing to the orientation of the transducer pairs, the digital outputs from the anemometer were not in Ua, Va, Wa directly. The transformation and calibration procedures were carried out in the main frame computer before data analysis. The transformation equations were

$$Ua = \sqrt{\frac{2}{3}}\,(B-C)$$

$$Va = \frac{\sqrt{2}}{3} (2A-B-C)$$

$$Wa = \frac{\sqrt{2}}{3} (A+B+C) \ .$$

From a sampling theory, the Nyquist frequency was 9.4 hertz. Any frequency components above 9.4 hertz would be aliased into low frequency domain. Therefore, the transducer signals should be lowpass filtered before digitizing. Presumably, this process had been done by the electronic cards built into the ultrasonic anemometer. This was confirmed by the computed spectra where no high frequency components of above a few hertzs could be found.

The mean values and variances of the raw Ua, Va, Wa were computed. The velocity components fluctuated wildly and were found to be nonstationary. The slow underlying trend had to be detected and removed from the original series. Least square and polynomial fitting methods were employed. Figure 1 showed a representative time series before and after second order trend removal. In order to avoid overflow during computations, the trend removed series were further normalized by its own variance. The treated time series used for further analysis were fluctuating components of the wind velocities with zero mean and unit variance.

The transfer of digital output from anemometer to floppy disc was not a real time process. Owing to the limitation of memory size, the A, B, C series were collected in the form of data files. Each file was composed of three time series, each with length of 3072 (3K) samples. The computation of both power spectrum and correlation function required segment averaging. However, there were infinite number of ways in dividing the 3K data into segments. If the segments were too long, the number of segments would be too small to reduce the statistical error significantly. Moreover, the second order trend removal would not work well if the segment length was too long. On the other hand, if the series was divided into too many segments, a lot of computing time would be wasted. Four run tests were performed on one time series to observe the effect of different segment lengths on randomness. It was found that the time series of length of 256 and 128 samples after second order trend removal could be classified as random at 0.05 level of significance.

The probability density of this time series was computed using 1024 data samples and 32 class intervals. Figure 2 showed the probability density of fluctuating components of X, Y, W when segment length of trend removal was 256. The solid line was the normal curve. Chi-square goodness of fit test was carried out on these functions. The square of discrepancies of all probability density functions with respect to Gaussian distribution were smaller than 45.72, the hypothesis that these fluctuating signals followed Gaussian distribution was accepted at 0.05 level of significance.

The power spectral density function of time series described the general frequency composition of the data in terms of the mean square value of its spectral density. Digital fast fourier transform method of the Sande-Tuckey version was used to compute both the auto- and cross-power spectrum. In order to reduce leakage, cosine tapering windows were used. Ten percent of data in the leading and trailing ends were cosine tapered before transformation. After transformation, the coefficients were all divided by 0.875 to readjust the variance of the series. To save space, only one raw power spectral density of X was shown in Figure 3, in both linear and logarithmic scales. The raw power spectral density was an inconsistent estimate. The minimum mean square error of one power spectral estimate was one, which meant that the standard deviation of the estimate was as great as the quantity being measured. Sample smoothed spectra of X, Y, W were shown in Figure 4. Twenty-three spectra were used in the smoothing.

A sample auto-correlation function of X was shown in Figure 5. Cross-corelations had also been computed. Figure 6 showed a sample cross-correlation function of XY.

CONCLUSIONS

Preliminary investigation of roof-top turbulence had been carried out. Auto and cross spectra revealed that the length scale of turbulence over the roof-top was large. This gave credence to the assumption on the turbulence length scale of Wilson's dispersion formula. His assumption was that the roof-top turbulence length scale was of the order of building length.

The structures of X, Y, W power spectra are quite similar. It was reasonable to assume the turbulence over roof-top nearly isotropic.

