ABSTRACT

Most of the turbulent flows are wall-bounded in practical applications. The formation of viscous sublayer very close to the wall is one of the distinguished characteristics of wall-bounded flows. The conventional wall functions which are widely used with RANS (Reynolds averaged Navier-Stokes) based high-Reynolds number turbulence models in forced convection boundary layer flows are not applicable in case of natural and mixed convection boundary layer flows. The equilibrium and other assumptions which form the basis of wall functions do not hold in case of natural and mixed convection boundary layers. Thus, low-Reynolds number turbulence models are more suitable as compared to high Reynolds number models for natural and mixed convection type boundary layer flows. The low-Reynolds number turbulence models do not require the wall functions; instead, the entire boundary layer is resolved with very fine grids to capture the sharp gradient near the wall. An in-house computer code is developed to solve wall-bounded turbulent flows using various low-Reynolds number models and the standard $k-\epsilon$ model. The computer code is first validated and then applied to study turbulent forced convection, natural convection and mixed convection type wall-bounded flows. A detailed computational study of flow and heat transfer characteristics of wall-bounded offset jet and wall jet has been carried out using standard $k-\epsilon$ model, shear stress transport (SST) model, low-Reynolds number $k-\epsilon$ models proposed by Launder and Sharma (LS) and Yang and Shih (YS). The existence of Moffatt vortices (secondary recirculation region) have been identified in the corner for low-Reynolds number modeling. The low-Reynolds number models have very accurately mimicked the law of the wall in the viscous sublayer. The predictions obtained from low-Reynolds number models for skin friction coefficient, near-wall velocity profile, near-wall temperature variation, heat transfer coefficient and other relevant variables are in closer agreement with the available experimental results. The entrainment cooling is higher for offset jet with higher offset ratio. The study is then extended to study the effects of freestream motion on flow and heat transfer characteristics of turbulent offset jet. Based on the study, it has been observed that the freestream motion reduces entrainment of the surrounding fluid and suppresses heat transfer from the jet to the surrounding fluid. Then, a detailed investigation has been made on the relative performance of various low-Reynolds number turbulence models (YS model, Wilcox $k-\omega$ model and SST model) for a buoyancy-driven flow (natural convection flow) in a tall cavity (aspect ratio 5) for Rayleigh number 4.56×10^{10}. The careful review of available literature shows that accurate prediction of turbulent buoyancy driven flow in an enclosure is numerically challenging due to complex flow that involves laminar, transition and turbulent regimes of flow, and some other problems reported in the literature e.g. grid dependency of solution, sensitivity of transition location with grid size, numerical stability problem, etc. The extensive grid independence study has been carried out and then the computed results are compared with the available experimental and computational results. Based on the study, it has been observed that YS model gives a very good agreement with the available experimental results among the models considered. In addition, YS model gives better prediction as compared to computational results of other RANS models available in the literature. Finally, a numerical investigation of a buoyancy-opposed wall jet flow has been carried out with the YS model. The buoyancy-opposed wall jet flow in a rectangular channel subjected to a slowly moving counter-current stream has been identified and declared as "application challenge" as the flow phenomenon is very complex despite relatively simpler geometry. The investigation reports the successful reproduction of the available experimental results for the non-buoyant as well as the buoyant cases.

Keywords: wall jet; offset jet; low-Reynolds number model; viscous sublayer; freestream motion; turbulent natural convection; buoyancy-opposed flow