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Introductory Paper

Setting the scene: CFD and symposium overview

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Abstract. The present situation of CWE(Computational Wind Engineering) and the papers presented to the CWE 2000 Symposium are reviewed from the following viewpoints; 1) topics treated, 2) utilization of commercial code (software), 3) incompleteness of CWE, 4) remaining research subjects, 5) prediction accuracy, 6) new fields of CWE application, etc. Firstly, new tendencies within CWE applications are indicated. Next, the over-attention being given to the application field and the lack of attention to fundamental problems, including prediction error analysis, are pointed out. Lastly, the future trends of CFD (Computational Fluid Dynamics) applications to wind engineering design are discussed.

1. Introduction

Over 60 papers were presented to the CWE 2000 Symposium. Many stimulating topics are treated in these papers. CWE is growing steadily. The application of CFD has spread throughout the field of wind engineering. On the other hand, we should also continue the efforts to resolve the remaining fundamental areas of CFD that are peculiar to wind engineering, in order to ensure the further development of CWE. An overview of the papers, together with some comments are presented below.

2. Review of topics treated and indication of new tendencies

2.1. Classification of topics treated

Various applications of CFD to wind engineering problems are presented in this Symposium. For example wind forces, oscillation, dispersion, ventilation, atmospheric boundary layer, regional climate etc. It is clear that CWE has become very familiar as an analysis tool for engineers and researchers belonging to the field of wind engineering.

The applications presented in this Symposium can be classified under the following categories: (1) subject treated, (2) turbulence model used, (3) flow field analyzed, (4) utilization of commercial code (commercial software).

- **Category 1 : Subject treated**

a. flow structure/features	: 21 papers
b. wind force	: 10 papers
c. dispersion	: 12 papers
d. fluid-structure interaction	: 11 papers

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- **Category 2 : Turbulence model used**

a.	no turbulence model	: 13 papers
b.	LES (Large Eddy Simulation)	: 16 papers
c.	standard k-ε model	: 16 papers
d.	RNG k-ε model	: 10 papers
e.	other revised k-ε models (LK, MMK, Chen models etc.)	: 14 papers
f.	DSM/ASM	: 10 papers

- **Category 3 : Flowfield analyzed**

a.	circular cylinder	: 4 papers
b.	square/rectangular cylinder	: 10 papers
c.	cube	: 3 papers
d.	long-span bridge	: 9 papers
e.	wall/fence	: 4 papers
f.	vehicle	: 2 papers
g.	wind turbine	: 2 papers
h.	buildings in town/city	: 7 papers
i.	hill	: 3 papers
j.	atmospheric/turbulent boundary layer	: 4 papers
... etc.		

- **Category 4 : Utilization of commercial code** : 27 papers

Several new tendencies can be found through the classifications denoted above. Some of them are discussed below in terms of the following points: (1) subject treated, (2) turbulence model used.

2.2. New tendencies in subjects being treated

As the analysis of flow structure is most fundamental in CWE, papers related to this subject are very popular. However, two new tendencies can be pointed out in the application subjects at the CWE 2000 Symposium. First is an increase in the analysis of contaminant dispersion processes in the field of environment engineering. Second is an increase in the analysis of fluid-structure interaction phenomena in the field of structural engineering. These two topics are becoming the most popular of all the applications of CWE, since these two problems are the most important and difficult research subjects for each field, and also suitable targets to be treated by CFD.

2.3. Review of turbulence model used

In the past, great efforts have been made to develop new turbulence models and revise classical turbulence models for CWE applications. The development of revised k-ε models, such as the LK (Launder-Kato) model, the MMK (Murakami-Mochida-Kondo) model, the Kawamoto model, etc., and the appearance of dynamic LES were particularly epoch-making in CWE applications. However, little effort to revise existing models or develop new ones can be found in this Symposium. I am afraid that the low importance given to the revision of existing turbulence models may slow down the growth of CWE. It should be noted that none of the existing models can be applied to the various types of flow field treated in CWE with an overall high prediction accuracy. Efforts to revise and develop turbulence models should be continued as before to ensure the further development of CWE.

