

VALIDATION DATA FOR ODOUR DISPERSION MODELS

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INTRODUCTION

The increasing urbanisation process and requests for quality of life from residents force the competent authorities to take care of inconveniences caused by neighbouring odour sources. These sources consist of gas released from industrial or agricultural activities. The smell of these gases may be a nuisance to inhabited areas. Odour dispersion problems are more complex than classical pollutant dispersion problems. The human nose is a very sensitive organ which when exposed to odorous gases recognises already short events that last only for seconds. Odour dispersion models should be able to take this into account and to predict not only mean concentrations but also concentration fluctuations. Some models for this purpose, usually of Lagrangian type, have been developed in the past. Due to a lack of adequate data the validation of these models is still not satisfactory. Field campaigns are expensive and the unsteadiness of the meteorological conditions makes the results non representative of the statistical characteristics of the phenomena. Physical modelling in wind tunnel offers an alternative and enables the study of dispersion of a tracer under steady meteorological conditions. Additionally, some geometrical aspects, like the topology and the shape of the buildings can easily be taken into account.

In the frame of the programme "BW PLUS– Lebensgrundlage Umwelt und ihre Sicherung"* financed by the German state of Baden-Wuerttemberg, a project was undertaken in which several project groups from universities and private consultancies worked together. Field measurements were carried out around a real pig barn located in nearly flat terrain. The Meteorological Institute of Hamburg University contributed to the project by:

- Replicating the field experiments in a boundary layer wind tunnel, suitable to validate the physical modelling of the phenomena (description of field measurements in *Rühling A and Bächlin W.*, 2001; the agreement between field and wind tunnel results are presented in *Aubrun et al.*, 2001),
- Generating a solid data set in order to validate odour dispersion models. The data set covers the influence of several parameters like the topology, the wind direction, the velocity ratio between the wind and the exhaust jet and the location of the exhaust source. The signal processing applied to the measurements supplied some converged statistical results related to the unsteady characteristics of the odour dispersion i.e., the intermittency, the percentiles and the persistence. The scattering in statistical results due to shorter averaging times was also assessed.

This complete data set will be available on the website of Hamburg University.

EXPERIMENTAL SET-UP OF THE PHYSICAL MODEL

A model of the pig barn was built to a scale of 1:400. The character of local surroundings were varied with one test case respecting the topology and the major vegetation of the surroundings and the other considering only flat terrain. The two ventilation chimneys of the pig barn were designed to model the forced plume of exhaust odorant gas that was emitted from that building. The exact location of one of the two stacks was the origin of the coordinate system (as in field measurements).

* The financial support from the "Forschungsprogramm BW PLUS – Lebensgrundlage Umwelt und ihre Sicherung" is gratefully acknowledged.

The “Blasius” boundary layer wind tunnel of the Meteorological Institute of Hamburg University (figure 1) is an open circuit type with a 7.5 m long boundary layer development section. Some spires are placed at the entrance of this section. The design of these spires, as well as the size and distribution of the roughness elements (Lego® pieces) fixed to the floor control the properties of the induced BL. The test section is 1.5 m wide, 1 m high and 4 m long. An adjustable ceiling covers the entire tunnel in order to compensate the longitudinal pressure gradient.

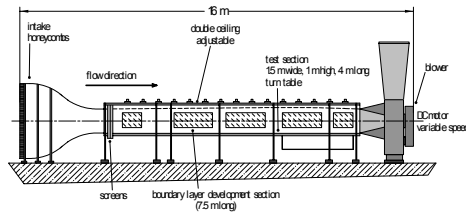


Figure 1. The “Blasius” boundary layer wind tunnel of Hamburg University.



Figure 2. The model with topology

A reference velocity was measured with a Prandtl tube. The measurement was performed at a height of 25 mm (or 10 m full scale) above ground, which corresponded to the location of the meteorological mast during field measurements.

The aerodynamic properties of the wind profile were measured with a 2D fibre-optic Laser-Doppler-Anemometer (FVA-LDA, Dantec®) with 50 mm focal distance.

