Challenges in Computation of Turbulent Slot Jet Impinging on a Heated Wall

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Abstract

Computations of impinging slot jet for high and low nozzle-to-plate spacings have been performed and discussed. Computations using the Reynolds-Averaged Navier-Stokes (RANS) equations based turbulence models and large eddy simulations (LES) have been performed in order to obtain detailed flow and thermal characteristics. For the case of low spacing the standard *k-ω* and SST *k-ω* models and for high spacing the standard *k-ε* model showed good agreement with the reported experimental results. LES computations of mean and instantaneous flow and thermal characteristics were observed to be close to the reported experimental results.

1. Introduction

Jet impingement heat transfer is widely used in industrial applications as an effective way of heat transfer between a fluid and a solid surface. Jet impingement heat transfer techniques are used wherever high performance cooling, heating or drying of a surface is required. Some important industrial applications [1] are cooling/heating of electrical equipment, drying requirement associated with textile industries, cooling of turbine blades, cooling of outer combustor wall, etc. Apart from its industrial significance it is widely used to test computational models, such as, RANS based turbulence models, LES models and hybrid models [1-3]. A jet impingement involves several complex flow and heat transfer phenomena, such as, free jet, potential core region, stagnation zone, wall jet region and existence of secondary peak in Nusselt number profiles for low nozzle-to-plate spacing [4-5]. Computations with all these complexities is a challenging task [1-3, 5]. Different RANS based turbulence models considered in the literature for impinging jet were not able to predict flow and heat transfer characteristics accurately excluding a few [1-3]. Some researchers have reported that LES is capable of predicting flow field and heat transfer data within the accuracy limits [1, 5]. Direct numerical simulation (DNS) can be useful but is limited to simple geometry with low Reynolds number. The application of DNS is computationally more expensive than that for LES [1].

The present work deals with a numerical investigation of heat transfer and flow structures arising due to a planar slot jet impinging on a heated plane surface. The computations were performed using the packages ANSYS Fluent 15 and OpenFOAM 4.1. Several RANS turbulence models were tested on a planar jet impinging on a smooth surface. LES computations were also carried out and obtained results showed better accuracy with the reported experimental data compared to those using RANS models.

2. General Specifications

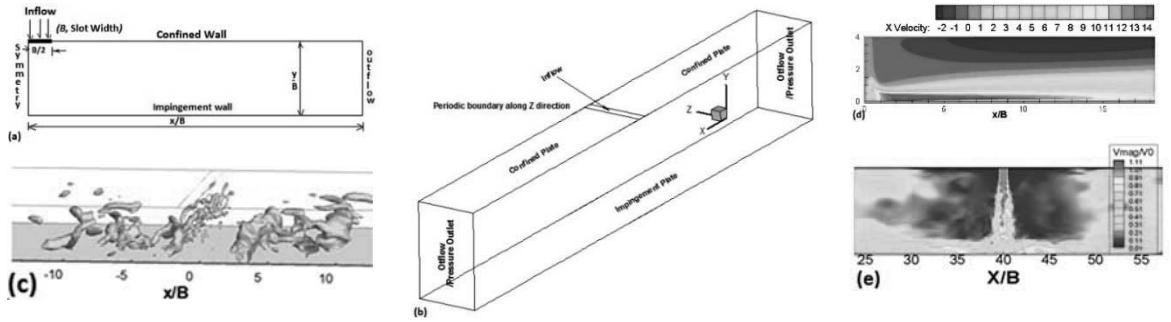


Figure 1. (a, b) Computational domain and important boundary conditions; (c, d, e) typical flow characteristics of iso-surface of low pressure, mean and instantaneous velocity contours.

Figure 1 shows details of the computational domain considered in the present study and typical flow pattern. Figure 1a shows 2D computational domain for RANS computations and Figure 1b 3D computational domain for LES computations of jet impingement on flat surface. The no slip boundary condition was applied at all the walls (confined and impingement walls). A constant temperature was considered at the impingement plate. A fully

developed velocity profile observed in experiments was applied at the nozzle exit with the specification of the nozzle exit velocity *U* based on *Re* with turbulence intensity (*I*) and turbulent length scale. The outflow boundary conditions were applied at sufficiently large distance to avoid a reversed flow. Periodic boundary conditions were applied at z = *0, W* [1].

3. Equations

In the RANS approach, the time-averaged governing equations are solved. The instantaneous velocity field can be decomposed into its mean (time-averaged) $\bar{u}_i(x)$ and fluctuating components $u_i'(x, t)$, such that, $\overline{u_i'} = 0$. The time-averaged governing equations for the conservations of mass, momentum and energy can be written as (here all symbols have their standard meanings):

$$\frac{\partial \rho}{\partial t} + \rho \frac{\partial \bar{u}_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial x_j}\left(2\mu \bar{S}_{ij} - \rho \overline{u_i' u_j'}\right) \tag{2}$$

$$\frac{\partial \bar{T}}{\partial t} + \bar{u}_j \frac{\partial \bar{T}}{\partial x_j} = \frac{1}{\rho}\frac{\partial}{\partial x_j}\left(\frac{\kappa}{c_p}\frac{\partial \bar{T}}{\partial x_j} - \rho \overline{u_i' T'}\right) \tag{3}$$

4. Results and Discussion

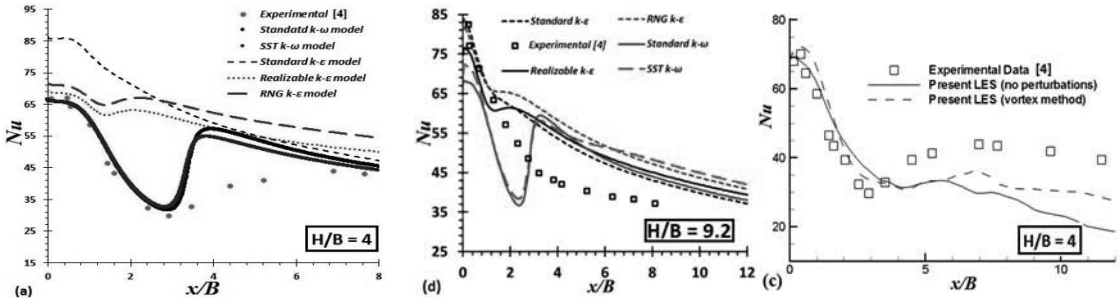


Figure 2. *Nu* Profiles for (a, d) *H/B* = 4 and 9.2 (RANS computations); (c) *H/B* = 4 (LES computations).

Figure 2 shows Nusselt number profiles obtained using different RANS based turbulence models and LES computations with Smagorinsky's SGS model. From Figure 2a one can observe that the standard and SST *k-ω* models perform better than other turbulence models. Both the models show a secondary peak in *Nu* as in reported experimental data. For high spacing the standard *k-ε* model performed better than other models, which showed a false secondary peak in *Nu*. A secondary peak in *Nu* can also be seen in LES computations for low spacing in accordance with the experimental data [4] (Figure 2c). Other flow quantities, such as, instantaneous, mean and turbulence profiles of velocity, temperature, etc., were also studied from the computations of RANS and LES. LES computations of turbulent slot jet impingement were observed to be quite accurate.

5. Summary

We have observed that the standard *k-ω* and SST *k-ω* models were able to predict a secondary peak in Nusselt number for low *H/B* value. The standard *k-ε* model was found to be appropriate for high *H/B* value. Turbulence quantities predicted by LES were more accurate than those by RANS computations.

6. References

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