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CONVECTIVE HEAT TRANSFER PREDICTIONS IN AN AXISYMMETRIC JET IMPINGING ONTO A FLAT PLATE

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ABSTRACT

The paper shows the results of the convective heat transfer prediction in turbulent axisymmetric jets impinging onto a flat plate using the newest version (2006) of the k-ω turbulence model of Wilcox [1]. Improvements to the heat transfer predictions are obtained in the strongly strained flow regions with the impingement invariant proposed by Manceau [2] together with the F_1 function proposed by Menter (1993). As an alternative, a modification based on the von Karman length scale is also discussed.

The heat transfer rates predicted by the new version of the k-ω model are closer to the experimental data than with earlier versions due to a stress limiter reducing production of turbulent kinetic energy in stagnation flow regions.

In order to further improve heat transfer predictions in stagnation flow regions even stronger damping of the turbulent viscosity is required, especially when the impingement plate is placed within the stress-free core of the jet. In the present simulations, the turbulent viscosity ν_t in the k-ω model is modified multiplying the limiter in Eq. (1) by the impingement function F_{imp}

$$\nu_t = \frac{k}{\tilde{\omega}},\ \tilde{\omega} = \max\left(\omega, C_{\lim} F_{imp}\sqrt{\frac{2S_{ij}S_{ij}}{\beta^*}}\right) \qquad (1)$$

where $\beta^*=0.09$, $C_{lim}=7/8$. The impingement function F_{imp} is

$$F_{imp} = 1 + A_{imp}F_1P_{norm} \ \text{where}\ P_{norm} = \frac{3}{2}\frac{\left[MIN\left(P,0\right)\right]^2}{\eta^2},\ P=\left\{\mathbf{SM}\right\},\ \eta=\sqrt{\left\{\mathbf{S}^2\right\}} \qquad (2)$$

where {.} denotes the trace of the tensor, $\boldsymbol{S}$ is the mean strain rate tensor and the components of the tensor $\boldsymbol{M}$ are $M_{ij}=n_in_j -1/3\delta_{ij}$, where n_i is the *i*-th component of the unit vector normal to the wall. This unit vector also has to be defined in the interior of the flow. The value of the constant A_{imp} in (2) was set to $A_{imp}=2.0$ by tuning it for one of the test cases in order to obtain good agreement with the experimental value of the Nusselt number in the stagnation flow region. On the other hand, a correction to the length scale is proposed defining the turbulent viscosity by

$$\nu_t = \sqrt{k}\,\frac{\sqrt{k}}{\omega}\,\frac{1}{\max\left[1,\left(C_{\lim}\sqrt{2S_{ij}S_{ij}/\beta^*}\right)/\omega\right]} \tag{3}$$

The second term in Eq. (3) is the turbulent length scale l_t which is modified by

$$l_t = \min\left(l_\mu, \sqrt{k}/\omega\right),\ \ l_\mu = 0.22y_n \tag{4}$$

where y_n is the distance to the wall. Since the turbulent length scale is overpredicted in the stagnation flow regions by the two-equation model, the relation (4) can be used in order to limit the length scale.

It should be stressed that the proposed modification based on inclusion of the impingement term F_{imp} has been designed such that the results of simulations of free shear flows, channel and pipe flows and the flow over a backward facing step are not changed compared to the k-ω model results. This is crucial since the model coefficients and the constants in the auxiliary relations have been calibrated for these flows.

The test cases are axisymmetric jet flows impinging onto a flat plate with nozzle-plate distances *H/D=2, 6, 10* and Reynolds numbers *Re=23000, 70000*. Detailed comparison of the predicted and experimental mean and fluctuating velocity profiles is performed. The heat transfer rates along the flat plate are analyzed.

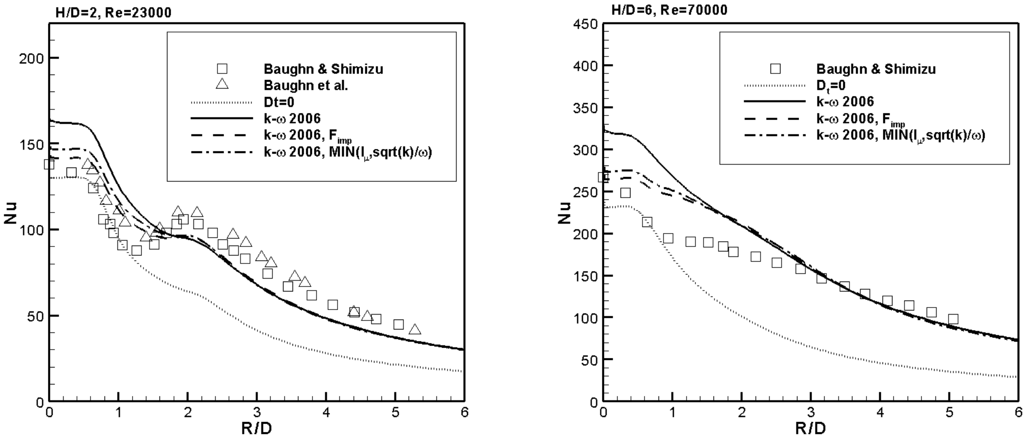

Fig. 1. Nusselt number profiles along a flat plate for various nozzle-plate distances *H/D* and for various Reynolds numbers: left *H/D=2, Re=23000,* right *H/D=6, Re=70000.*

Fig. 1 shows the Nusselt number profiles obtained with the new version of the k-ω (2006) model (solid lines), while the dashed and dashed dotted lines show the results obtained with the proposed modifications. The dotted lines ($D_t=0$) are the Nusselt numbers obtained for turbulent flow simulation but setting to zero the turbulent diffusivity in the energy equation. The stagnation Nusselt numbers are predicted correctly using the proposed modifications.

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