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Validation study of the experience Mock Urban Setting Test

B. Medjahed[1*], M. Bouzit[2]

1. Laboratory of Numerical and Experimental Modeling of Mechanical phenomena, University of Abdelhamid Ibn Badis, Faculty of Science and Technology , Mostaganem, Algeria

2. Laboratory of Applied Mechanics; University Of Science and Technology of Oran, Faculty of Mechanical Engineering, BP. 1505 El-Mnaouar, Oran, Algeria.

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L G Bousiakou
madepodim2006@yahoo.fr
+213661426640

Abstract

The study presented in this paper includes a comparison, and a statistical validation. The results that are obtained by a numerical simulation in CHENSI Code are compared with the experimental results that are taken from an experimental wind tunnel study of field experience Mock Urban Setting Test. The wind tunnel measurements within a scaled model (1:75) of that configuration were carried out at the University of Hamburg. We focus only on main wind direction (0° and -45°) which correspond to those cases selected within the COST 732 Action. The work is to exploit the experimental data obtained from the wind tunnel results of the University of Hamburg and those of the numerical simulation. The purpose of this study was to compare and statistical validation of CHENSI code. Numerical results presented in this study in the mean flow field, turbulent kinetic energy and the concentration field. To compare, objectively, the performance of the model withexperimental data, statistical indicators proposed by Chang and Hanna [1]were calculated for different measurement points. Note; however, that the model results are in a very good agreement with experimental measurements.

1. Introduction

Air pollution is an issue increasingly topical; its control requires first having effective means of forecasting can provide estimates as close as possible to reality. In the particular context of the dispersion of a passive scalar (without consideration of chemical reactions), for a point source and a continuous release. An application example is the study of the impact of an accidental release. The dispersion of pollutants in the layer of urban area is a direct result of the air turbulence: an important characteristic of turbulence is in fact the ability to transport and mix more efficiently. The COST Action 732 provided a model evaluation guidance document, [2], leading model developers through the steps of proper model validation and documentation. On the other hand, the Action also gives recommendations on model set-up for users of micro-meteorological CFD models with a comprehensive Best Practice Guideline [3]. Emphasizing the necessity of applying validation data sets, the Action will recommend and publish several data sets at its ending in 2009. One of them is the Mock Urban Setting Test, which was also extensively investigated in wind tunnel [4], and was already run by a plenty of models during the Action, including also MISKAM 5.01 simulations of Goricsán et al [5]. Summarized results were presented, e.g. by Franke et al [6] and Olesen et al [7]. This article discusses the dispersion of a passive scalar in simplified urban environments. The main objective is the detailed study of the flow and dispersion of pollutants in a city of modeling the mean flow, turbulence and concentration. Numerical simulations were undertaken using a CFD (Computational Fluid Dynamics) model and the code used in our case the calculation is CHENSI code [8, 9]. The simulation shows the case of experimental wind tunnel study of field experience MUST (Mock Urban Setting Test).

2. Simulation model

In the present work of the Mock Urban Setting Test (MUST), a total of 120 standard size shipping buildings was set up in a nearly regular array consisting of 12 rows of 10 buildings, covering an area of around 100 by 100 m, and each building has the same dimensions (L=12.2 m, l=2.42 m and H= 2.54 m) as the MUST experiment shipping containers [10, 11].

3. CHENSI Code

The objective of this calculation code is to simulate the atmospheric out-flows in the layer limits urban surface. One considers that all obstacles of the layer limit urban are constituted possibly of parallelepipeds rectangles, what drives to consider a Cartesian three-dimensional mesh only, non homogeneous, that is - to say of which the size of the stitches is not constant in each of the three directions.

In this article of presentation, we expose the choices that we did at the time of the development of this code succinctly:

- The model of turbulence adopted: the model of the first order to two equations [12].

- The used numeric model: the method of the volumes finishes with the disposition baffled of the unknowns, also named MAC method (Marker and Cell) [13].

- The coupling speed - pressure solved by the artificial compression method developed by Viecelli [14].

- The conditioning or, in particular, the conditioning in the presence of an inspired partition of the partition law developed by Launder & Spalding [15].

