Simulation of Simple Test Case 2D1

Two-Dimensional Isothermal Forced Convection

Skovgaard, M.; Nielsen, Peter Vilhelm

Publication date:
1991

Document Version
Publisher's PDF, also known as Version of record

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

International Energy Agency, Energy Conservation in Building and Community Systems, Annex 20: Air Flow patterns Within Buildings

M. SKOVGAARD & P. V. NIELSEN

SIMULATION OF SIMPLE TEST CASE, CASE 2D1
(Two-Dimensional Isothermal Forced Convection)

SEPTEMBER 1991 ISSN 0902-7513 R9131

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

International Energy Agency, Energy Conservation in Building and Community Systems, Annex 20: Air Flow patterns Within Buildings

M. SKOVGAARD & P. V. NIELSEN

SIMULATION OF SIMPLE TEST CASE, CASE 2D1
(Two-Dimensional Isothermal Forced Convection)

SEPTEMBER 1991 ISSN 0902-7513 R9131

International Energy Agency
Energy Conservation in Building and Community Systems
Annex 20 : Air Flow patterns within Buildings
Subtask 1 : Room Air and Contaminant Flow

RESEARCH ITEM 1.46dk

SIMULATION OF SIMPLE TEST CASE, CASE 2D1

(two - dimensional isothermal forced convection)

Author	:	Skovgaard, M. and Nielsen, P.V. The University of Aalborg, Department of Building Technology and Structural Engineering. Sohngårdsholmsvej 57, 9000 Aalborg, Denmark

Date	:	May the 1st. 1991 (revised 25.07.91).
Report no.	:	
Report type	:	Annex report.
Distribution	:	Unlimited.
Available	:	The University of Aalborg.

Table of contents

LIST OF FIGURES

SUMMARY

The turbulent flow pattern is calculated with a low Re number version of the k-ϵ model in a room with two-dimensional isothermal flow.

The results are compared both to LDA measurements obtained in a scale model and to other data obtained by numerical simulation.

The overall performance is good and indeed satisfactory. With respect to maximum velocity and turbulence level in the occupied zone the results are very good and with respect to the decay of the maximum velocity in the wall jet and the growth of jet width small discrepancies are found.

ACKNOWLEDGEMENTS

This report is partly made while one of the authors (Skovgaard, M.) stayed at UMIST, Manchester, UK.

The authors would like to send many thanks to the staff of UMIST, who made the stay very pleasant and especially we would like to thank *Dr. N. Inze* and *Prof. B. Launder* who have been very supportive and participating throughout the work at UMIST.

INTRODUCTION

This annex 20 report shows the results of the simulation of the test case given by *Nielsen (1990)*. The test case is two-dimensional and is chosen because of the detailed experimental data available. The experimental result is obtained by the laser-Doppler anemometry technique *Restivo (1979)* and *Nielsen et al. (1978)*.

SIMULATION METHOD

Mathematical model

The numerical predictions are obtained by a numerical solution of the time averaged momentum equations, the continuity equation and an Eddy viscosity concept for the turbulent Reynolds stresses.

The governing equations for two-dimensional steady, isothermal flow are

$$\frac{\partial}{\partial x_i}(\rho U_i) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_i}(\rho U_i U_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \rho\overline{u_i u_j}\right) \tag{2}$$

For description of the Reynolds stresses several models can be adopted, see *Patel et al. (1985)*. Here the *Launder-Sharma (1974)* version of the *Jones-Launder (1972)* low Reynolds number k-ϵ model is used (for detailed description see also *Inze (1989)*) :

$$\rho\overline{u_i u_j} = \frac{2}{3}\delta_{ij}\rho k - \mu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \tag{3}$$

$$\mu_t = C_\mu f_\mu \rho \frac{k^2}{\tilde{\varepsilon}} \; ; \qquad \tilde{\varepsilon} \cong \varepsilon - 2\frac{\mu}{\rho}\frac{\partial}{\partial x_i}\left(\frac{\partial\sqrt{k}}{\partial x_j}\right)^2 \tag{4}$$

