NUMERICAL INVESTIGATION OF COMBINED IMPINGEMENT AND CONVECTION HEAT TRANSFER

A. Abdon and B. Sundén
Division of Heat Transfer
Lund Institute of Technology, Box 118, 22100 Lund, Sweden

The present paper concerns development of a prediction method for combined impingement and convection heat transfer, which is very relevant in gas turbine cooling systems. In the first step, a prediction of a single round unconfined impinging air jet without crossflow is investigated. This is to assess the performance of various turbulence models (linear and non-linear two-equation models). The next issue considered is the influence of crossflow for which a plane confined air jet is investigated. As detailed experimental data on this is scarce the purpose is partly to provide an understanding of the flow and heat transfer processes, but a relative comparison of the performance of different models is also made.

PROBLEM FORMULATION AND NUMERICAL METHOD

The cases (1-4) investigated here are a single unconfined impinging round air jet (Re_D=23000 and 70000, H/D=2 and 6, 0<r/D<10) and a confined plane air jet with crossflow (Re_j=16700, u_j/u_c=5, H/W=5, –20<x/W<70). As the jets were fully developed flows in all the experimental setups this was also used as inlet condition in the calculations (profiles computed separately). It was also applied to the crossflow entering twenty slot widths (W) upstream the jet. The numerical method is based on the finite volume method[1] and uses a co-located non-uniform grid (code is CFX4.2). Cylindrical coordinates are used for the round jet. A hybrid differencing scheme is applied for the convective terms in the momentum and energy equations to reduce numerical instabilities. An investigation of grid dependency was made by doubling the number of nodes in each direction for the first (180×120) and last (275×120) case. The result was a change less than 7% in local heat transfer rates which was considered acceptable. The grids of the other cases had about the same density, and the first grid points were always at a dimensionless distance (y^+) less than 0.5 from the heated walls. In all computations the residuals were reduced about five orders of magnitude from an initial guess.

RESULTS AND DISCUSSION

In Figs. 1-4 the results for all test cases are displayed and compared to experimental data[2-5]. The turbulence model used are all low Reynolds number models; Abe et al[6] (“k-eps”), Lien et al[7] (“NL k-eps”), Wilcox[8] (“k-omega”), Larsson[9] (“NL k-omega”), Rokni[10] (“EASM k-eps”). A realizability constraint[11] is applied on the linear models to prevent severe heat transfer overprediction. For the single unconfined jet very good results can be produced by a simple linear model at Re=23000 having the spread in experimental data in mind (local variation of 30% in case 2). However, the deviation from experiments is rather large for the case Re=70000. The model which has best overall performance for test cases 1-3 is “NL k-omega”, although it does not clearly reveal the second maximum for test case 3. Test case 4 shows severe differences between calculations and measurements which may be due to the experimental method used (mass transfer and Chilton-Colburn analogy[5]). It also reveals significantly different Nu-profiles between the turbulence models. This seems to be caused by the equation determining the length scale as the epsilon based models show a strange drop in heat transfer beginning around x/W=4. The explanation to this is not yet fully understood but suggests further investigations of the performance of these models before they can be applied to more complex impinging flows.

CONCLUSIONS

The present investigation shows that realizable and/or non-linear two-equation models may successfully be used for impinging jet heat transfer predictions but there are significant differences between different formulations. Among the models tested, a non-linear k-omega showed superior performance.

REFERENCES

1. Versteeg, H.K., Malalasekera, W., ”An introduction to computational fluid dynamics the finite volume method”, Longman Scientific & Technical, Essex, England, 1995.
2. Baughn, J., Hechanova, A., Yan, X., “An experimental study of entrainment effects on the heat transfer from a flat surface to a heated circular impinging jet”, *J. Heat Transfer*, Vol. 113, 1991.
3. Yan, X., “A preheated-wall transient method using liquid crystals for measurement of heat transfer on external surfaces and in ducts”, Ph.D. Thesis, University of California, Davis, 1993.
4. Lytle, D., Webb, B., “Air jet impingement heat transfer at low nozzle-plate spacings”, *Int. J. Heat Mass Transfer*,Vol. 37, pp. 1687-1697, 1994.
5. Chong, Y.K., Hammond, G.P., Macaskill, C., Ward, J., “An experimental study of two-dimensional jet-impingement heat/mass transfer in a confined cross-flow”, Heat Transfer 1986, Vol. 3, pp. 1225-1230, 1986.
6. Abe, K., Kondoh, T. Nagano, Y., “A new turbulence model for predicting fluid flow and heat transfer in separating and reattaching flows-I. Flow field calculations”, *Int. J. Heat Mass Transfer*, Vol. 37, No. 1, pp.139-151, 1994.
7. Lien, F.S., Chen, W.L., Leschziner, M.A., “Low-Reynolds-Number eddy-viscosity modelling based on non-linear stress-strain/vorticity relations”, Proc. 3rd Symp. Engineering Turbulence modelling and Measurements, Crete, Greece, 1996.
8. Wilcox, D.C., ”Turbulence modelling for CFD”, DCW Industries Inc., 1993.
9. Larsson, J.,”Two-equation turbulence models for turbine blade heat transfer simulations”, ISABE Paper 97-7163, Proc. 13th ISABE Conf., Vol. 2, pp.1214-1222, Chattanoga, 1997.
10. Rokni, M., “Numerical investigation of turbulent fluid flow and heat transfer in complex ducts”, Ph.D. Thesis, Div. Heat Transfer, Lund Institute of Technology, Sweden, 1998.
11. Durbin, P.A., “On the k-ε stagnation point anomaly”, *Int. J. Heat Fluid Flow*, Vol. 17, pp. 89-90, 1996.