Instantaneous concentration measurements were carried out with a fast Flow-Ionisation-Detector (FID, Cambustion®). The frequency response was up to 130 Hz (0.33 Hz full scale, which corresponds to the breath frequency of humans).

The background concentration level of the flow was recorded with a slow FID and removed from instantaneous measurements of the fast FID.

The hydrocarbon used in the experiments as tracer gas was ethane.

THE BOUNDARY LAYER

The boundary layer modelled with a scale ratio of 1:400 in the wind tunnel must reproduce the properties of a real neutral atmospheric BL. The *German guideline VDI 3783/12 (2000)* provides the following requirements. For grasslands or farmlands, which belong to the “moderately rough” class, the power law exponent should be between $0.12 < \alpha < 0.18$ and the roughness length between $5\text{mm} < z_0 < 100\text{mm}$. Longitudinal turbulence intensity should be between $0.07 < I_u < 0.12$ at 150 m height full scale and between $0.14 < I_u < 0.22$ at 10 m height full scale.

Figure 3a presents the time-mean velocity and the turbulence intensity profiles obtained in the wind tunnel. The boundary layer had a power law coefficient α of 0.16 and the turbulence intensity distribution was in the authorised band. Figure 3b shows that the time-mean velocity follows a perfect logarithmic profile in the lower 60 m of the BL. Knowing that exits of the

chimneys were 8.5 m above ground and that the velocity of the exhaust jet was less than twice the wind speed, one can assume that the plume dispersion process will take place in this lower layer. The extrapolation of the logarithmic law towards the zero-value of velocity gave the associated roughness length $z_0 = 65\text{mm}$. Figure 3c shows that the vertical distribution of the vertical momentum flux is constant up to 50 m full scale (constant flux layer), which confirms the absence of vertical shear effect in this range.

The spectral content of the flow is essential since it drives the dispersion process. The spectra measured in the wind tunnel at 10, 20 and 40 m full scale above ground were in full agreement with the empirical law published by *Kaimal and Finnigan* (1994) (figure 4). Figure 5 presents a histogram of the instantaneous lateral deviations from the mean wind direction of the velocity measured in the same wind tunnel at 10 m height full scale. Unfortunately, the equivalent information for the field case was not available.

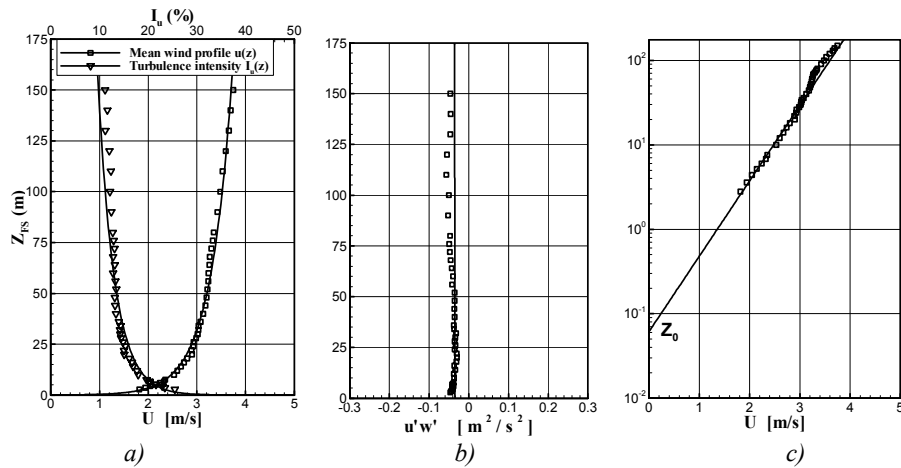


Figure 3. a) Mean velocity profile and longitudinal turbulence intensity profile in the wind tunnel, b) profile of vertical momentum flux, c) Time-mean velocity profile in a semi-logarithmic scale.