- The discretisation of the different terms and, in particular, the discretisation of the term of advection by the Hybrid diagram of Spalding.

4. Statistical Methods Used In Evaluation

The performance measures recommended by (Chang and Hanna [1]), also used in other model evaluations the following statistical performance measures, they include the fractional bias (FB), the normalized mean square error (NMSE) and the fraction of predictions within a factor of two of the observations (FAC2) given inthe table, where C_o, Cp and C are respectively observations, model predictions and the average over the dataset.

Table 1: Statistical tools of assessment of a numeric model.

Name	Definition	Model perfects	Acceptable model
FB	$\mathrm{FB} = 2 \times \left(\dfrac{\overline{C_0} - \overline{C_p}}{\overline{C_0} + \overline{C_p}} \right)$	0	-0.3<FB<0.3
NMSE	$\mathrm{NMSE} = \dfrac{\overline{\left(C_0 - C_p\right)^2}}{\overline{C_0} \times \overline{C_p}}$	0	NMSE<4
FAC2	$\mathrm{FAC2} = \dfrac{C_p}{C_0}$	1	FAC2>0.5

5. Simulation And Analysis

In figure 1 present the vertical profiles of wind and turbulence components are measured locations ('towers') shown. The wind blows from the left.

Top: the 0degree case. The points can be classified into three groups, so Tower 1 represents a 'Narrow Street', Tower 20 a 'Crossing', and Tower 21 a 'Wide Street'.

Bottom: the -45degree case. Tower 1 represents a 'Narrow Street', Tower 11 a 'Crossing', and Tower 6 a 'Wide Street'.

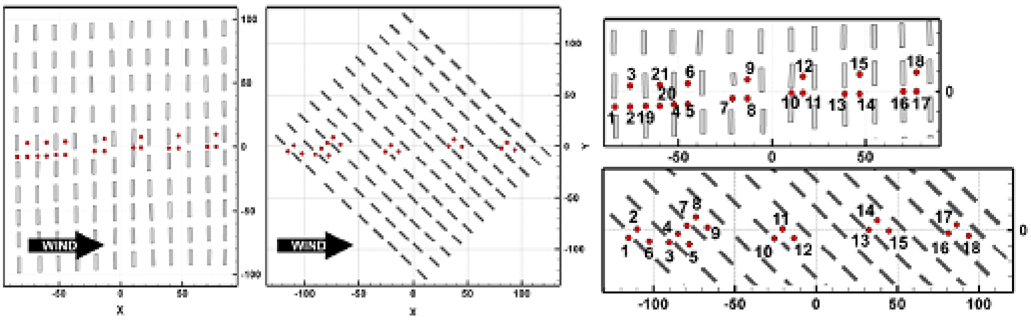

Figure 1: Layout of measurements and the buildings for the flow cases.

5.1 Plots and metrics for the 0 degree flow case

The results underlying the figure should be further examined. In the parameters ($U/U_{ref,}$ W/W_{ref} and TKE/U_{ref}^2) Figure 3: shows the same data as Figure 2, but split into three classes of data: "Wide streets", "Crossings", "Narrow Streets". The model appears much less successful in performance of u for Narrow Streets than for the other locations. Close to the ground the modelled (U) comes close to zero, whereas this is not the case for the measured values. The performance measures recommended by Chang and Hanna are fractional bias (FB), normalized mean square error, (NMSE), correlation coefficient (R^2) and fraction of predictions within a factor of two of the observations (FAC2), they are presented in Table 2 for the velocity profile of (U, W) and turbulent kinetic energy (TKE). In figure 2 shows an example, referring to the 0 degree flow case. For one model - in this case CHENSI - information for all towers is summarized. There are 21 towers, with altogether 566 data pairs (Observed, measured) for the parameters ($U/U_{ref,}$ $W/W_{ref}$and TKE/U_{ref}^2). We have computed the corresponding statistical measures (Table 2). As stressed before, CHENSI gives good agreement in R^2 and FAC2, with satisfactory results for vertical with the parameters (U/U_{ref} and TKE/U_{ref}^2) of respectively (FAC2=79% and FAC2=52%) for all towers (21 towers). For NMSE the model gives globally satisfactory results, so much on the speed of wind (with a NMSE = 0.01) that on the turbulent kinetic energy (with a NMSE = 0.99). CHENSI presents a top of the party took fractional (FB=1.09, 0.72> 0.3) with the parameter of speed (U) accept (FB=0.01<0.3).