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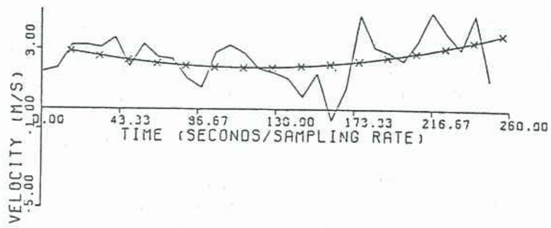
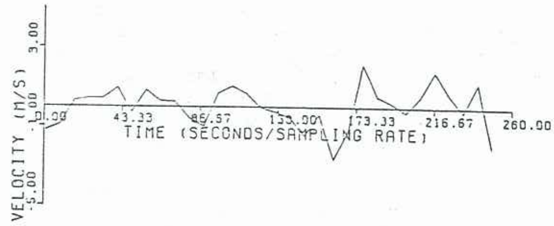


X and its second order trend



X after trend removal

FIG. 1

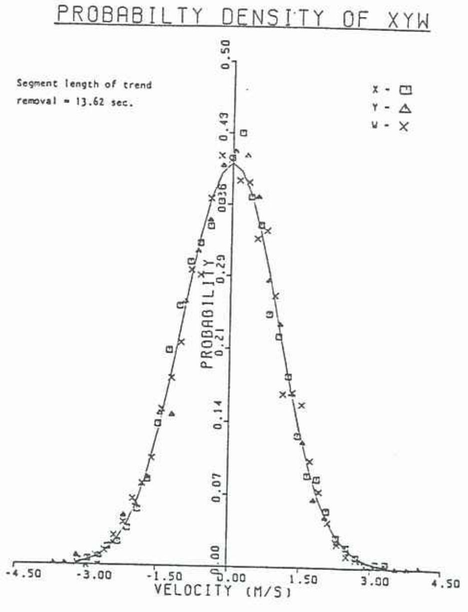