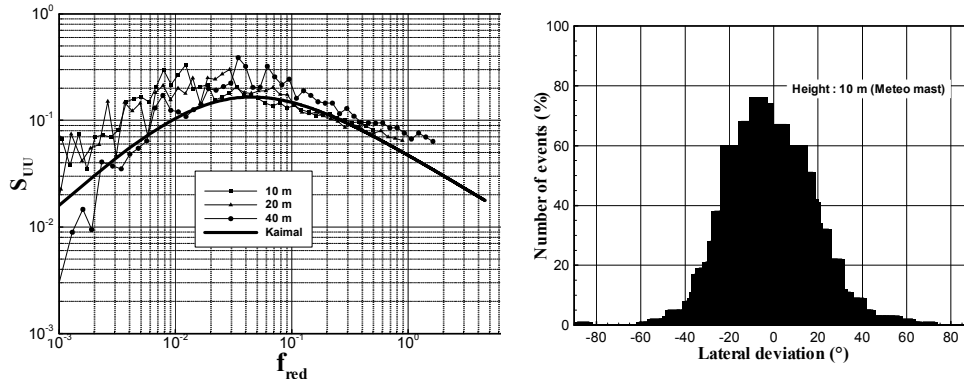


Figure 4. Spectra of kinetic energy of turbulence in the modelled boundary layer

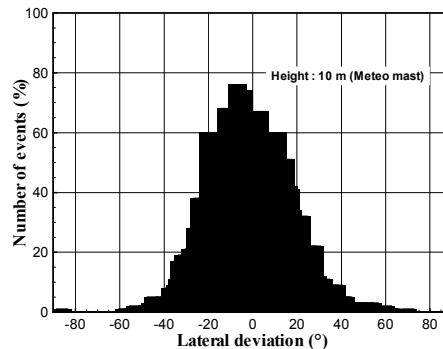


Figure 5. Lateral deviations of the wind direction measured in the wind tunnel

PARAMETRIC STUDY THE ODOUR DISPERSION

Several parameters, which influence the dispersion process, were varied. To simplify the comparison between different configurations, the concentration levels were always measured at the same grid points. All samples were taken at 1.6 m full scale above ground (the average height of human nose). The origin of the coordinate system was the main stack of the ventilation system. Long time series (33.33 hours full scale) were collected with a sampling frequency of 1.25 Hz full scale, which enables calculation of some converged statistical results about the dispersion process. Additionally, These long samples were cut into shorter ones in order to study the variability of statistical results due to shorter averaging times, as during field campaigns.

The configurations were:

- The model of the pig barn with and without topology.
- 36 different wind directions. More detailed measurements were made at 220° and 240°, wind directions encountered during the field campaigns.
- 3 different velocity ratios $I = U_e / U_w$ between the reference wind speed U_w and the vertical exhaust velocity from the ventilation stack U_e .
- 2 different stacks used separately or simultaneously.

The data processing applied on each of the measured time series was composed of:

- Long-term (33 h. full scale) mean and RMS concentrations non-dimensionalized by the source concentration, providing information about the steady shape of the plume.
- The intermittency factor (part of the total time during which the concentration is higher than a certain threshold), the persistence (main duration of the bursts of concentration) and the 30-, 50-, 70-, 90-, 95-, 98-, 99- percentiles (concentration values which are exceeded during 30, 50, 70, 90, 95, 98, 99 % of the total time), which inform on the unsteady characteristics of the plume: how often, how long and how strong the bursts of concentrations are. These values are essential for the description of odour dispersion and, are commonly used as regulatory standards. For example, in an odour dispersion model like the German ordinance “TA-Luft”, the magnitude of the odorous events are related to the 90-percentile, which is assessed by multiplying the mean concentration by a factor 10. The current results showed that a factor 4, in our particular case, was sufficient, as proposed by Rühling and Lohmeyer (1998).
- The standard deviation of each of these previous values processed on short averaging times (10, 30 and 60 min), determined according to the values processed with the long averaging time. One can see that the scatter bars, related to the variability of the results when processed on short time series, are not neglectable, especially on the border of the plume. This highlights the danger to extrapolate such short-term averaged and often scarce results, to a statistically representative value

Figures 6 and 7 provide some examples of the new database.

