NUMERICAL STUDY OF THE TURBULENT SLOT JET IMPINGEMENT HEAT TRANSFER USING THE MODIFIED SST K-W MODEL BASED ON OPENFOAM

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Abstract: Jet impingement heat transfer has been applied in many industry fields due to its high heat and mass transfer rate. A numerical simulation about the turbulent slot steady jets has been carried out using the modified SST- *k-ω* model based on OpenFOAM. The cases studied are of nozzle-plate spacing of 4 and 9.2, respectively, and the Reynolds number is 20,000. The modified SST *k-ω* turbulence model is constructed based on the Kato-Launder mode. To test the modified SST *k-ω* model's validation for jet impingement, the velocity profiles, skin friction and Nusselt number distribution are investigated in detail. By comparing with both experimental data and other numerical results, the good agreement between the present model and the experimental data has indicated the model's ability for predicting the transition in slot impinging jets.

1 Introduction

The SST *k-ω* model proposed by Menter [1] which blends the standard *k-ε* model and *k-ω* model is very popular in many applications. However, the complex impinging jet flows are also challenges for various turbulence models, due to the complex phenomena including the vortex developing, separation and high adverse pressure gradient [2, 3]. For a typical impinging jet, there are a dip and second peak of the Nusselt number along the impinging plane at low nozzle-plate spacing ($H/B \leq 4$), which disappear at high nozzle-plate spacing. This phenomenon is affected by the laminar to turbulence transition [2]. Thus, the turbulence models with the ability of predicting the transition have been carried out to investigate the jet impingement problems in recent years [3-5]. Based on earlier studies, the SST *k-ω* model has been recommended due to its appropriate performances [6]. And the SST *k-ω* model has been used in many studies, which shows good performances in jet impingements [7-10]. However, the SST *k-ω* model predicted the second peak and dip of Nusselt number earlier than the experiment and provided a false secondary peak of the Nusselt number at high nozzle-plate spacing [3, 11]. These findings imply that there is not a single turbulence model which shows best for different conditions, which leads to the importance of studying the new modifications using the same framework to assess their relative performances.

The work of this paper modifies the SST *k-ω* model based on the Kato-Launder model to the available reference data [3, 12-14] for different nozzle-plate spacing of 4 and 9.2. The Kato-Launder modification has been succeeded in improving the flow structures not only in the stagnation region but also in the wall jet region [15]. Various comparisons against the experimental data and numerical results in terms of velocity profiles, skin friction and Nusselt number distribution are presented in this work.

Section 2 describes the modified work for SST *k-ω* model. Section 3 shows the results of the velocity profiles, skin friction and Nusselt Number distribution. Section 4 presents the conclusions draw from the present study.

2 The modified SST *k-ω* model

The modifications based on the Kato-Launder model are carried out using the open software OpenFOAM platform to ensure the codes' accuracy and robustness. The eddy viscosity for modified SST *k-ω* model is defined as:

$$\mu_t = a_1 k \frac{1}{\max\left(a_1\omega, b_1\sqrt{S}F_2\right)} \tag{1}$$

where a_1 is 0.31, b_1 is 1.0, k is the turbulent kinetic energy, ω is the specific dissipation rate, S is the strain rate and F_2 is the blending function.

The equation k and ω are modified as following:

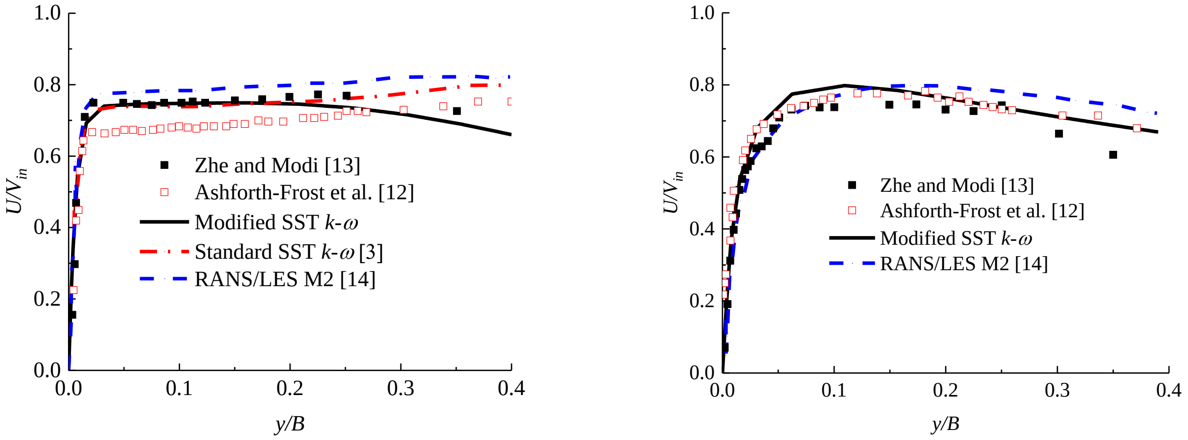
$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = \min\left(P_k, 10\beta^* k\omega\right) - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_k \mu_t\right)\frac{\partial k}{\partial x_j}\right] \tag{2}$$

$$\begin{aligned}\frac{\partial \omega}{\partial t}+U_i\frac{\partial \omega}{\partial x_i}&=\alpha\frac{\omega}{k}\min\left(Gu,\frac{c_1\beta^*\omega}{a_1}\max\left(a_1\omega,b_1F_{23}\sqrt{S}\right)\right)\\&-\beta\omega^2+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\omega}\right)\frac{\partial \omega}{\partial x_j}\right]+2\left(1-F_1\right)\frac{\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}\end{aligned} \tag{3}$$

where $P_k = 2S\Omega$, Ω is the vorticity rate, β_0^* is 0.09, $Gu=\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}$, $\beta^*=0.09$.

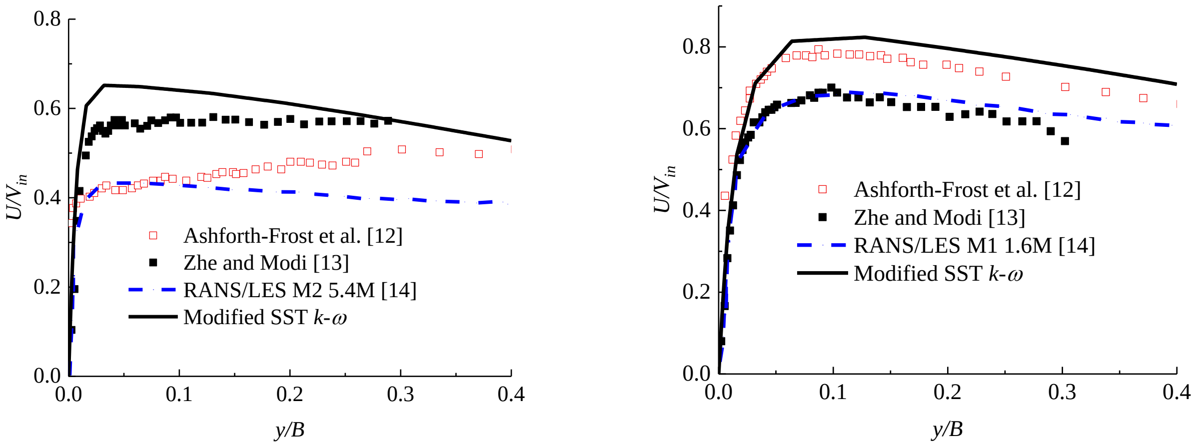
3 Results and discussion

3.1 The velocity profiles



(a) *x/B*=1 (b) *x/B*=7

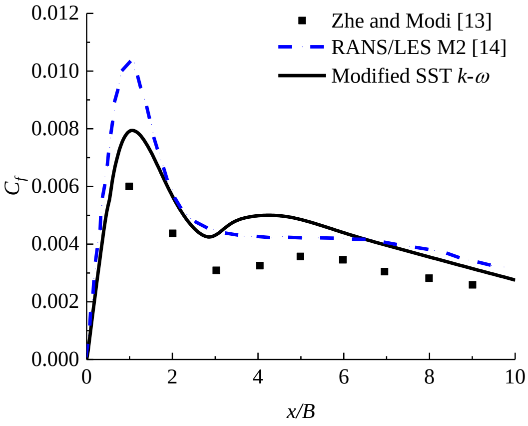
Figure 1. The comparison of velocity profiles against the experimental data and numerical results for *H/B* = 4