3. Spread of utilization of commercial code and its effect on CWE engineers

Various commercial codes have been used in a number of papers. These days, various convenient and user-friendly commercial codes have been developed, in which many of the more tedious tasks required for CFD simulations, e.g., grid generation etc., have become automatic. Almost any type of simulation related to wind engineering becomes possible now, with the aid of commercial codes. They have contributed greatly to the development of CWE.

However, we should be careful about the performance of commercial codes, since their prediction accuracy is sometimes insufficient. The primary importance of these codes is usually their ability to carry out computations successfully without calculation instability. As the designers of commercial codes take particular care about the numerical stability in computations, the performance of the scheme for reducing numerical viscosity is sometimes seen as of secondary importance in some codes. In many codes, not only the commercial ones but also the home-made ones, an amount of numerical viscosity is intentionally or unintentionally included in the algorithm because numerical viscosity is very effective to stabilize the computation. Such numerical viscosity often gives significant errors in the case of LES computation. Consequently, the predication accuracy is sometimes insufficient here.

The application of various codes, including commercial ones, should be made using a step-by-step method. A rehearsal computation using a simple flow field (e.g., a channel flow) is recommended in order to confirm the accuracy of the code before commencing the computation of a more complicated flow field. The computation results of a complicated flow field often cover up numerical errors. When we applied several commercial LES codes to a channel flow, unfortunately the codes we tried could not provide results of sufficient accuracy. The cause of the errors included in these codes was thought to be numerical viscosity. An example of decay of turbulence predicted by LES with numerical viscosity in presented in Fig. 1.

It therefore seems to be rather dangerous for the future of CWE to rely too heavily on commercial codes. On the other hand, a number of CFD subjects that should be solved for the more reliable CWE applications, still remain. Without coding the program ourselves, it seems to be difficult to develop new numerical methods for CWE by ourselves.

4. Incompleteness of CWE and lack of description on numerical procedures

CWE is still under development and remains incomplete. The results of CFD predictions always include various numerical errors to a greater or lesser extent and their prediction accuracy is far from perfect. Therefore, it is essential to describe the details of numerical procedures in a paper, i.e., numerical schemes, turbulence models, boundary conditions used etc. We cannot evaluate the accuracy of the prediction results without such information. These descriptions were unfortunately lacking in many papers.

5. Higher reliability of CWE and concern about the fundamental subjects of CFD

As the prediction accuracy of CWE is often insufficient, it is most important to increase the reliability of CWE through improving prediction accuracy. I am afraid that the concerns of many CWE engineers are too oriented towards applications. We should also be concerned about more

