The CFX approach to turbulence modeling

Accurate and effective turbulent flow simulations

CFX-5 offers a wide range of turbulence models, from the standard k–ε model to Second Moment Closure (SMC) and Large-Eddy-Simulation (LES). SST, one of the most effective models in CFX-5 has been well validated for accuracy.

Introduction

Most industrial flows include turbulent structures, which cannot be resolved numerically on currently available computers. To overcome these limitations, CFD methods solve the Reynolds-averaged Navier-Stokes equations, using turbulence models to compute the averaged turbulent stresses. These models often limit the accuracy of CFD simulations.

Turbulence Models

The standard k–ε model is used in the prediction of most turbulent flow calculations because of its robustness, economy, and reasonable accuracy for a wide range of flows. However, the model performs poorly when faced with non-equilibrium boundary layers. It tends to predict the onset of separation too late and to under-predict the amount of separation. Separation influences the overall performance of many devices, such as diffusers, turbine blades and aerodynamic bodies. It also has a strong influence on other effects, such as wall heat transfer and multi-phase phenomena. Predicting reduced separation usually results in an optimistic prediction of machine performance. In some applications, this can have dangerous consequences, a notable example being the prediction of wing stall on airplanes.

The Shear Stress Transport Model

To solve this problem, new models have been developed. One of the most effective is the Shear Stress Transport (SST) model of Menter, [1]. The model works by solving a turbulence/frequency-based model (k–ω) at the wall and k–ε in the bulk flow. A blending function ensures a smooth transition between the two models. The SST model has been validated in a large number of studies. In a NASA Technical Memorandum, [2], SST was rated the most accurate model for aerodynamic applications.

Dr. Menter heads the turbulence modeling program at CFX, resulting in a robust accurate implementation of SST in CFX-5. Advanced near-wall treatments have been developed, allowing users to benefit from SST, even for grids with reduced near wall spacing.

A typical application of SST is the flow separation in a plane diffuser, shown in Figures 1 and 2. The model predicts correctly the separation, which has been missed by the k–ε model. More examples can be found in [1,2] where a wide range of Reynolds and Mach number cases have been computed.

When the separation point is fixed by the geometry, such as in sudden pipe expansions, k–ε usually over predicts the turbulence length scale, leading to over-prediction of the heat transfer at reattachment. SST avoids this deficiency and Figure 3 shows that it is in closer agreement with experimental data. The graph also shows simulations with a 2-layer k–ε model, which significantly under predicts the Nusselt number.

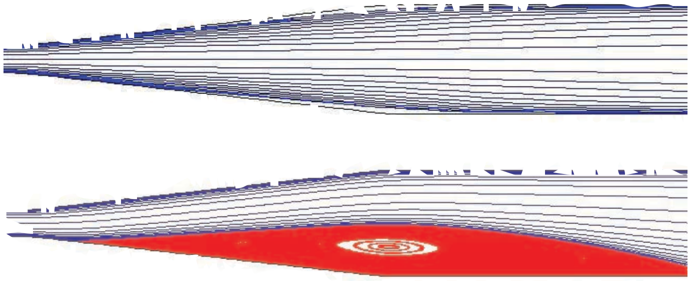

Figure 1: Streamlines for plane diffuser flow for both models. The SST model predicts the separation zone in close agreement with data, whereas the k-e model fails to capture the physics of this flow entirely.

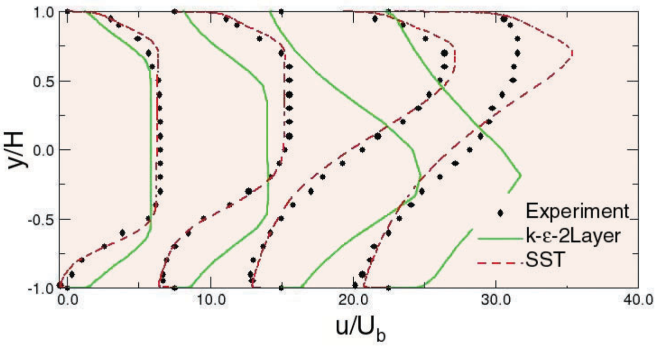

Figure 2: Comparison of the axial velocity profiles with experimental data.

