2D turbulent buoyant flow

A. Sibo Anthony

Abstract

In this study, we simulate the turbulent buoyant flow in a square enclosure using the $k-\omega$ turbulence model with the QUICK, UMIST and van Leer schemes for convection discretization. Predictions in the boundary layer and the free stream regions are analysed. Simulation is performed using the openFoam solver **buoyantSimpleFoam**. Thermal and turbulence quantities in the boundary layer and free stream region are predicted by the schemes are analysed.

1 Introduction

Natural convection is important in engineering with application in ventilation of buildings, cooling of electronic equipments etc. Due to its broad area of application, numerical study of this phenomenon is an active field of research in engineering.

2 Numerical Method

The flow domain is a square enclosure of dimensions 0.75×0.75 m^2 and discretized by a 200×200 grid. The left and right walls are isothermal and at a temperature of 50°C and 10°C, respectively, while, the top and bottom walls are adiabatic. Properties of air are taken at a reference temeperature of 30°C and listed in the table 1.

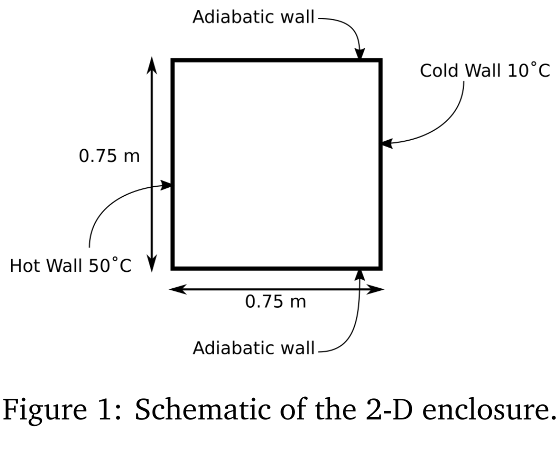

Figure 1: Schematic of the 2-D enclosure.

Cp	1006.7 $J/kg\,K$
μ	1.8689 × 10 $^{-05}$ m^2/s
Pr	0.7
Mol. weight	28.9 g/mol
Ra	1.5 × 10^9

Table 1: Properties of air

Predicted quantities are normalized by $V_{naught} = \sqrt{g\beta H\Delta T}$, where $\Delta T = T_{hot} - T_{cold}$, g = 9.81 ms^{-1}, H = 0.75 m and β = 0.0033; resulting in V_{naught} = 0.98ms^{-1}. The simulation is performed using the Wilcox $k-\omega$ turbulence model, which is known to perform well in wall bounded flows. QUICK, UMIST and van Leer schemes [1] are used for the discretization of the convective term.

The solver used in this study is **buoyantSimpleFoam** [1] and the results are compared with the experimental data of Ampofo and Karayiannis [2]

3 Results

3.1 Velocity

All the schemes predict a temperature profile that fits very well with the experimental data. However, UMIST and van Leer schemes overpredict the peak velocity in the boundary layer. As the velocity profile approaches the free stream, there is underprediction in the predicted profiles. Comparison between the schemes show that predictions are identical, however, the QUICK scheme gives the best match to the experimental data.

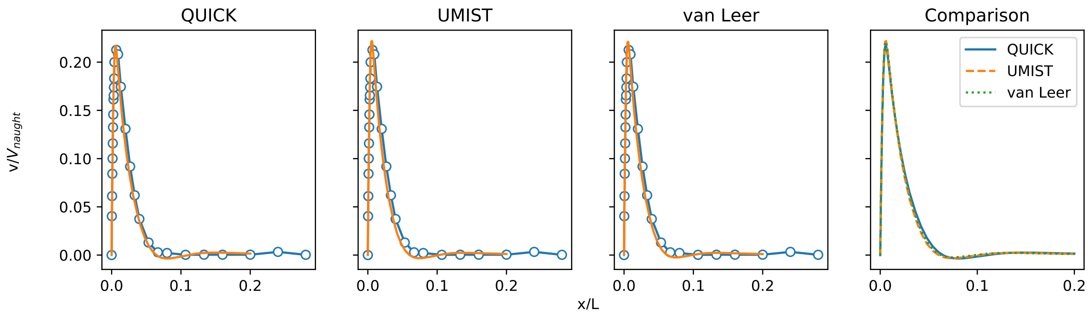

Figure 2: Vertical velocity component near the hot wall along a horizontal line at a height of 0.375 m.

