Effect of the attack angle of the ribs on the flow and heat transfer in a flat channel

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Abstract. The results of numerical simulation of a turbulent flow in a flat channel with periodic inclined ribs by the RANS method are presented. The Reynolds number, calculated from the rib height and the superficial velocity, is Re = 12600. The obtained data are analyzed in order to determine the influence of the inclination angle on heat transfer. It is shown that the optimal angle of inclination, at which the average heat transfer in the channel is maximum, is 60°.

1. Introduction

The relevance of studies of complex turbulent separation flows is due to practical applications, requiring heat transfer enhancement with minimizing hydraulic losses. As a rule, the flow separation occurs due to a change in geometry, which has a great influence on the flow structure. One of the ways to control the flow structure and, as a result, the intensity of heat transfer is the use of vortex generators, the dimensions of which are significantly smaller than the characteristic size. The use of vortex generators refers to passive methods of controlling the parameters of the separation flow. Elements of various shapes can act as a vortex generator. So, in works [1,2], the tabs, being a cubic barrier, were used as a means of changing heat transfer. The authors demonstrated that the tabs have the greatest effect on the heat transfer in the flow recirculation zone. Their use leads to the destruction of the stagnant region due to the appearance of three-dimensional large-scale turbulent structures. At that, the height of the tabs also has a significant impact.

The use of a two-dimensional barrier in the form of a transverse rib allows intensifying heat transfer more strongly, but for the account of increasing hydraulic losses. So, in work [3], the influence of position and height on the intensity of heat transfer is studied. It is shown that the presence of transverse ribs increases the value of the Nusselt number up to 25%.

Another variant of the passive control method is presented by the authors of [4]. In the paper, a numerical simulation of a channel with inclined ribs located on the channel wall behind the backward-facing step is carried out. The calculation is performed for different Reynolds numbers and for different slopes of the ribs. In accordance with the results, for a small Reynolds number (Re = 4000), the angle between the rib and the channel wall slightly affects the level of heat transfer. A correctly selected angle with a high Reynolds number (Re = 24000) allows improving the heat transfer in the channel up to 1.21-1.74 times as compared to a smooth channel. Such an increase in heat transfer is associated with better mixing of the liquid, caused by the vortex movement between the ribs and the channel surface.
This paper is devoted to the numerical simulation of the separation flow in a flat channel in the presence of a transverse periodic rib. The influence of the inclination angle of ribs on the behavior of the separation flow is analyzed.

2. 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 height of the step and the superficial velocity, is equal to $Re = 12,600$. The computational domain includes one rib, the middle line (h) of which is constant in all cases. The variable parameter is the angle of inclination. 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 technical conditions are set. Figure 1 shows the computational domain.

The numerical simulation is performed by the RANS method. 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 served to select optimal grids, in which the solution ceases to depend on the number of cells.

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

3. Result and discussion
Data on the dynamics and heat transfer of the turbulent flow in the flat channel with periodic transverse ribs are obtained. Figure 2 shows the stream lines for a rib with a different angle of inclination (45°-135°). In all cases, the middle line of the rib is the same (h/H = 1/5), and the distance between adjacent ribs is $w = 9.7h$. The flow runs from left to right. It can be seen from the figure that the presence of a roughness element leads to a significant flow restructuring. So, for all cases, the formation of an extended recirculation zone behind the rib is characteristic. At that, this zone extends to almost the entire space between the ribs. The flow velocity in this area reaches 15% of the maximum one. The figure shows that for all cases, in addition to the main recirculation zone, a secondary vortex is formed before and after the rib, except for the geometry with an angle of inclination of 45° and 135°. The velocity value for all cases is approximately the same, and the difference may be only a few percent. This may be explained by a small rib height as compared to the channel width.
Figure 2. Flow structure in a flat channel with inclined ribs for the angle of inclination: a) 45° b) 60°, c) 90°, d) 120°, e) 135°.

Figure 3a shows the dependence of the local Nusselt number on the lower wall of the channel, starting from the area located directly behind the rib. To calculate the local Nusselt number, the temperature on the wall surface and the average cross-section temperature are used. The figure shows that the profiles have a similar shape. To evaluate the effectiveness, Figure 3b presents the values of the maximum and average Nusselt numbers depending on the inclination angle of the rib. It follows from the graph that the optimal angle in terms of heat transfer efficiency is 60°. Since the heat transfer intensity is significantly affected by the size of the vortex generator, the results presented in Figure 4b are similar in their values. When the angle of inclination varies, the transverse size of the rib changes slightly. The table shows the results of the hydraulic resistance from the inclination angle. The table shows that an increase in heat transfer is accompanied by an increase in hydraulic resistance.
4. 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 method. The change in the inclination angle is shown to lead to the flow restructuring, and the formation of a recirculation zone with the appearance of secondary vortices. The angle of inclination also affects the efficiency of heat transfer. It is shown that the optimal angle of inclination of the rib is 60° for this geometry.

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