Windtunnel Studies on Traffic Produced Turbulence and its Influence on Pollutant Dispersion in an Urban Street Canyon

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1. Introduction

The need for mobility has increased over the last decades. Cars have extended their position as the most important individual means of travel. In the transportation sector more goods are freighted on roads. Thus physical modelling of urban air pollution has to include exhaust gases from urban traffic. In addition there is a constantly progressing urbanisation, which unites more than half of mankind in cities and population centers world-wide.

The highest pollutant concentrations within cities are observed during calm episodes. In this case the amount of turbulence produced by the mean flow within the street canyon might be smaller than that produced by the moving vehicle. Therefore the influence of traffic produced turbulence (TPT) has to be quantified. Up to now TPT has been modelled physically utilizing an energy based design rule developed by Plate (1982), not taking care of the length scale of the turbulence produced. Moving turbulence generators for the simulation of traffic need to be Reynolds number independent even at low generator velocity due to the technical realisation. Geometric similarity to real traffic would require uncapable high velocities. Therefore ground bounded plane plates have been used.

Former investigations showed some weak points of this modelling technique. The distubance of the flow sidewards and upwards of the moving model vehicle has been found too large (Kovar 1998). The plates also create a strong mean flow in their moving direction. This is not observed under natural conditions.

To reduce the observed shortcomings new shaped plates have been designed. Their turbulence characteristics have been measured in a windtunnel experiment. To draw a comparison a turbulence measurement in a street canyon took place. The experimental setup is described in Section 2. Utilizing wavelet analysis a method for comparing produced turbulence spectra is developed in Section 3. The results of this comparison are shown and discussed in Section 4. Section 5 draws a conclusion and suggests an improved model shape for former investigations.

2. Experimental Setup

2.1 Measurement of TPT in an urban street

The measurement took place in the city of Hannover, Germany, during calm weather periods between August and September 1999 (Frantz, 2000). The examined two-lane street is surrounded by a dense building structure. The height-to-width ratio of the street canyon is approximatly 1.2. Three ultra sonic anemometers (USA) were used to record the turbulence produced by the passing traffic with a sampling rate of 10 Hz. All three flow components were measured simultaneously. The USA were located at several positions on the roadside next to the traffic lane to gain a horizontal and a vertical section of the flow. The passing traffic was recorded on video tapes. Different categories of traffic have been made up to sort the vehicles according to velocity and shape. The velocity has also been gained from the video tape. As it's a straight and wide street most of the traffic moved about 50 km/h and faster. The USA and the video were synchronised before each measurement.

2.2 Modell measurements

2.2.1 Turbulence generator shapes

The shapes of the four different turbulence generators used are shown in Fig. 2.1. They consist of

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metal plates. Cases FK and FG are plane, case RD is bend like a half circle. Case GB is bend with a nose in the lower part of the generator. All cross sectional areas are equal except case FK. Its size is reduced due to its increased drag coefficient compared to real traffic. This technique was used in former experiments (Kastner-Klein 1999). The generators are sticked to a needle of hardened steel, which is fixed to the drive belt. Therefore the air can flow underneath the generator like in case of a real vehicle. Former techniques used ground bounded generators, thus all the flow was displaced upwards and sidewards. The geometric modell scale is 1:200, according to trucks of an average height of 3.2 m and width of 2.4 m.

2.2.2 Measurement setup

An LDA measurement system has been used for the sampling of all three flow components independendly. A sampling rate between 1000 and 2000 Hz has been reached.