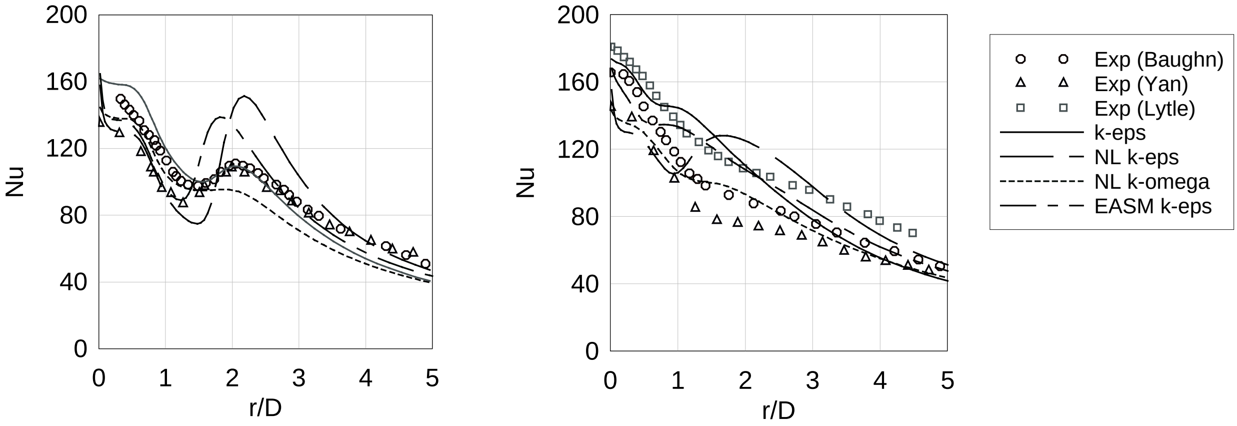

Figure 1. Test case 1 & 2: single round jet, Re=23000 and H/D=2 (left) and H/D=6 (right).

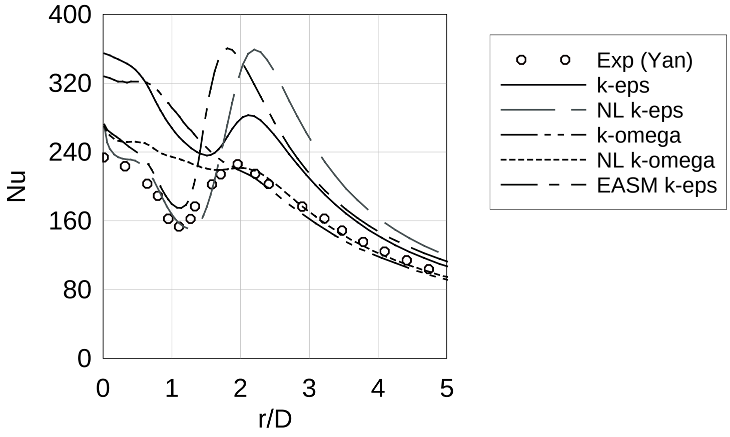

Figure 3. Test case 3: single round jet, Re=70000 and H/D=2.

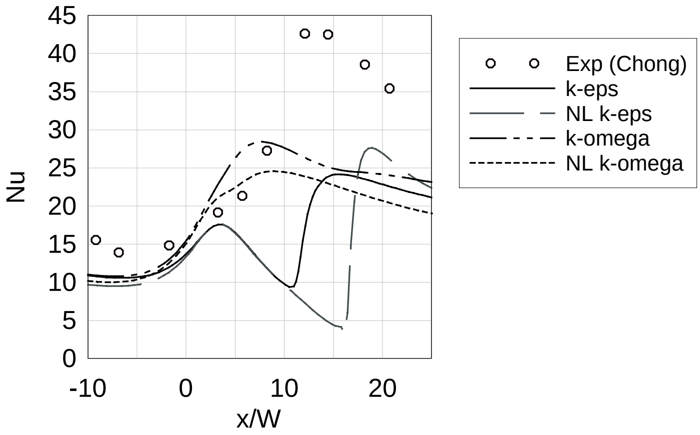

Figure 4. Test case 4: plane jet with crossflow, Re_j=16700, u_j/u_c=5 and H/W=5.