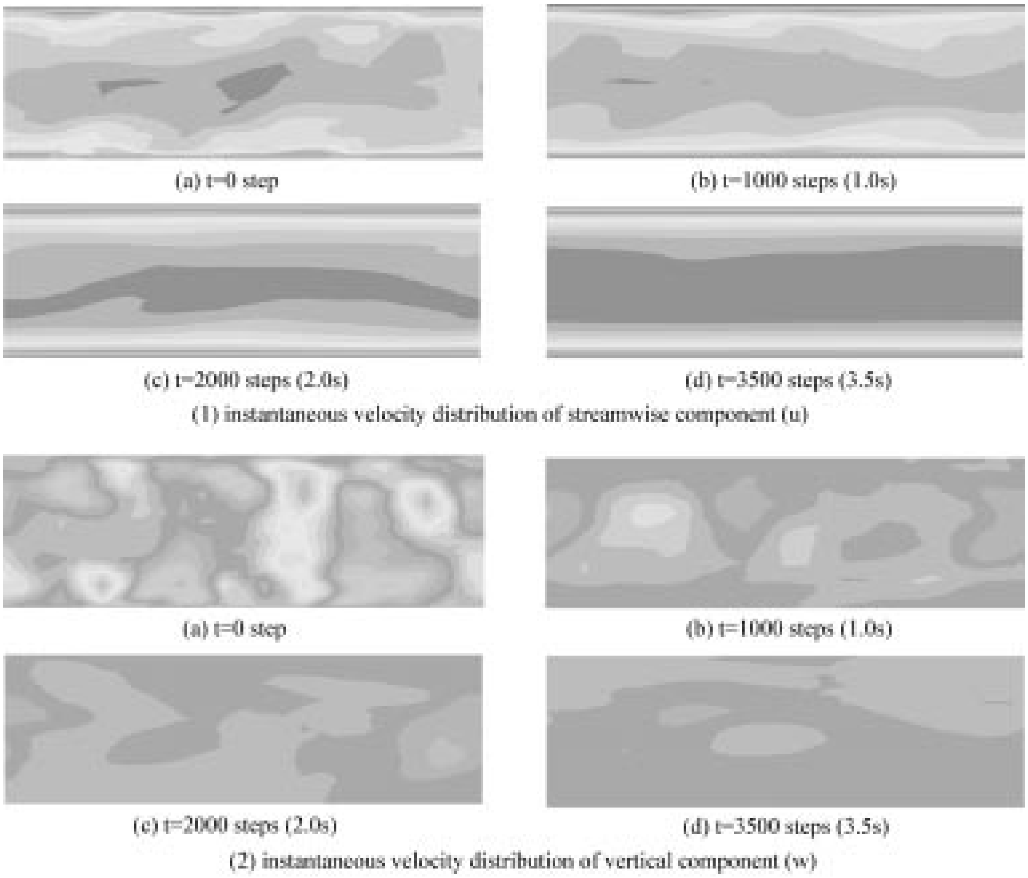

Fig. 1 Decay of turbulence in channel flow predicted by LES with numerical viscosity ($\Delta t = 1.0\times10^{-3}$ s)

fundamental subjects of numerical methods in order to improve prediction accuracy; for example, new turbulence models, new boundary conditions etc. There are fewer remaining issues concerned with improving the prediction accuracy of CWE, but they are all highly problematic issues. Most of the less complex matters were solved at the early stages of the development of CWE. We should make more effort to resolve the fundamental problems peculiar to wind engineering that still remain.

6. Remaining research subjects for CWE

As mentioned above, we have several remaining research subjects to be investigated, i.e., turbulence models, boundary conditions, etc.

6.1. Remaining subjects related with turbulence models

CWE 2000 included little research related to the application of new turbulence models or revising existing models, as mentioned earlier. As the standard *k*-*ε* model has some drawbacks in its application to bluff bodies, several revised *k*-*ε* models have been proposed. But these revisions are not perfect. Efforts to revise RANS models, including the *k*-*ε* model should be continued.

Many applications concerning LES are found in this Symposium. However, there are few applications concerning dynamic LES. The advantage of dynamic LES over conventional LES is quite clear. I cannot understand why the application of dynamic LES has not increased.

Several turbulence models are compared in the applications concerning bluff bodies in some papers. Interesting and useful results are reported in these papers. However, there are not many observations or insights into the difference of the structure of turbulence models that gives rise to the difference in prediction results.

6.2. Remaining subjects related with boundary conditions

In the application of CWE with a large Reynolds number, the treatment of the wall boundary condition is a most difficult and important matter. The wall function of the log-law type is very widely used. Everybody knows the inadequacy of this boundary condition when it is applied to a flow field with separation. It is always hoped that an adequate wall boundary condition to be applied to the flow field around bluff bodies will be developed. This research target has been pointed out from the very beginnings of CWE.

The generation of the inflow turbulent boundary condition for LES computations is investigated in some papers. These are most valuable for the application of LES.

