Numerical simulation of flow dynamics and heat transfer in a rectangular channel with periodic ribs on one of the walls

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Abstract. The result of numerical simulation of a turbulent flow in a flat channel with a periodic transverse rib by the RANS and LES methods is presented. The Reynolds number, calculated from the rib height and the superficial velocity, is Re = 12600. The data obtained as a result of the study demonstrate the influence of the modeling method and the turbulence model on the quality of heat transfer prediction. The optimal model for this type of problems is presented.

Introduction

The flow separation and re-connection are often found in various technical devices. Therefore, the research in this area remains relevant and topical. One of the most effective ways to increase the efficiency of heat exchange equipment is the ribbing of the channel walls. When one of the channel walls is ribbed, many geometric parameters, such as heat transfer and the recirculation zone length, affect the flow characteristics.

The authors of [1,2] experimentally studied and numerically simulated the effect of a longitudinal pressure gradient on heat transfer on the lower wall of the channel. In accordance with data of [1], with an increase in the pressure gradient, the maximum heat transfer (indicated by the local value of the Nusselt number) increases for a converging channel and decreases for an expanding one. In this case, the position of the maximum heat transfer behaves in a similar way. In [2], in order to change the longitudinal pressure gradient, the ratio between the channel height before and after expansion (ER is expansion coefficient) was changed. Thus, an experimental study of the backward-facing step for Reynolds numbers of up to 180,000 was conducted. One of the aspects studied was the influence of the Reynolds number and the degree of expansion on the length of the recirculation zone. As a result of the obtained data and their comparison with other works, it was shown that the length of the recirculation zone decreases with an increase in the Reynolds number. However, at that, for Re > 10^4, the expansion coefficient becomes the determining parameter. At the same time, the length of the recirculation zone increases with an increase in the degree of expansion. In addition, the flow characteristics are influenced by the height of the vortex generator [3], its position [4], etc.

When using different turbulence models, the data on the flow structure and heat transfer in the channel may be very different, despite the relatively simple geometry of the problem. Specifically, the authors of [5] carried out numerical modeling of a turbulent flow in a channel with periodic ribbing using various closure methods. Approaches were proposed to improve the prediction of the flow behavior, which provided for better results.
A problem with such a geometry has also been investigated experimentally. Specifically, in [6,7], heat transfer was measured by holographic interferometry at almost identical Reynolds numbers (Re = 12,600 and 13,100). The distribution of the local Nusselt number was obtained. The data on heat transfer demonstrated that in [6] it increased with a distance from the edge, reaching its peak before the next rib, while in [7] it had an almost uniform distribution along the channel.

This paper is devoted to the numerical simulation of the separation flow in a flat channel in the presence of transverse periodic ribs using different modeling methods and closure models.

**Computation details**

This paper presents the results of numerical simulation of the separation flow in a flat channel in the presence of periodic inclined ribs. The Reynolds number, calculated from the rib height and the superficial velocity, is equal to Re = 12,600. The computational domain shown in Figure 2 includes two ribs, with the height being e/H =1/5. A constant heat flux is set on all the walls except the upper one, which is thermally insulated. At the inlet and outlet of the computational domain, periodic boundary conditions are set.

Numerical simulation is performed by the RANS and LES methods. The RANS simulation is implemented using the k-omega SST and v2f models. When modeling by the LES method, the Smagorinsky model is used. The integration of all equations included in the mathematical model is carried out using the second-order precision control volume method in a stationary (iterative) formulation using the simpleFoam solver from the OpenFOAM package. Preliminary calculations serve to select optimal grids, in which the solution ceases to depend on the number of cells.

![Figure 1. Layout of computational domain.](image)

**Result and discussion**

Data on the dynamics and heat transfer of a turbulent flow in a flat channel with periodic transverse ribs are obtained. Figure 2 shows the results of modeling of the turbulent flow in comparison with the experiment and calculations of other authors. Local heat transfer is shown on a surface with a constant heat flux. It can be seen from the figure that v2f has the best agreement with the experiment. However, it does not reflect the peaks that are present in the experiment at x/e =7. The calculation performed by the LES method gives slightly overestimated values of the local Nusselt number, but at the same time it registers the presence of peaks. It is also worth noting that the presence of these peaks is not a reliable criterion, since they may be absent in various experiments or calculations. Despite the fact that the k-omega SST model is considered a universal model for wall modeling, it is the least suitable for this task. The values of the Nusselt number differ from the experiment in most part of the channel by 50%.
**Figure 2.** Distribution of the local Nusselt number when using different approaches for modeling.

Figure 3 shows the distribution of the kinetic energy of turbulence. It can be seen that in the case of using the v2f model, the kinetic energy is significantly greater than for the k-omega SST model, which is consistent with the data on heat transfer.

**Figure 3.** Distribution of the kinetic energy of turbulence for: a) k-omega SST; b) v2f model c) LES.

Figure 4 shows the distribution of friction on the surface under various modeling methods. As a rule, when using different turbulence models, the flow dynamics weakly depends on the selected
RANS model. However, for this task, these differences are significant. In the case of LES modeling, the maximum flow velocity in the recirculation zone is greater than when using the RANS method. When using the v2f model, a larger secondary vortex is formed directly behind the rib than in the case of the k-omega SST model. The greatest difference is observed in the area where the flow is incident to the rib. With LES modeling, the vortex flow intensity is much higher than when using the RANS method.

![Figure 4. The distribution of friction on the surface for k-omega SST, v2f, LES.](image)

**Conclusion**

Numerical simulation of the dynamics of turbulent flow and heat transfer in a flat channel in the presence of periodic transverse ribs has been carried out by the RANS and LES method. The use of different modeling methods and closure models is shown to lead to significantly different data on heat transfer. Thus, the use of the k-omega SST model leads to an underestimation of the value of the Nusselt number. The best agreement with the experiment has been achieved using the v2f model.

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