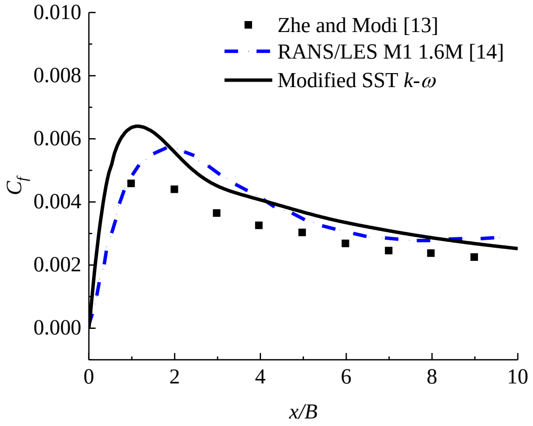


(a) *x/B* = 1 (b) *x/B* = 5

Figure 2. The comparison of velocity profiles against the experimental data and numerical results for *H/B* = 9.2

3.2 The skin friction

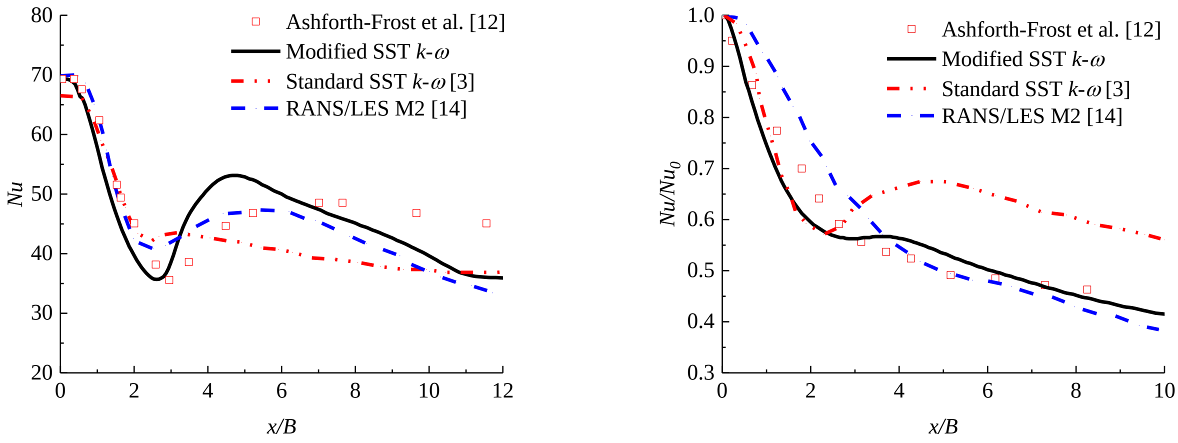




(a) *H*/*B* = 4 (b) *H*/*B* = 9.2

Figure 3. The comparison of skin friction against the experimental data and numerical results

3.3 The Nusselt Number distribution



(a) *H*/*B* = 4 (b) *H*/*B* = 9.2

Figure 2. The comparison of Nusselt Number against the experimental data and numerical results

4 Conclusions

The modified SST *k-ω* model has been assessed in this work for turbulent slot impinging jet with two different nozzle-plate spacing of 4 and 9.2. The results are compared with the standard SST *k-ω* model, the RANS/LES model and the experimental data in terms of fluid structures including the velocity profiles, skin friction and Nusselt number distribution. It is observed that the modified SST *k-ω* model improves the ability of predicting the transition process and overcomes the false secondary peak of the Nusselt number at high nozzle-plate spacing (*H*/*B* = 9.2) which is predicted by the standard SST *k-ω* model. In general, the modified SST *k-ω* model provides fair performances using low computational resources comparing with the RANS/LES model.

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