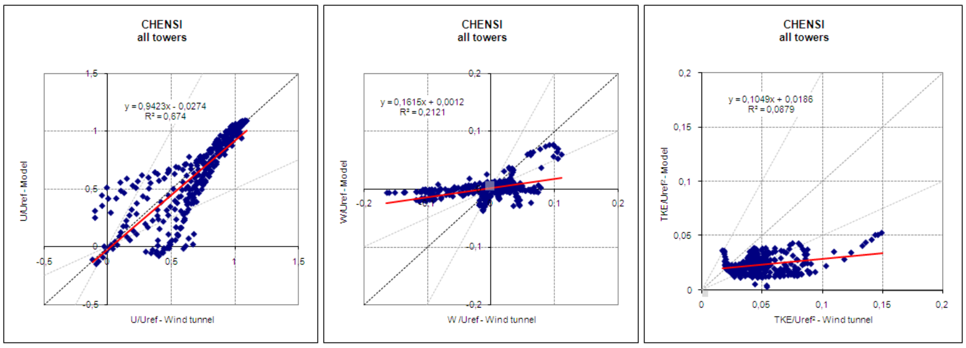

Figure 2: Flow, 0 degree case. Scatter plots for velocity components U/Uref (left), W/U_{ref} (center) and TKE/U_{ref}^2 (right) for one particular model (CHENSI). The figure is from SavedMetrics_UVWtke_45degree_5Dec07.xls with a filter applied (as explained by Olesen and Berkowicz [7]).

Table 2: Statistical measures for the parameters (U/Uref, W/Uref and TKE/Uref2), for all towers simulated (21 towers), 0 degree case.

0 degre	All towers			
	R^2	FB	NMSE	FAC2
U/U_{ref}	0.67	0.01	0.01	0.79
W/U_{ref}	0.21	1.09	4.31	0.303
TKE/U^2_{ref}	0.08	0.72	0.99	0.52

In figure 3 shows an example, referring to the 0 degree flow case. One model - in this case CHENSI - information, but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 20), "Wide streets" (Tower 21), cf. Figure 1, with altogether 13 data pairs (Observed, measured) for the parameters (U/U_{ref}, $W/U_{ref}$and TKE/U_{ref}^2). We have computed the corresponding statistical measures (Table 3). As stressed before, CHENSI gives good agreement, with better results for vertical tower T01, T20 and T21 with the parameters (U/U_{ref}, W/U_{ref} and TKE/U_{ref}^2) of respectively (FAC2=100%, FAC2=91.7% and FAC2=91.7%) for tower 01 "Narrow Streets", (FAC2=100%, FAC2=58% and FAC2=29%) for tower 20 " Crossings " and (FAC2=72%, FAC2=18% and FAC2=72%) for tower 21 " Wide streets ". In table 3, NMSE (normalized mean square error) CHENSI gives globally very satisfactory results, so much on the speed of wind (with a NMSE = 0.002) that of the turbulent kinetic energy (with a NMSE = 0.24), notably on the measures far from the obstacles or above the canopy. In the prisfractionnaire, the results exhibit a small over prediction of the observations with the parameter of speed U (|FB|<0.3), but a high over prediction for the parameters of speed (W) and turbulent kinetic energy (|FB|>0.3).