$$\frac{\partial}{\partial x_i}(\rho U_i k) = \frac{\partial}{\partial x_i}\left(\left(\mu\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right) + P - \rho\varepsilon \tag{5}$$

$$\frac{\partial}{\partial x_i}(\rho U_i \tilde{\varepsilon}) = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \tilde{\varepsilon}}{\partial x_i}\right) + C_{\varepsilon 1} f_1 \frac{\tilde{\varepsilon}}{k}\rho P - C_{\varepsilon 2} f_2 \frac{\tilde{\varepsilon}^2}{k} + C_{\varepsilon 3}\frac{\mu \mu_t}{\rho}\left(\frac{\partial}{\partial x_i}\left(\frac{\partial U_i}{\partial x_j}\right)\right)^2 \qquad (6)$$

where P is the generation rate due to turbulent shear effects

$$P = -\overline{u_i u_j}\frac{\partial U_i}{\partial x_j}$$

The values of the turbulent model constants and functions can be seen in the table below

	Fully turb. version	Low Re numb. version
C_μ	0.09	0.09
$C_{\epsilon 1}$	1.44	1.44
$C_{\epsilon 2}$	1.92	1.92
$C_{\epsilon 3}$	-	2
σ_k	1.0	1.0
σ_ϵ	1.3	1.3
f_μ	1.0	$\exp(-3.4/(1+R_t/50)^2)$
f_1	1.0	1.0
f_2	1.0	$1-0.3\exp(-R_t^2)$

$$R_t = \frac{\rho}{\mu}\frac{k^2}{\tilde{\varepsilon}}$$

Computer code

The two-dimensional elliptic flow solver *TEAM* (*Huang (1986)*), which has been extensively used and validated, was used to obtain the flow solutions. The code is using the finite volume technique employing the staggered grid layout to overcome the checkerboard phenomenon. The solution scheme used is SIMPLE and the differencing scheme is PLDS for all terms. A non-uniform grid is used in order to produce a finer grid in the boundary layer. In fact the solution is rather sensitive to grid layout if coarser grids are used, especially in the region $5<y^+<30$. The equations are solved line by line in an ADI iterative manner.

As expected the convergence is rather slow because of the slow diffusive process in the boundary layer and because of the fine grid required.

TEST CASE - geometry and boundary conditions

The geometry of the test case is L/H=3.0, h/H=0.056 and t/H=0.16 (see fig.1) and the actual dimensions used in the present simulation are H=3.0m, L=9.0m, h=0.168m and t=0.48m. As pointed out in the specification the inlet opening is rather large compared to practical diffusers (it can be mentioned that the ratio $a_o^{1/2}/H$ is equal to 0.035 in the three-dimensional test case), but this will only make it easier to use a standard k-ϵ model. In the present case where a low Re number k-ϵ model is used it is necessary to use fine grid in the opening because of the inlet location close to the ceiling. The grid used is 38x78.

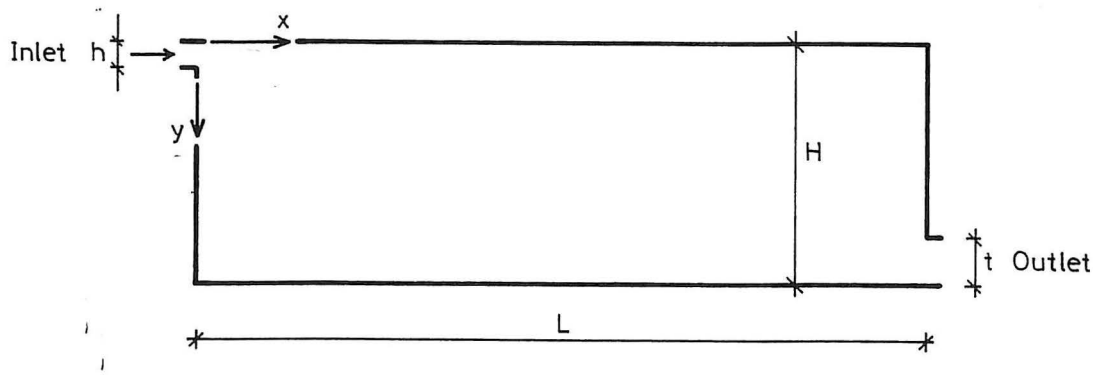

Fig. 1. The geometry of test case 2D1.

