Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird
DAAAM Symposium

CFD CODE TURBULENCE MODELS VALIDATION FOR TURBULENT FLOWS OVER A WAVEY SURFACE

RAMAJ, V[ehbi]; DHORI, A[ltin]; RAMAJ, V[albone]; DHOSKA, K[lodian]; KOLECI, A[bdyl] & KONJUSHA, E[lmi]

Abstract: *In this paper different turbulence models for turbulent separated flows in a wavy channel are evaluated. The standard k - ε (ske) model, realizable k - ε (rke) model and Reynolds Stress Model (rsm) are tested using the finite-volume code Fluent and compared with Direct Numerical Simulation (DNS) data [5] in order to evaluate their accuracy. A second order accurate discretization is employed to solve the governing equation of the flow. A 2D domain is considered and the Reynolds number of the flow is 6850 based on the inlet velocity and channel height. The dimensionless results obtained for the flow parameters: velocity components (U, V), turbulent kinetic energy (k) and Reynolds stress ($\overline{uv}$) show a strong similarity between ske and rke models, while some differences when compared to the rsm. The analysis of results has shown that the main features of this complex flow can be predicted with reasonably reserve, at last with the rsm method. The major difference between turbulence models are related to k and $\overline{uv}$ near the wavy wall region.*

Key words: *Wavy channel, turbulence models, Reynolds stress*

1. INTRODUCTION

Wavy wall flows occur under a wide variety of engineering applications and have received considerable attention in different numerical and experimental investigation [1, 2, and 4]. The most interesting examples ranging from the turbulent transition in wavy ducts, particle dispersion over hills and heat transfer enhancement in heat exchangers. Therefore, flow over wavy wall haves a great importance in a wide range of applications. Turbulent flow over a wavy surface displays characteristics that are not found in flow over a flat surface, since further spatial variations of the velocity and pressure are induced [1]. Moreover, turbulence dynamics is significantly affected by the waviness of the surface because of the periodic changes of the pressure gradient and streamlines curvature which causes changes in the turbulence structure.
In the present work we are mainly focused to the turbulence modeling of the flow in a wavy channel. For this purpose, three different RANS turbulence models are compared: standard *k - ε* (ske) model, realizable *k - ε* (rke) model and Reynolds Stress Model (rsm) using the commercial CFD code Fluent. The objective of this work is to compare three different RANS turbulence models above mentioned by using previous DNS investigation [5] for a specific problem in order to investigate the difference between them. For all three turbulence models a second order accurate discrimination is employed to solve the governing equations of the flow. (Dellil, et.al. 2004)

2. TURBULENCE MODELING

In most industrial process the flow is always turbulent and turbulence prediction is one of the most principal challenges for the researchers. Since no single turbulence model is universally accepted as being superior for all classes of problems, major attention is devoted to the choice of turbulence model [3]. This choice will depend on considerations such as the physics encompassed in the flow, the established practice for a specific class of problem, the level of accuracy required, the available computational resources, and the amount of time available for the simulation [6]. Turbulence plays an important role in the flow phenomena considered; especially when the Reynolds numbers are high in practical problems and the influence of turbulence must be accounted for in a prediction method in one way or another. Turbulence models range from RANS models to DNS with LES in between and with an increase in computational cost per iteration. RANS models have been frequently used for industrial flow calculations due to their robustness and reasonable accuracy. The purpose of this paper is to use RANS models for a specific problem, above mentioned, and comparing the results with DNS data in order to see their predictive capability in such application. The way toward RANS equations is described as follow.
For the incompressible flow of a Newtonian fluid with constant properties considered in this case, the flow governing equations in orthogonal Cartesian coordinates are as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial (u_i u_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j^2} \qquad (2)$$