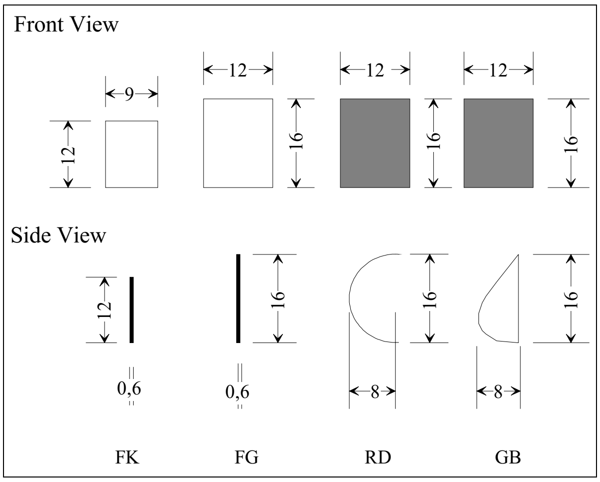

Figure 2.1 Used generator shapes

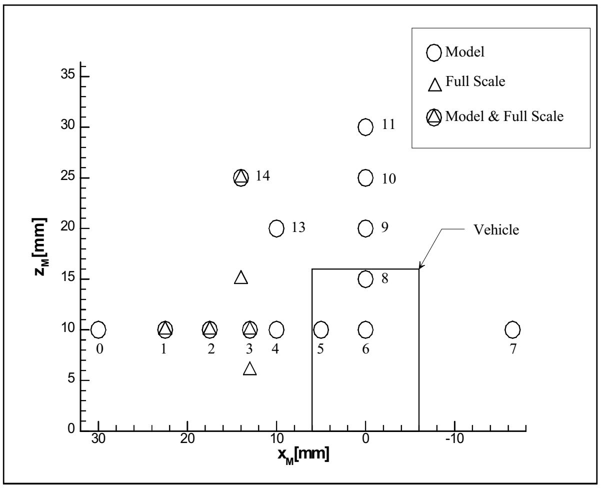

Figure 2.2 Measurement positions

The velocity of the turbulence generators has been measured by using a photo sensor on the shaft of the stiring motor.

Fig. 2.2 shows the cross section of the measurement area. The generator is moving perpendicular to the plane. Circles represent measurement positions in the model case. Triangles indicate the points of full scale measurements scaled to model scale. The y-axis points in the direction of movement, the x-axis is directed perpendicular and the z-axis indicates the height. The origin is in the middle of the lane. x and z are scaled by the height of the generator. The whole measurement took place without any mean flow inside the small windtunnel of the Meteorological Institute of the University of Hamburg.

To ensure the Reynolds number independence of the generators the flow has been measured with different generator velocities. It turned out that the flow is already Reynolds number independent for a velocity of 2 m/s. For all following measurements the generator velocity was held constant at about 4 m/s. This corresponds to a generator frequency of 3 Hz. For each data point one time series with a length of 120s (360 events) has been recorded.

3. Wavelet Analysis of Instationary Turbulence Events

The measured time series represents a strong instationary flow. Turbulence is generated by passing traffic and turbulence generators, respectively. The turbulence decays until the next traffic event. The analysis of the integral time scale for traffic events yielded no significant difference between traffic events and periods without traffic (Frantz 2000). Obviously this approach is not suitable to analyse instationary flow phenomena.Therefore this study concentrates on the characteristics of the produced turbulence spectra. To compare turbulence spectra of real traffic to those of modelled vehicles it is necessary to focus on the spectra immediately after the event in the wake of the vehicle. Information about the development of turbulence with time has to be obtained. Wavelet analysis (WA) is a powerful tool for reaching this aim. Compared to a conventional windowed fourier analysis the WA enables the analysis of events with unknown length and frequency. For this study the so called Morlet function was used. A detailed description of the methods used for this study can be found in Torrence et al. (1998). For each time step the WA provides a power spectrum which is limited in frequency only by the length of the whole dataset (not the window length like in a windowed fourier analysis) and the sampling rate.

To underline the influence and significance of single turbulence events it is possible to normalize the gained spectra by the global spectrum which is the average spectrum of the whole time series.

The next step is to average these spectra in time for a single event. For this reason the time has been normalized by the vehicle velocity and height. A time interval of 1 then represents the time the vehicle needs to move forward about its height. For this examination an average time of 4 was chosen to focus on the turbulence just behind the vehicle. The last step is to perform an ensemble average for all traffic events. In the model case the number of ensemble members is 100. In full scale the number differs for each measurement point due to different traffic situations. A number of 50 events was found to gain smooth spectra independent of the number of ensemble members.

For comparing model scale and full scale spectra both are plotted with respect to the normalized frequency. Again the vehicle velocity and height have been used for the normalization. In addition to Plate's design rule the spectral similarity and its spatial change should be demanded for correct physical modelling of TPT.