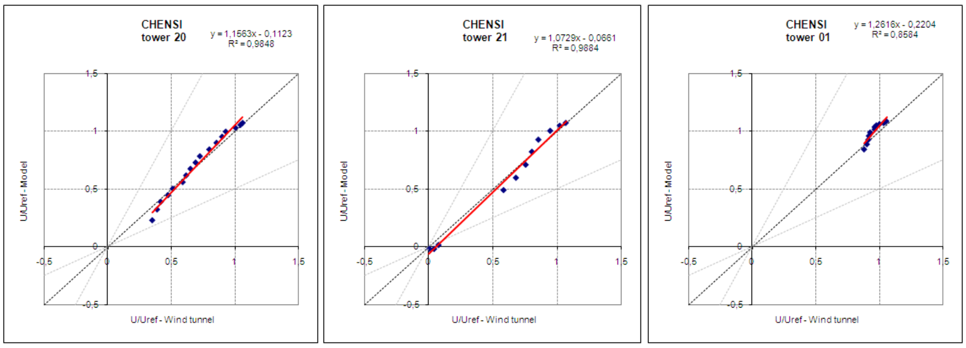

Figure 3: Flow, 0 degree case. Same data as Figure 5.2 for the parameters (U/Uref, W/U_{ref} and TKE/U_{ref}^2), but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 20), "Wide streets" (Tower 21), cf. Figure 1. The figure is from SavedMetrics_UWtke_ UVWtke_0degree_5Dec07.xls with a filter applied (as explained by Olesen and Berkowicz [7]).

Table 3: Statistical measures for the parameters (U/Uref, W/Uref and TKE/U_{ref}^2), but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 20), "Wide streets" (Tower 21), cf. Figure 1, 0 degree case.

0 degre	Tower 1 (Narrow Street)				Tower 20 (Crossing)				Tower 21 (Wide Street)			
	R^2	FB	NMSE	FAC2	R^2	FB	NMSE	FAC2	R^2	FB	NMSE	FAC2
U/U_{ref}	0.85	-0.03	0.002	1	0.98	0.001	0.004	1	0.98	0.02	0.007	0.72
W/U_{ref}	00	0.30	0.16	0.917	0.39	0.74	1.08	0.58	0.58	1.19	4.81	0.18
TKE/U^2_{ref}	0.58	-0.42	0.24	0.917	0.20	0.72	0.75	0.29	0.17	0.65	0.63	0.72

5.2 Plots and metrics for the -45 degree flow case

The results underlying the figure should be further examined.In the parameters (U/U_{ref}, W/U_{ref} and TKE/U_{ref}^2) Figure 5: shows the same data as Figure 4, but split into three classes of data: "Wide streets", "Crossings", "Narrow Streets". The model appears much less successful in performance of u for Narrow Streets than for the other locations. Close to the ground the modelled (U/U_{ref}) comes close to zero, whereas this is not the case for the measured values.
The vertical velocity (W/U_{ref}) and turbulent kinetic energy (TKE/U_{ref}^2), figure 4 shows that the range of modelled values is smaller than the range of measured values. In particular, predicted downward velocities are numerically much smaller than measured. The available material permits one to determine whether this behavior of w is peculiar to the model examined or whether it is a common feature for many models.
In figure 4 shows an example, referring to the - 45 degree flow case. For one model - in this case CHENSI - information for all towers is summarized. There are 18 towers, with altogether 497 data pairs (Observed, measured) for the parameters (U/U_{ref}, $W/U_{ref}$and TKE/U_{ref}^2). We have computed the corresponding statistical measures (Table 4). In total, similar to the mean velocities and turbulent kinetic energy results, the model predicts the observations well (FAC2=54% to 66%), higher than the limit (50%). Also, there is a small data (NMSE=0.47 to 3.38 < 4) and also presents a high for the fractional bias (FB=0.54 to 0.89> 0.3). It fulfills obvious for the total measurements of this computer case the quality acceptance criteria well.