The boundary conditions for the test case are :

Inlet : $U_o=5000\mu/(\rho h) = 0.455$ m/s
$V_o=0.0$
$k_o=1.5(0.04U_o)^2$
$\epsilon=k_o^{1.5}/(h/10)$

Outlet : $U_{out}=U_o h/t = 0.159$ m/s
$dV/dx=d\epsilon/dx=dk/dx=0.0$

Wall : $U=V=\epsilon=k=0.0$

RESULTS AND DISCUSSION

Comparisons with LDA measurements

Figure 2 shows the predicted velocity field and the distribution of turbulent kinetic energy.

Fig. 3 shows the comparison between the computed velocity and kinetic energy profiles. As seen the overall agreement is very good. It is seen that the inlet conditions for k_o have very little effect on the turbulence level in a distance from the inlet, which again means

that the turbulence is created by the shear effect. The $k^{1/2}$ level can be compared to the measured level of $(u^2)^{1/2}$ (*Nielsen 1990*). It is noted that the decay of U_{max} is sligthly higher than in the measurements which becomes more evident in fig. 5.

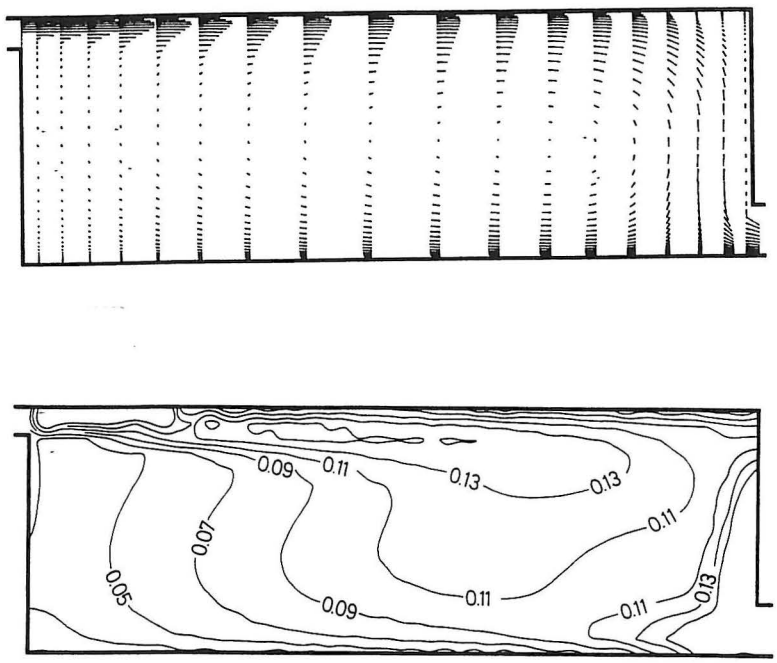

Fig. 2. The predicted velocity field U/U_o and the distribution of turbulent kinetic energy $k^{1/2}/U_o$