Equations 1 and 2 are mass and momentum conservation respectively. Time-dependent solutions of the Navier-Stokes equations for high Reynolds-number turbulent flows in complex geometries which set out to resolve all the way down to the smallest scales of the motions are unlikely to be attainable for some time to come. To this purpose the Reynolds-averaged Navier-Stokes (RANS) equations govern the transport of the averaged flow quantities, with the whole range of the scales of turbulence being modeled. In Reynolds averaging, the solution variables in the instantaneous (exact) Navier-Stokes equations are decomposed into the mean (ensemble-averaged or time-averaged) and fluctuating components. For the velocity components yield:

$$u_i = U_i + u_i' \qquad (3)$$

U_i and u_i' are the mean and fluctuating velocity components (i=1; 2; 3). Substituting expressions of this form for the flow variables into the instantaneous continuity and momentum equations 1 & 2 and taking a time (or ensemble) average yields the ensemble-averaged momentum equations. They can be rewritten in Cartesian tensor form as fellow:

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (4)$$

$$\frac{\partial (U_i U_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 U_i}{\partial x_j^2} - \frac{\partial}{\partial x_j}(\overline{u_j u_i}) \qquad (5)$$

Equations 4 & 5 are called Reynolds-averaged Navier-Stokes (RANS) equations. (Park, et.al. 2004)

They have the same general form as the instantaneous Navier-Stokes equations, with the velocities and other solution variables now representing ensemble-averaged (or time-averaged) values. Additional terms now appear that represent the effects of turbulence and RANS models wrestle with the problem of predicting the Reynolds stresses, $\overline{uv}$, whose presence in the equation 5 prevents closure. The Reynolds-averaged approach to turbulence modeling requires that the Reynolds stresses in the equation 5 must be appropriately modeled. In the following paragraphs the guidelines provided in the Fluent User's Guide [3] are reported in order to highlight the different capabilities of the chosen turbulence models based on RANS equations for the present study. (Park. Et.al. 2004)

2.1 The Reynolds Stress Model (RSM)

Physically it is the most sound and elaborated RANS model. The RSM closes the RANS equations by abandoning the isotropic eddy-viscosity hypothesis and solving transport equations for the individual Reynolds stresses, together with an equation for the dissipation rate. This means that five additional transport equations are required in 2D. The exact form of the Reynolds stress transport equations may be derived by taking moments of the exact momentum equation. This is a process where in the exact momentum equations are multiplied by a fluctuating property, the product then being Reynolds-averaged. Unfortunately, several of the terms in the exact equation are unknown and modeling assumptions are required in order to close the equations. Since the RSM accounts for the effects of streamline curvature, swirl, rotation, and rapid changes in strain rate in a more rigorous manner than one-equation and two-equation models, it has greater potential to give accurate predictions for complex flows. However, the fidelity of RSM predictions is still limited by the closure assumptions employed to model various terms in the exact transport equations for the Reynolds stresses. The RSM might not always yield results that are clearly superior to the simpler models in all classes of flows to warrant the additional computational expense. However, use of the RSM is a must when the flow features of interest are the result of anisotropy in the Reynolds stresses (Cherukat et.al, 1998).

3. COMPUTATIONAL MODEL

The quality of a computational solution is strongly linked to the quality of the grid mesh. So a highly orthogonal zed, no uniform, fine grid mesh was generated with grid nodes considerably refined in the near-wall region. The grid adapted for the computations consists of 6144 cells disposed on a global array 64x96 cells in *x* and *y* directions. The normalized y^+ values at the near wall node are less then unity in order to apply the Enhanced Wall Treatment (EWT) for the Wall Treatment options in *Fluent*. The flow is driven by a constant pressure gradient and it is assumed fully developed in the stream wise direction *x*, corresponding to the value adopted in the DNS [5]. The Reynolds number of the flow is based on the inlet velocity and channel height. (Rosi.et.al.2006)

In order to achieve higher accuracy for all three turbulence models, a second order accurate discrimination is employed to solve the governing equation of the flow. In the case of the RSM model the iterations have been started from the standard k - ε model results, in order to improve the stability of the simulation. (Spalart. et.al. 2000)