CFX's Near-Wall Treatment

An important issue in turbulence modeling is the numerical treatment of the equations in regions close to walls. The near-wall formulation determines the accuracy of the wall shear stress and heat transfer predictions. CFX has recently introduced a new formulation for wall function-based models, called scalable wall functions. This is the only available formulation that allows users to apply arbitrarily fine grids without violating the underlying logarithmic profile assumptions.

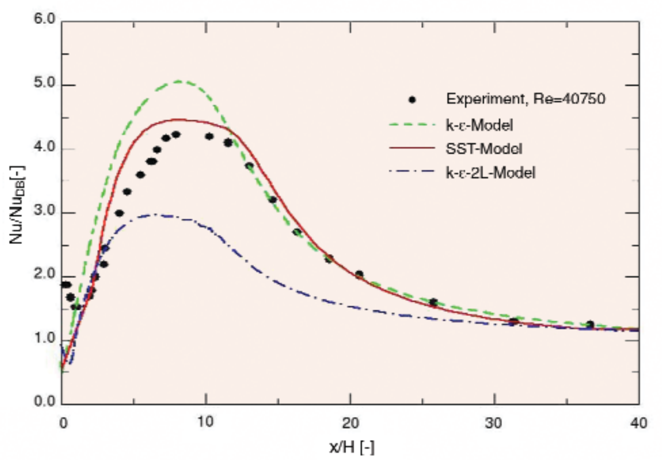

Figure 3: Non-dimensional wall heat transfer coefficient for an axisymmetric sudden pipe-expansion [3].

For SST, the new wall boundary treatment exploits the simple and robust near-wall formulation of the k-ω model and switches automatically from a low-Reynolds number formulation to a wall function treatment based on grid density. The user can then make optimal use of the advanced performance of the turbulence model for any given grid.

Figure 4 shows the heat transfer prediction for a flat plate boundary layer on a number of grids with different near-wall spacing. The usual near-wall treatment of the ω-equation, available in standard CFD codes, leads to an immediate deterioration of the results for grids with reduced near wall resolution, but CFX's automatic wall treatment of the SST model gives accurate results for a wide range of grid densities.

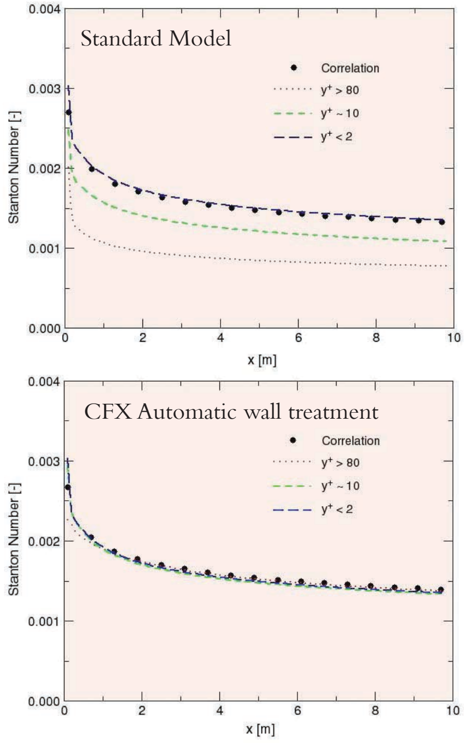

Figure 4: Grid sensitivity for wall heat transfer predictions

Conclusion

The SST turbulence model is available in CFX-5 offers significant advantages for non-equilibrium turbulent boundary layer flows, including heat transfer predictions. CFX's new approach to the near-wall treatment of the equations frees the user from the stringent grid resolution requirements of other CFD codes.

References

[1] Menter, F.R., "Zonal Two Equation k-w Turbulence Models for Aerodynamic Flows", AIAA Paper 93-2906, 1993

[2] Bardina, J.E., Huang, P.G. and Coakley, T.J., "Turbulence Modeling, Validation, Testing and Development," NASA Technical Memorandum 110446, 1997. (see also Bardina, J.E., Huang, P.G. and Coakley, T., "Turbulence Modeling Validation", AIAA Paper 97-2121)

[3] Baughn, J.W., et al., "Local Heat Transfer Downstream of an Abrupt Expansion in a Circular Channel With Constant Wall Heat Flux", Journal of Heat Transfer, Vol. 106, 1984, pp. 789-79

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