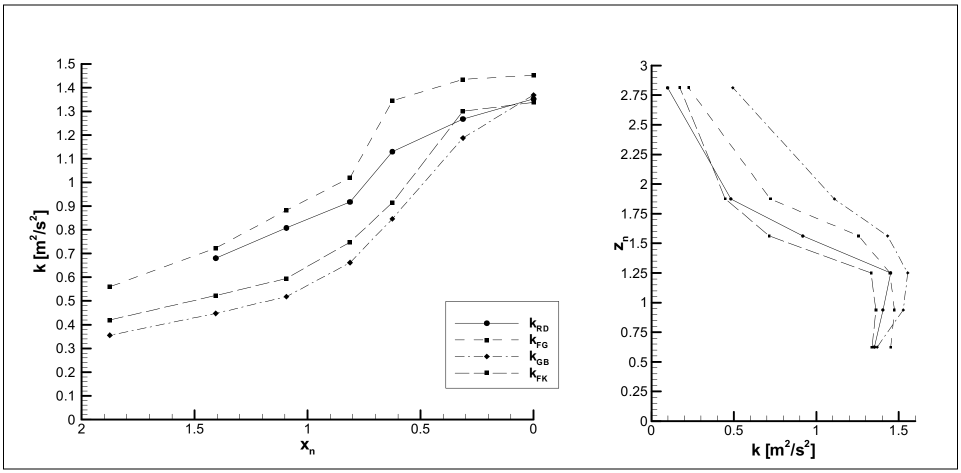

Figure 4.1 Profiles of TKE for different generator shapes

4. Results

4.1 Full scale spectra for different traffic categories

Analysing the full scale data it turned out that only trucks and commercial vehicles with a velocity equal and greater than 50 km/h leave a significant turbulence signal at measurement point 3 (see Fig 2.2). Due to the lack of vehicles with lower velocity it has not been possible to analyse these categories accurate. Therefore the further analysis only focuses on trucks and turbulence generators of a model scale of 1:200.

4.2 Spatial behaviour of modelled TPT

In Fig. 4.1 profiles of the turbulent kinetic energy (TKE) of the whole time series are shown for the model case. The four different shapes show obvious differences. Case FG dominates in the horizontal profile while the influence of plate GB on the TKE distribution is very small. The vertical profile shows the great influence of case GB and a smaller of FG. RD and FK are even smaller and show similar behaviour. It is an interesting fact that the maximal TKE is reached at the top of the turbulence generators.

4.3 Comparison of turbulence spectra

The following discussion of spectra of TPT is limited to three measurement points and the lateral flow component only. Fig. 4.2 shows the normalized wavelet spectra of the four used tubulence generator shapes and the full scale measurements plotted against the normalized frequency for measurement position 3 (see Fig. 2.2). Differences between the shapes and the full scale case are obvious. While the amplitude of cases FK, GB and RD are of the same order as in full scale, the frequency of rising amplitude is larger in all modell cases than in full scale. This means that the size of the largest eddies produced by the traffic is too small in the model. The amount of produced turbulence is too large in case FG. For the other measurement points a similar undistinctive spectral behaviour is found. Which leads to the presumption that a shape like case GB fits best with the full scale data.

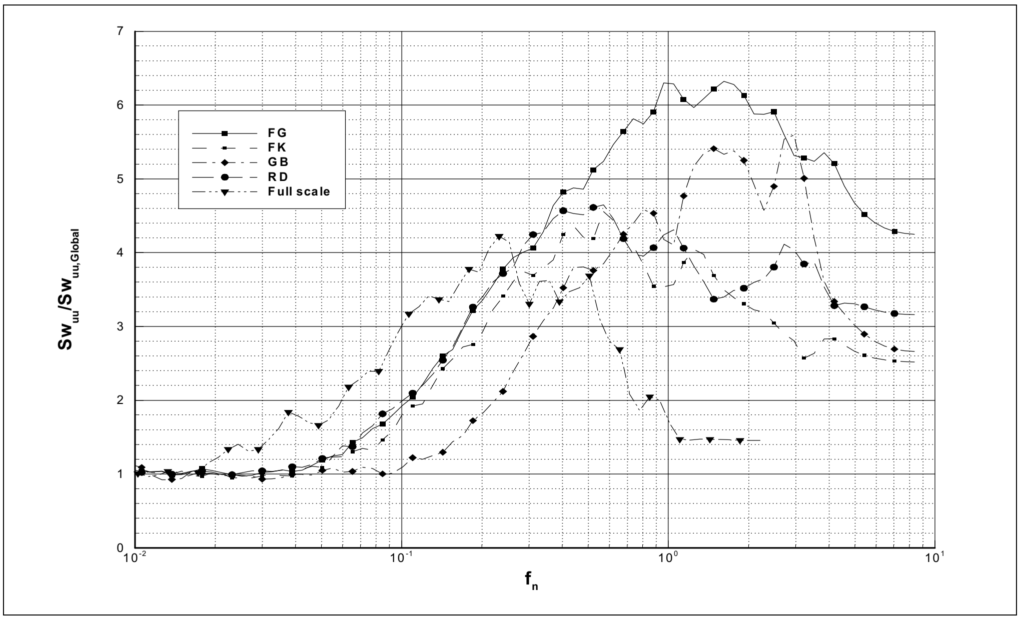

Figure 4.2 Normalized wavelet spectra for lateral velocity at point 3

5. Conclusion

A comparison between different by shape turbulence generators for physical modelling TPT has shown the need of developing the model further. The results of the present study do not allow definitive conclusions to be drawn. Another model shape is presently testet and a tracer gas experiment will underline the influence of the model shape.

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