4. RESULTS AND DISCUSSION

The results obtained with the three turbulence models are now discussed and compared with the DNS data. The flow parameters under examination have been the: X-velocity (*u*), Y-velocity (*v*), turbulence kinetic energy (*k*) and Reynolds stress ($\overline{uv}$). The measurements are made at two different streamwise locations: $x/L = 0$ (wave crest) and $x/L = 0.5$ (wave trough). The results for the flow parameters are made dimensionless with the mean (bulk) velocity U_b. Figure 3 and 4 shows the mean *X*-velocity for the $x/L = 0$ and $x/L = 0.5$ location respectively. As can be seen the ske and rke model give almost the same results, while the rsm model differ from them in the near wavy wall region even though each model overpredict the profiles when compared to the DNS data. It can be observed that for the location $y/H \approx 0.7$ the rke model gives more reasonable results compared to the ske and rsm models.

5. CONCLUSION

In this paper the turbulent flow in a wavy channel has been investigated by three different RANS turbulent models. The CFD commercial code *Fluent* has been used to solve the flow governing equations through a second order accurate discretization. The wavy channel studied corresponds to the geometry of Rossi [5]. For the near-wall treatment Enhanced Wall Treatment (EWT), has been employed. Different flow parameters have been predicted and compared with DNS data [5], in order to highlight how RANS models can be effective in the study of such flow. The analysis of results has shown that the main features of this complex flow can be predicted with reasonably reserve, at last with one of the methods (rsm). The major difference between ske, rke models compared to DNS have been found in the near wavy wall region, where k - ε models produce poor results (especially for the Reynolds stress) due to complexity of geometry and periodic changes. Away from the wavy wall generally the k - ε models results with overproduction of the flow parameters. On the other hand, rsm model generally seems to work better near the wavy wall region and especially for the Reynolds stress predictions.

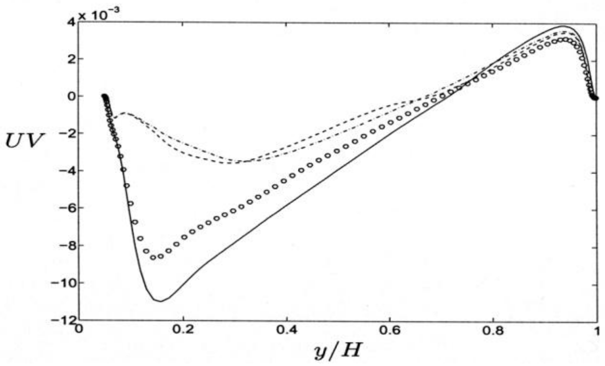

Fig. 1. Comparison of dimensionless Reynolds stress *UV* with DNS at location $x/L = 0$: (o) DNS of [5], (-.) ske model, (- -) rke model, (-) rsm model

6. REFERENCE

Cherukat, P., Na, Y., Hanratty, T.J. & Mclaughlin, J.B. (1998) *Direct numerical simulation of a fully developed turbulent flow over a wavy wall*, Theoret. Comput. Fluid Dyn. 11, 109-134

Dellil, A.Z., Azzi, A. & Jubran, B.A. (2004) *Turbulent flow and convective heat transfer in a wavy channel*, Heat and Mass Transfer 40, 793-799

Park, S.T., Choi, H.S. & Suzuki, K. (2004) *Nonlinear k-ε –f_μ model and its application to the flow and heat transfer in a channel having one undulant wall*, Int. J. Heat & Fluid Flow. 47, 2403-2415

Rossi, R. 2006 Passive scalar transport in turbulent flows over a wavy wall, PhD Thesis, Universita di Bologna, Italy.

Spalart, P.R. (2000) *Strategies for turbulence modelling and Simulations*, Int. J. Heat & Fluid Flow. 21, 252-263