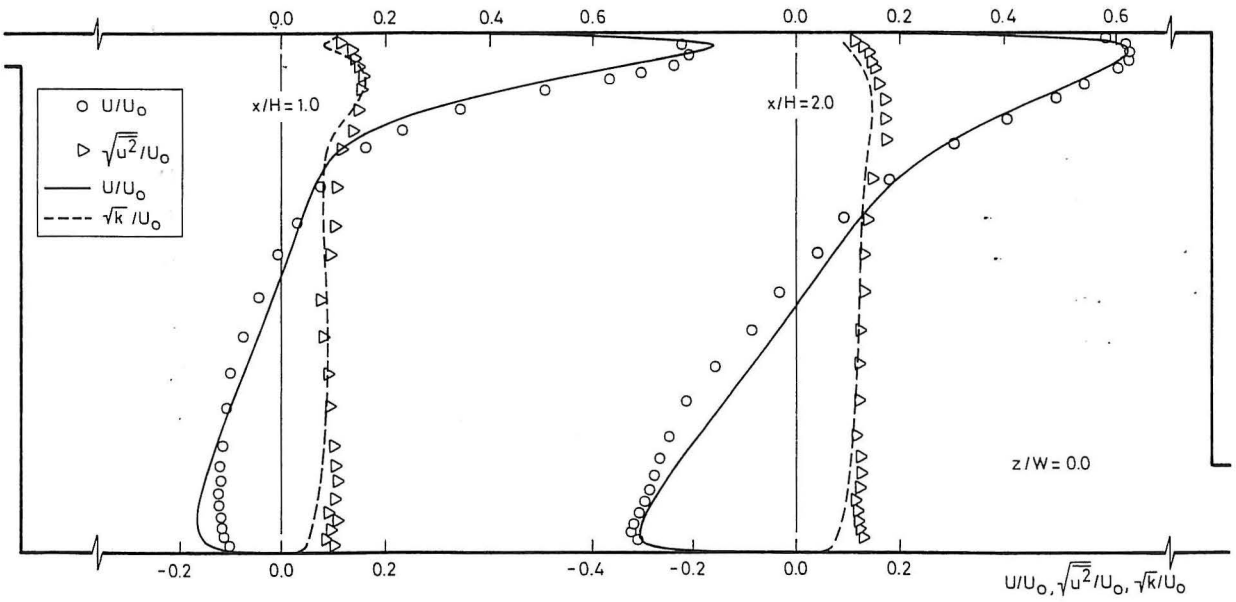

Fig. 3. Measured and simulated flow profiles.

In fig 4. results from two cross sections in the y-direction are compared with measured data.