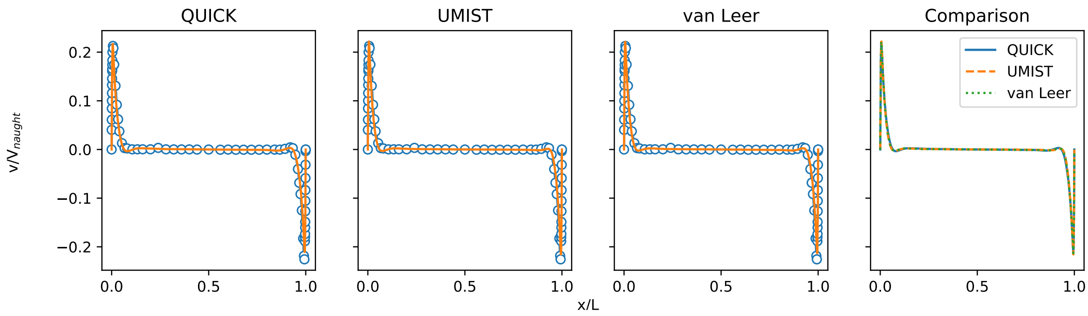

Figure 3: Vertical velocity component along a horizontal line at a height of 0.375 m.

3.2 Temperature

Prediction of the temperature profile in the conductive layer is accurate as it overlaps with the experimental data, but under predictions are observed as the free stream is approached. Among the numerical schemes tested, no significant difference is observed.

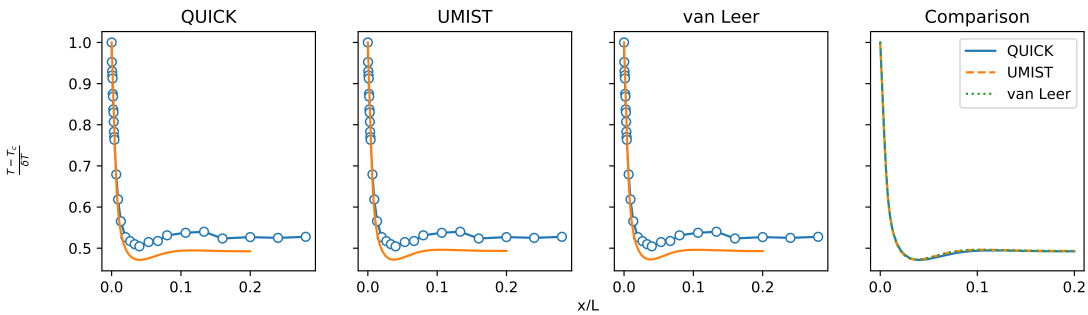

Figure 4: Temperature profile near the hot wall along a horizontal line at a height of 0.375 m.

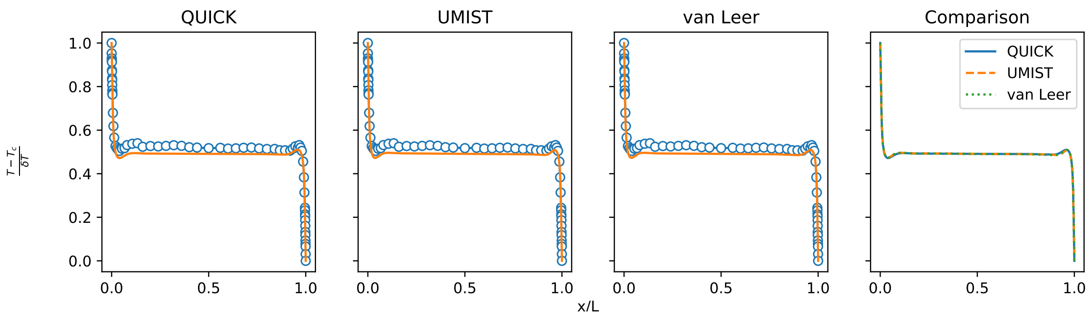

Figure 5: Temperature profile along a horizontal line at a height of 0.375 m.