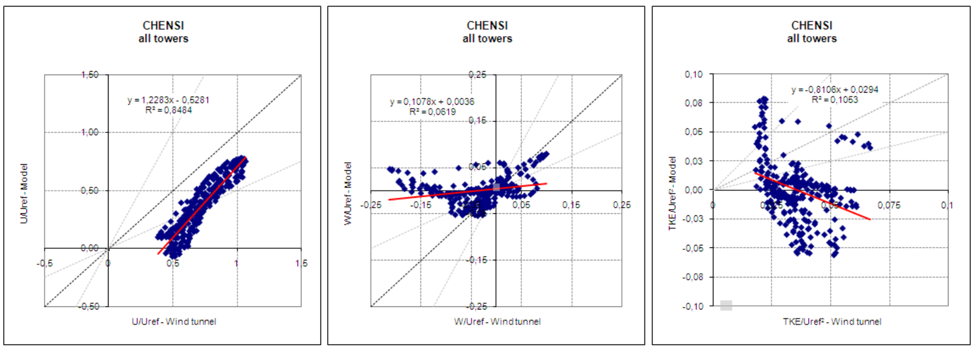

Figure 4: Flow, -45 degree case. Scatter plots for velocity components U/U_{ref} (left), W/U_{ref}(center) and TKE/U_{ref}^2 (right) for one particular model (CHENSI). The figure is from SavedMetrics_UVWtke_45degree_5Dec07.xls with a filter applied (as explained by Olesen and Berkowicz, [7]).

Table 4: Statistical measures for the parameters (U/Uref, W/Wref and TKE/U_{ref}^2) for all towers simulated (18 towers), -45 degree case.

-45 degre	All towers			
	R^2	FB	NMSE	FAC2
U/U_{ref}	0.84	0.63	0.47	0.54
W/U_{ref}	0.06	0.89	3.38	0.37
TKE/U^2_{ref}	0.105	0.54	0.51	0.66

In figure 5 shows an example, referring to the - 45 degree flow case. One model - in this case CHENSI - information, but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 11), "Wide streets" (Tower 6), cf. Figure 1, with altogether 16 data pairs (Observed, measured) for the parameters (U/U_{ref}, $W/U_{ref}$and TKE/U_{ref}^2). We have computed the corresponding statistical measures (Table 5). The computational case shows good model performance into 3 classes of data: (Narrow Streets, Crossings, Wide streets) for the statistical metrics. As stressed before, CHENSI gives good agreement in a high correlation coefficient (R^2=93 >50%) and especially it also presents a high FAC2 for the tower 1 "Narrow Streets" (100%), tower 11 "Crossings" (100%) and the tower 6 "Wide streets" (75%), higher than the limit (50%). Also the present model exhibits small data for the tower 1 and the tower 6 according to the NMSE. Concerning the FB, the computational results exhibit a small over prediction of the observations for the narrow Streets (|FB|=0.19 <0.3), but a rather high over prediction for the crossings (|FB|=0.58 to 1.67 >0.3) and wide streets (|FB|=0.37 to 0.62 >0.3).

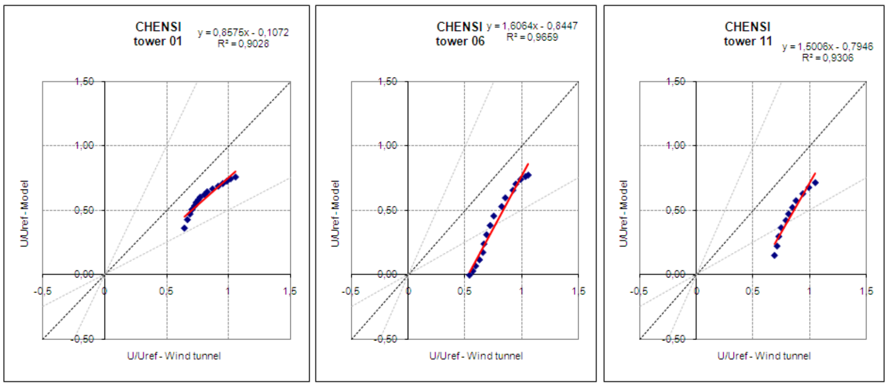

Figure 5: Flow, -45 degree case. Same data as Figure 4 for the parameters (U/U_{ref}, W/U_{ref} and TKE/Ur_{ef}^2), but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 11), "Wide streets" (Tower 6), cf. Figure 1. The figure is from SavedMetrics_UWtke_ UVWtke_0degree_5Dec07.xls with a filter applied (as explained by Olesen and Berkowicz [7]).

Table 5: Statistical measures for the parameters (U/Uref, W/Wref and TKE/U_{ref}^2), but split into 3 classes of data: "Narrow Streets" (Tower 1), "Crossings" (Tower 11), "Wide streets" (Tower 6), cf. Figure 1, -45 degree case.