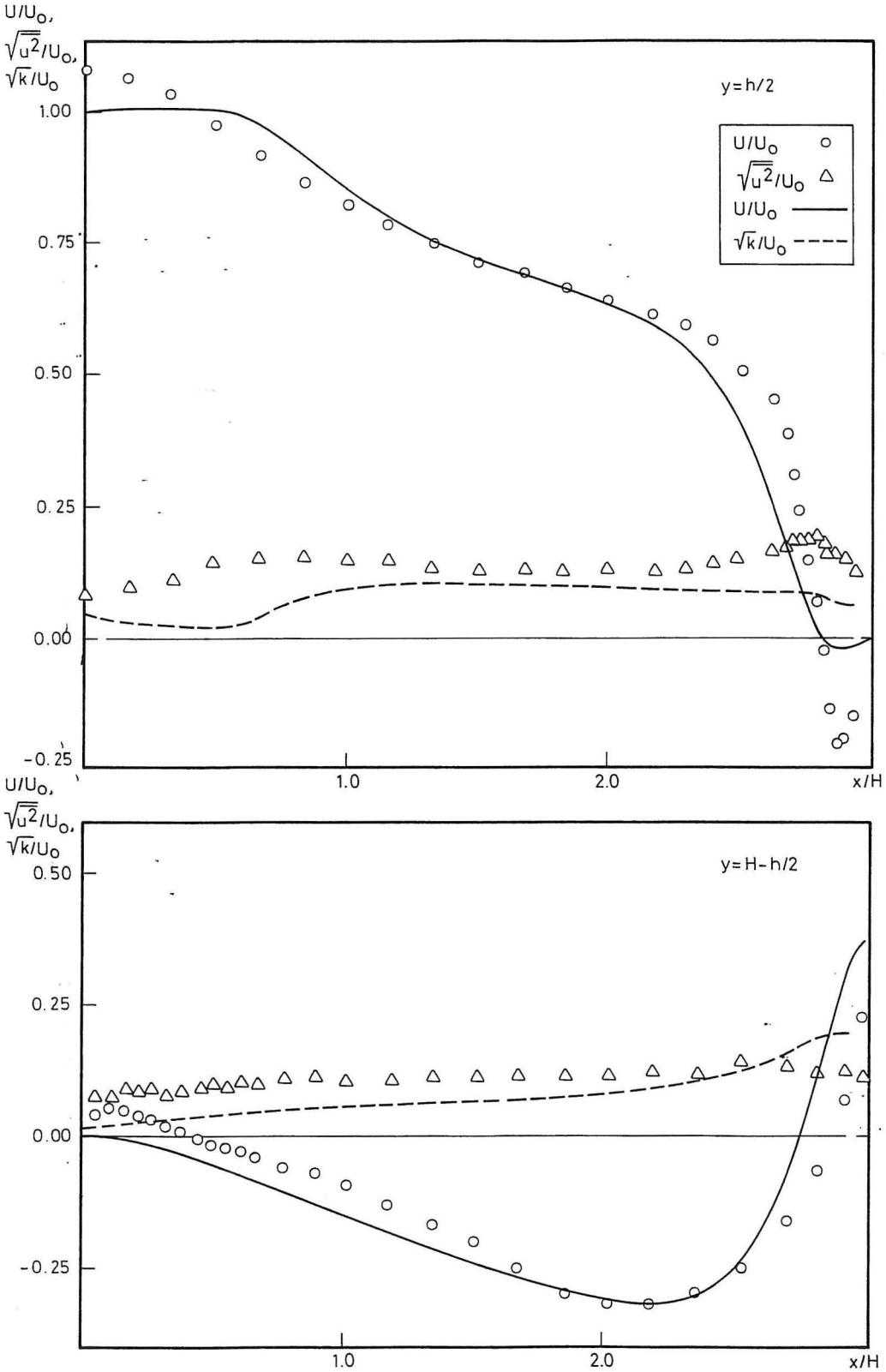

Fig. 4. Comparison between predicted and measured values in cross section y=h/2 and y=H-h/2.

The effect from the shear layer outside the potential core of the jet is seen. It is seen that the recirculating flow recorded in the measurements in both cross sections is predicted in the simulation, although the magnitude of the counter flow is too low. The maximum velocity in the occupied zone is well predicted both with respect to location and to magnitude.

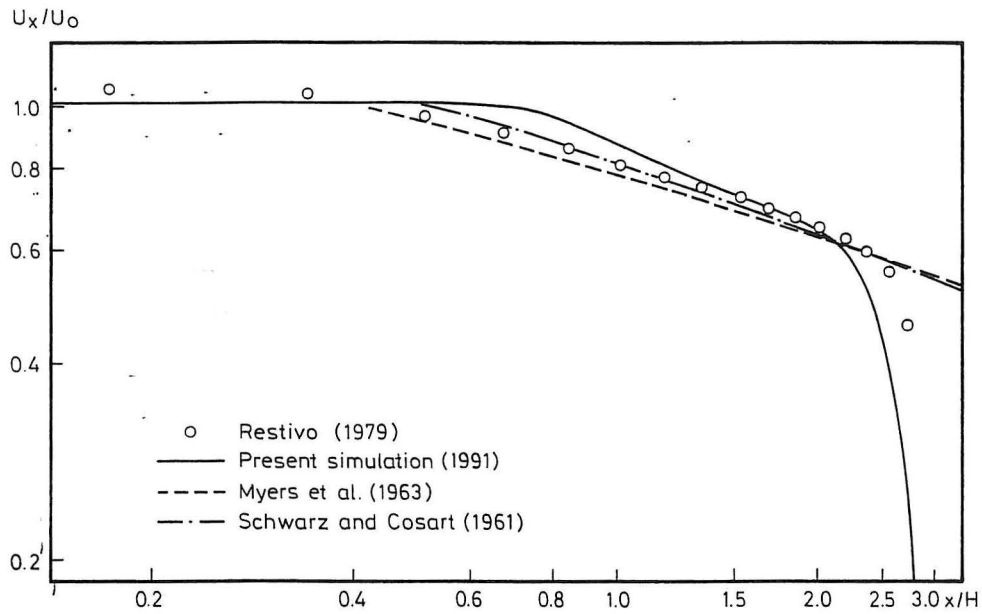

Fig. 5. Decay of the maximum velocity in the wall jet.