3.3 Turbulence kinetic energy

The prediction of the turbulence kinetic energy (k) is very poor as all the schemes underpredict it by a very large margin. Underprediction of turbulence quantities is one of the chief disadvantages of the RANS turbulence models. Within the boundary layer, the peak value is underpredicted, however, as the profile approaches the free stream prediction begins to improve but with overprediction. In this connection, the van Leer scheme gives the best prediction followed by the UMIST and QUICK schemes.

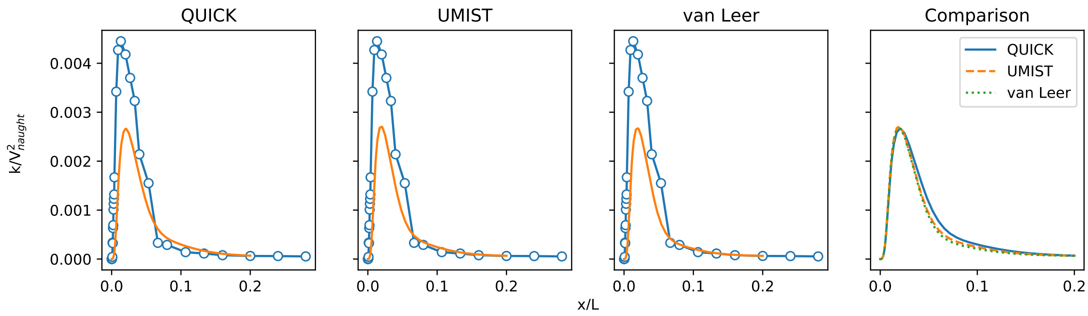

Figure 6: Turbulent kinetic energy profile near the hot wall along a horizontal line at a height of 0.375 m.

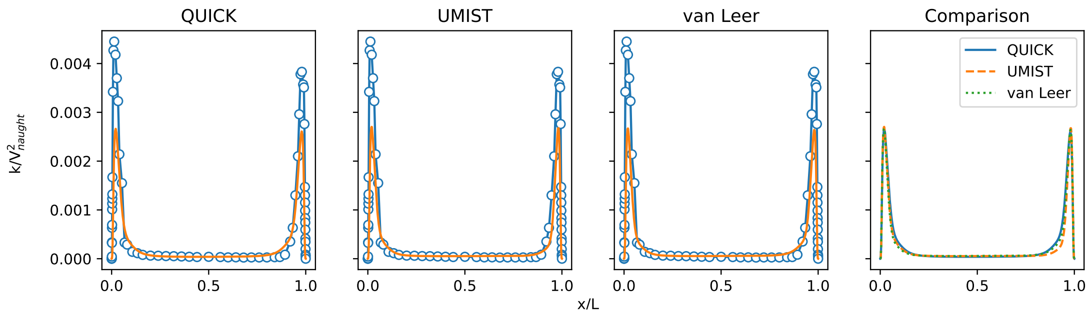

Figure 7: Turbulent kinetic energy profile along a horizontal line at a height of 0.375 m.

4 Conclusion

Turbulent natural convection in a square enclosure was simulated using the Wilcox $k-\omega$ turbulence model with three convective discretization schemes i.e. QUICK, UMIST and van Leer. It was observed that the QUICK scheme gave the best prediction of the vertical velocity component while the UMIST and van Leer over predicted peak velocity in the boundary layer. All turbulence model gave similar results in temperature prediction with no significant difference. In the prediciton of the turbulence kinetic energy, van Leer gave the best prediction followed by the UMIST and the QUICK scheme.

Nomenclature

β volume expansivity

μ Dynamic Viscosity

ω specific dissipation rate

ρ density

Cp Specific heat

k turbulence kinetic energy

Pr Prandtl number

Ra Rayleigh number

Mol. weight Molecular Weight

QUICK Quadratic Upwind Interpolation for Convection Kinetics

UMIST Upwind Monotonic Interpolation for Scalar Transport

References

[1] The OpenFOAM Foundation, OpenFOAM v6 User Guide, url: ***https://cfd.direct/openfoam/user-guide***

[2] Ampofo F., Karayiannis T.G., Experimental benchmark data for turbulent natural convection in an air filled square cavity, **International Journal of Heat and Mass Transfer** 46 (2003) 3551-3571.