7. Confirmation of prediction accuracy

It seems that insufficient attention has been paid to prediction errors in many papers. We should always anticipate some numerical errors for all types of turbulence models, in particular when the k-ε model is applied. Thus we should be careful to confirm prediction accuracy. The comparison between the prediction and the experiment and also the comparison between various predictions are always made under various uncertainties, since both the prediction and the experiment possess some errors. The evaluation of the comparison is vague, since noise level is often high. Therefore, a step-by-step comparison is recommended. For example, 2D→3D, laminar→turbulent, isothermal→non isothermal, etc.

Accurate experimental data that can be used as a reference for evaluating prediction accuracy are lacking. Are many of the current experimental results sufficiently reliable?

8. From analysis tool to design tool

CFD is currently widely utilized in wind engineering as an analysis tool. And at the final stage of CWE applications, CFD is sure to be utilized as a design tool. Some papers attempt to utilize CWE from this viewpoint. To utilize CFD as a design tool, it is necessary to develop the following points: firstly, an analysis method that includes a feedback system in the simulation procedure; secondly, the coupled simulation method of momentum transport, heat transport, moisture transport, etc. Fig. 2 illustrates two types of CFD analysis in the case of outdoor climate simulation. (a) is the utilization of CFD as an analysis tool and (b) is the one as a design tool.

Furthermore it is necessary to develop an integrated system of various numerical simulations including CFD; i.e., the development of a software platform as detailed in reference (Murakami *et al.* 2000).

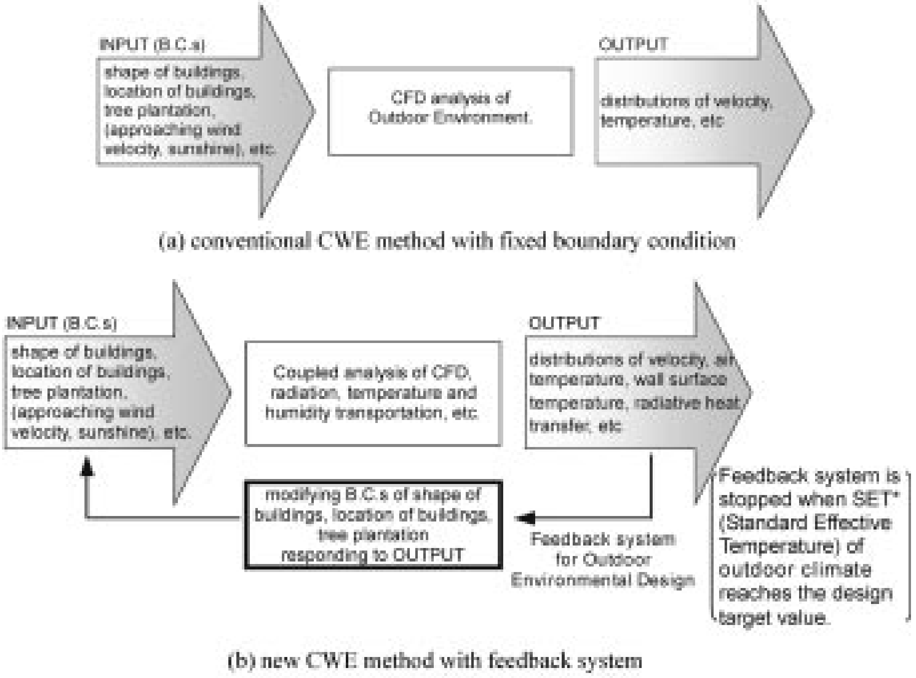

Fig. 2 Concept of outdoor climate simulation with/without feedback system for outdoor environmental design (B.C. : boundary condition)

9. Concluding Remarks

CWE is growing steadily. The range of applications has spread greatly. However, I am afraid that the concerns of many CWE engineers are too oriented towards applications using commercial codes.

The prediction accuracy of CWE is far from perfect. Basic research efforts to resolve the fundamental subjects for improving the prediction accuracy should be continued. At the same time, we should make efforts to enlarge the application fields for CWE, which goes beyond the simple application of CFD as an analysis tool. New research fields will be opened when CFD is utilized as a design tool.

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