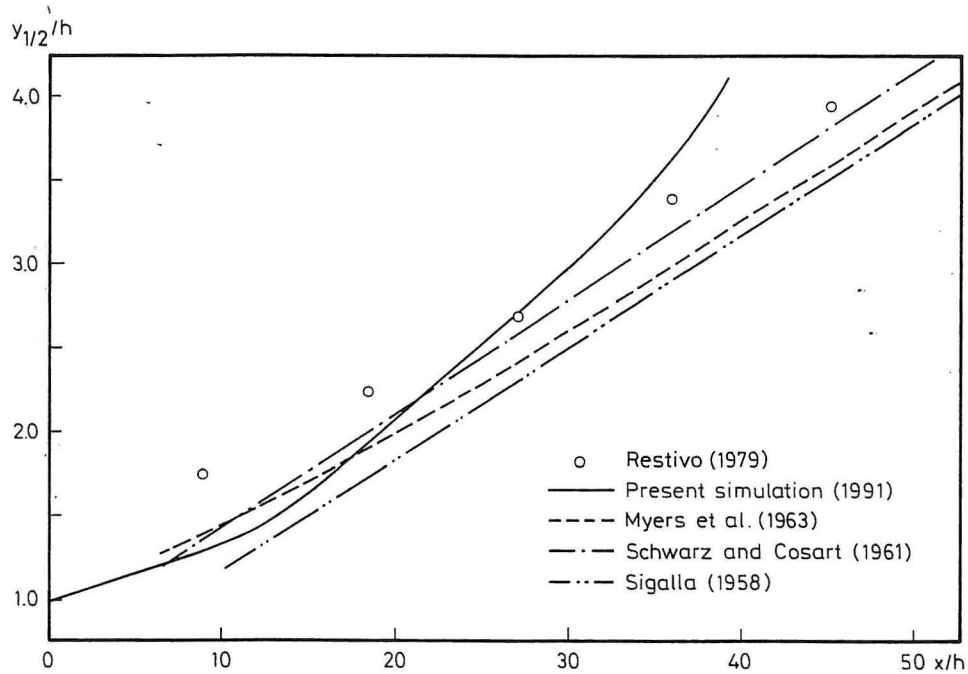

Fig. 6. The growth in wall jet width.

The decay of the maximum velocity and the downstream growth of the jet width are

depicted in fig 5 and 6. The velocity decay is slightly overpredicted and it can be seen that the faster decay corresponds to a faster growth in the jet width than recorded in the experiments (fig. 6). No investigation of grid dependency of the solution has been carried out so it is possible that some numerical diffusion may be present.