The repeatability of these measurements were also tested and it was found that, with an averaging time of 33 hours full scale, the maximal deviation encountered was 3.8 % for mean concentrations, 5.6 % for intermittency factors, 4.8 % for persistences and 3.7 % for 90-percentiles.

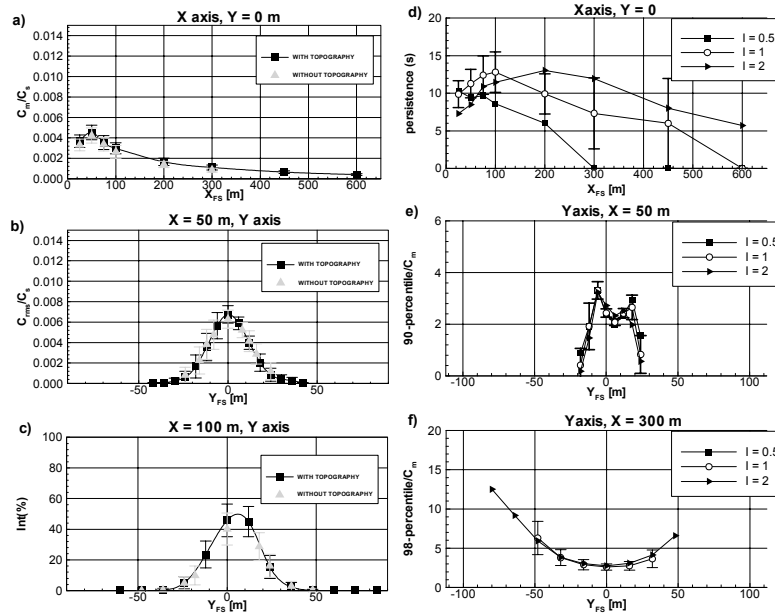


Figure 6. Examples of results supplied in the database: Influence of the topography on the mean (a) and RMS (b) concentrations and on the intermittency factor (c). Influence of the velocity ratio on the persistence (d) and the 90- (e) and 98-percentiles (f). The error bars correspond to the variability of the similar value processed on time series of 10 minutes.

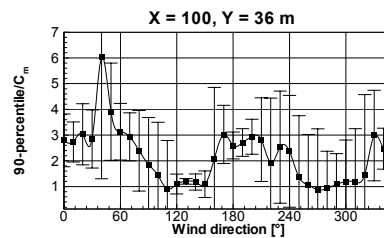


Figure 7. Examples of results supplied in the database. Influence of the wind direction on the 90-percentile. The error bars correspond to the variability of the similar value processed on time series of 10 minutes.

REFERENCES

- Aubrun S., Leitl B., Schatzmann M., 2001: Wind tunnel modelling of odour dispersion in the vicinity of a pig barn. International Workshop on Physical Modelling of Flow and Dispersion Phenomena. September 3 – 5, 2001, Hamburg, Germany
- Kaimal J.C. and Finnigan J., 1994: Atmospheric Boundary Layer Flows, Oxford University Press.
- Rühling A and Bächlin W., 2001: Bereitstellung von Validierungsdaten für Geruchsausbreitungsmodelle – Naturmessungen. Beitrag zum Statusseminar des Baden-Württemberg Programs “Lebensgrundlage Umwelt und ihre Sicherung.” (BWPLUS). 28.2 and 01.03.2001 in Forschungszentrum Karlsruhe.
- Rühling A and Lohmeyer A., 1998: FuE-Vorhaben “Modellierung des Ausbreitungsverhaltens von luftremden Schadstoffen/Gerüchen bei niedrigen Quellen im Nahbereich”
- VDI-guideline 3783 / part 12, 2000: "Physical modelling of flow and dispersion processes in the atmospheric boundary layer – Application of wind tunnels", Beuth Verlag, Berlin 2000