-45degre	Tower 1 (Narrow Street)				Tower 11 (Crossing)				Tower 06 (Wide Street)			
	R^2	FB	NMSE	FAC2	R^2	FB	NMSE	FAC2	R^2	FB	NMSE	FAC2
U/U_{ref}	0.90	0.30	1.06	1	0.93	0.58	0.38	0.63	0.96	0.62	0.47	0.56
W/U_{ref}	0.92	0.19	0.059	1	0.81	1.67	13.1	0.09	0.79	-0.5	0.55	0.56
TKE/U^2_{ref}	0.52	-0.21	0.05	1	0.49	0.30	0.106	1	0.08	0.37	0.25	0.75

5.3 Concentration field at -45°

Normalized concentrations shown in the following are defined as:

$$C^* = C\left(\frac{U_{ref}\,H^2}{Q}\right) \quad (1)$$

With C: measured or simulated concentration, U_{ref}: inlet velocity taken at container height H and Q: source strength.

Figure 6 shows a rather typical scatter plot of modelled versus measured concentrations for all measuring points (271). Despite the obvious male-predictions for some high concentrations (close to the source), many points with low concentration values where the model fits fairly well (further away from the source). The observations are below the threshold value, and such values are not so difficult to predict. For dispersion results for the MUST case with the mean wind at -45° angle to the obstacle orientation suggested that the plume direction was the same for the particles at heights below and above the obstacle height. The observation showed a significant shear. It will be interesting to see the results of your comparison of the model simulations to the observations [9, 16].We calculated in the table 6, the statistical sizes presented in the figure 6. In total, similar to the mean concentration results, the model predicts the observations very well (R^2=58%) and (FAC2=60%). Also, there is a small scatter in the data (NMSE =0.79) and a small over prediction (FB=0.047). It is obvious that the metrics for the total measurements of this computer case fulfill the quality acceptance criteria well. As a conclusion for the concentration standard deviation, the present model shows, in general, a very good behavior, especially near the source where the travel time effect is stronger.

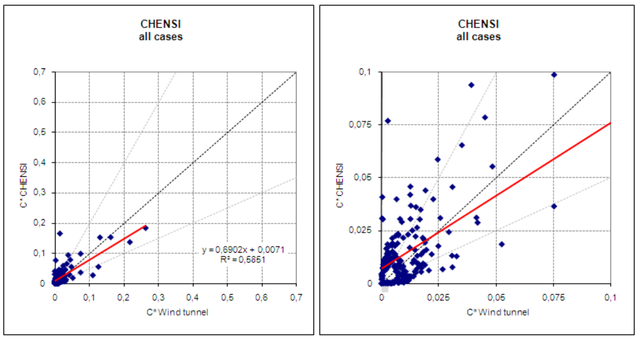

Figure 6: Scatter plots of concentrations for the CHENSI code. The figure is from Saved Metrics_UVWtke_45degree_5Dec07.xls with a filter applied (as explained by Olesen and Berkowicz [7]).

Table 6: Statistical measures of concentration for the 26 towers simulated.

-45°	All towers			
	R^2	FB	NMSE	FAC2
C*	0.58	0.047	0.79	0.60

6. Conclusions

According to the results exposed on this paper, the agreement deduced - between the experimental profile and that obtained numerically in the CHENSI code environment is acceptable. The current study was designed to study the wind flow, the dispersion of a passive scalar in simplified urban and validate the results obtained by numerical simulation using the CHENSI code by comparing the results of the experience MUST (Mock Urban Setting Test) on the one hand and the results of wind tunnel simulation miniature conducted at the University of Hamburg. Two angles of incidence of the wind were taken into account to achieve the simulations 0 ° and -45 °. It can be concluded that the angle of incidence is an important factor in the dispersion of pollutants, since the change will influence the speed and the rate of turbulence and consequently on the dispersion. The flow at an angle to minimize the recirculation zone, which moves to the lower sides of incidence of 45°, had resulted. Remarkable, since this orientation leads to an increased movement, thus the state of turbulence and a portion of the other obstacles promote transport and dispersion of turbulent kinetic energy. The simulation of these results is confirmed by experimental measurements (Statistical Validation). Using the method of statistical calculation to better appreciate the results, it has been proven good quality of the latter.

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