FIG. 2

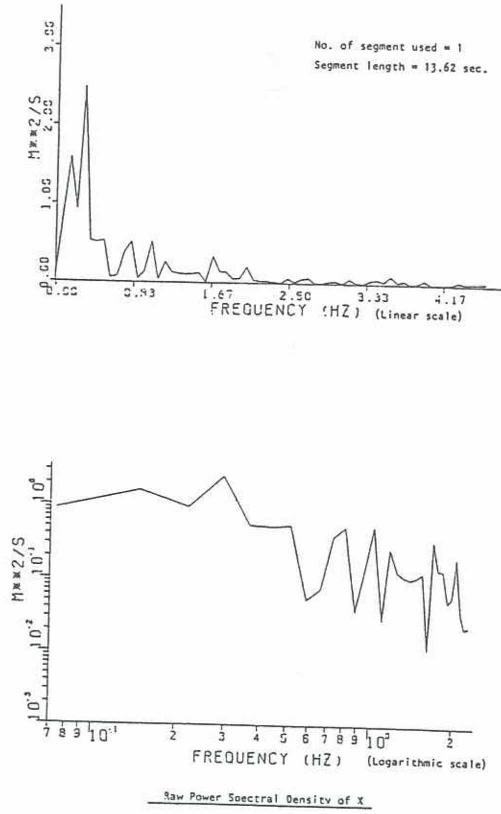


FIG. 3

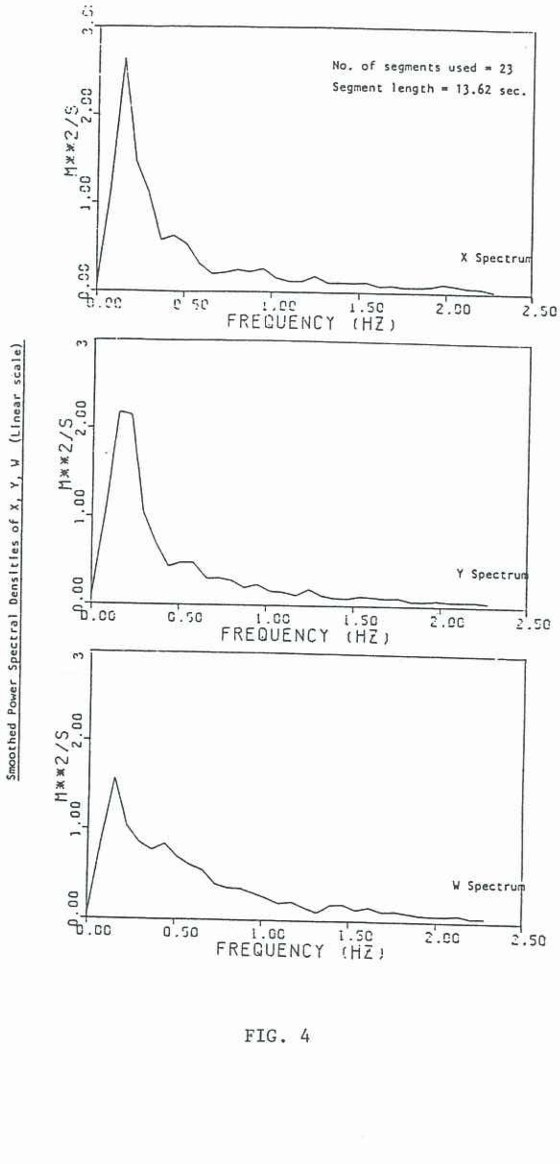


FIG. 4

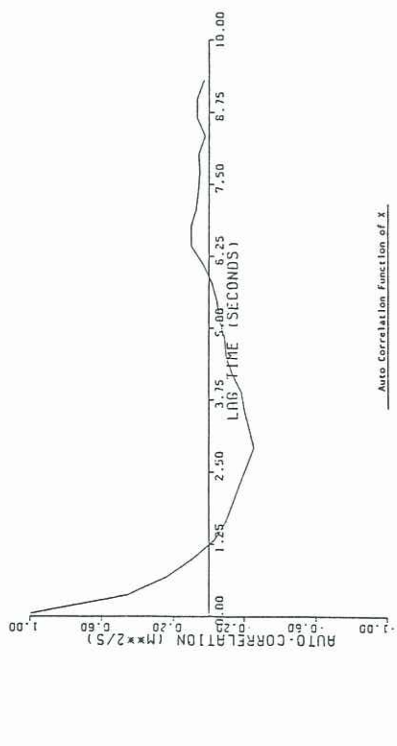


FIG. 5

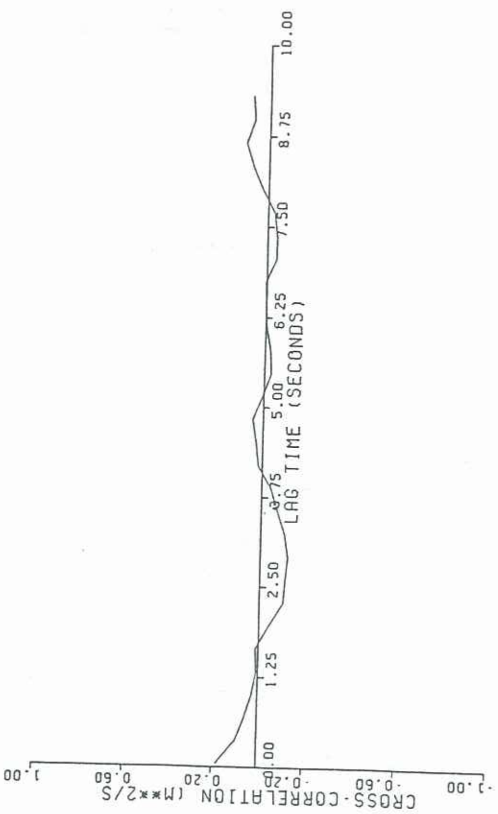


FIG. 6