Other numerical predictions

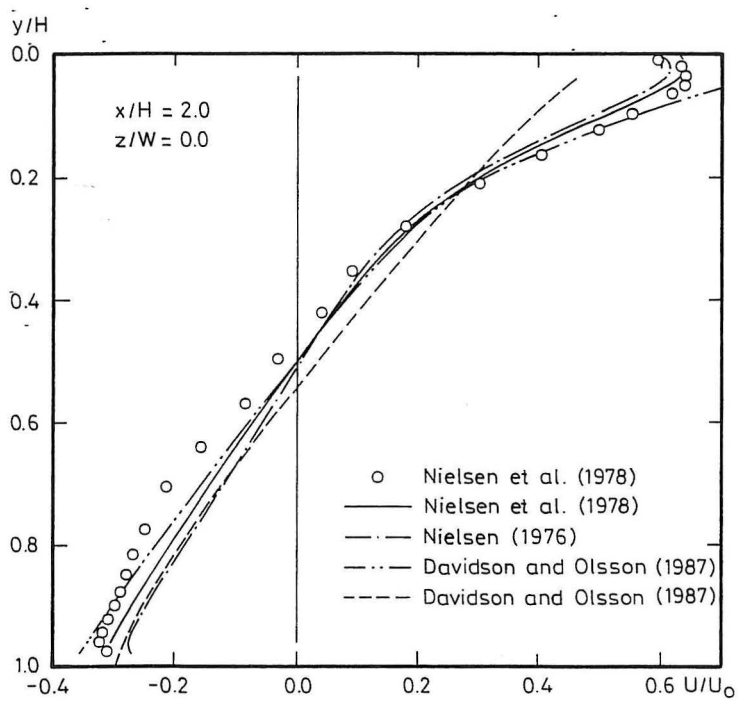

Fig. 7. Predictions of the velocity distribution in the two-dimensional test case.

Fig. 7 shows some other numerical predictions which can be used for comparisons. The measurements are made by *Restivo 1978* and reported by *Nielsen et al. 1978.*

One set of predictions is made by the TEACH-T code and a k,ϵ turbulence model with wall functions (*Nielsen et al. 1978*). Fig. 7 also shows some old predictions made by vorticity-stream function as dependent variables and a k,ϵ model. The predictions are made at a Reynolds number of 7100 and the inlet conditions are given by a box method.

The predictions by *Davidson and Olsson 1987* are made by a k,ϵ model and with a one-equation turbulence model. The one-equation model is giving a lower velocity level in the wall jet below the ceiling, see fig. 7.

REFERENCES

Davidson, L. and Olsson, E.
Calculation of Some Parabolic and Elliptic Flows Using a New One-Equation Turbulence Model. Proc. 5th. International Conference on Numerical Methods in Laminar and

Turbulent Flow. Montreal. *1987.*

Huang, P.G. and Leschziner, M.A.
An Introduction and guide to the computer code TEAM. UMIST Mechanical Engineering Dept. *July 1983.*

Inze, N.Z. and Launder, B.E.
On the Computation of Buoyancy-driven Turbulent Flows in Rectangular Enclosures. Int. J. Heat and Fluid Flow. Vol. 10, No. 2. *June 1989.*

Jones, W.P. and Launder, B.E.
Int. J. Heat and Mass Transfer, 15, 301. *1972.*

Launder, B.E. and Sharma, B.I.
Letters in Heat Mass Transfer, 1, 131. *1974.*

Myers, G.E., Schauer, J.J. and Eustis, R.H.
The Plane Turbulent Wall Jet. Jet Development and Friction Factor. Trans. A.S.M.E., J. Basic Eng., 85, p. 47. *1963.*

Nielsen, P.V.,
Flow in Air Conditioned Rooms (English translation of Ph.D. thesis, Technical University of Denmark, 1974), Danfoss A/S, Denmark. *1976.*

Nielsen, P.V., Restivo, A. and Whitelaw, J.H.
The Velocity Characteristics of Ventilated Rooms. Journal of Fluids Engineering. vol. 100, pp. 291-298. *Sept. 1978.*

Nielsen, P.V.
Specification of a Two-Dimensional Test Case. Internal report for the International Energy Agency, Annex 20. University of Aalborg, Denmark. ISSN 0902-7513 R9040. *Nov. 1990.*

Restivo, A.
Turbulent Flow in Ventilated Rooms. Ph.D. Thesis. Imperial College, London. *March 1979.*

Schwarz, W.H. and Cosart, W.P.
The Two-Dimensional Turbulent Wall Jet. J. Fluid Mech. Vol. 10. *1961.*

Sigalla, A.
Measurements of Skin Friction Factor in a Plane Turbulent Wall Jet. J.R. Aeronaut., Soc., 62, p. 873. *1958.*