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Decrease of pressure losses in elbow fittings of ventilation systems of thermal power plant buildings

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Abstract. The paper presents the results of a numerical study of the flow in the elbows of the ventilation systems in buildings of thermal power plants. Elbow fittings, as well as other shaped elements of ventilation systems are the main causes of energy losses. A method is proposed for reducing such losses through the use of an insert profiling the sharp edge of the elbow along the outline of the vortex zone. For a wide range of practical dimensions, numerical models of "sharp" elbows at 90° have been studied, a good correspondence between pressure losses in them, numerical and known experimental data has been shown. The outlines of the vortex zones, as well as the lengths of the influence zones of the elbow on the flow parameters upstream and downstream, are determined. Next, numerical models of profiled elbows are constructed and studied; a significant reduction in pressure losses (up to 64%) and lengths of influence zones (up to 45%) as compared with unprofiled ones is shown. Dependence has been found to determine the local resistance coefficient of the profiled elbow, which can be used in the design of ventilation systems.

Introduction

The main energy losses of ventilation systems in buildings of thermal power plants are related with local resistance of various shaped parts of ductworks - elbows, tees, cross junctions and other duct fittings. The cause of the loss is the change in the flow direction in this disturbing elements (DE) and in the formation of vortex zones (VZ) due to separation of flow on the sharp edges.

Due to inertia, the flow begins to deform long before the shaped element and completes the reorganization far beyond it. Such places of transformation of the flow structure are called influence zones (IZ) upstream and downstream of disturbing element. Available data about the length of IZ are poor and often have an experimental character [1]. This lack of information makes difficult to calculate the local resistance coefficients and, accordingly, local pressure losses in the ventilation systems during its design. A little more is known about the outlines of vortex zones in the elbows [2, 3]. However, information on the three-dimensional outlines of the VZ for elbows of different depths for different flow regimes is lacking.

One of the most advanced methods for studying hydro- and aerodynamic phenomena today is a numerical simulation. At present, there are many works on the profiling of DE using the methods of computational fluid dynamics (CFD), for example, [4, 5].



In this paper, we propose a solution for reducing the local resistance coefficients (LRC) and pressure losses in the ventilation ductwork by placing a special profiling insert inside the "sharp" shaped element, which completely repeats the outline of the free streamline separating the main flow in the channel and the region of VZ [6]. The outlines of the VZ and the lengths of the influence zones are also given.

Methods

To implement the proposed solution at the initial stage, the task was set is to determining the LRC of "sharp" elbows to compare the obtained results with reliable data of other authors [1]. To determine the dependence of LRC of the DE on its geometric characteristics, a number of problems for flow in a three-dimensional channel with an 90° elbow in a wide range of dimensions have been solved (Figure 1). The width of the channel before the bend (b_0) (Check: under the text b_0 is often called the height) took the values 0.1 m and 0.2 m, after (b_1) - 0.02; 0.06; 0.1; 0.2 and 0.3 m. The depth of the channel (a_0) was 0.025; 0.05; 0.1; 0.2 and 0.4 m and ∞ (two-dimensional task). The input boundary $ABCD$ was modeled using the "velocity inlet" boundary condition (BC), which defines a uniform velocity profile $v = 10$ m/s; at the output boundary $EFGH$, the gauge pressure was assumed to be zero, the remaining boundaries were set as a solid wall.

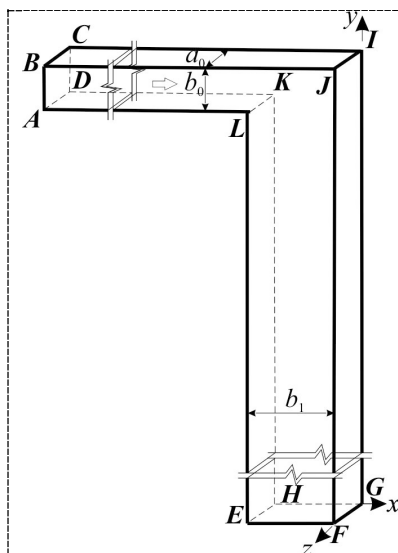


Figure 1. Geometry of the calculated area of unprofiled "sharp" elbow (for the case $b_1/b_0 = 2$ and $a_0/b_0 = 4$).

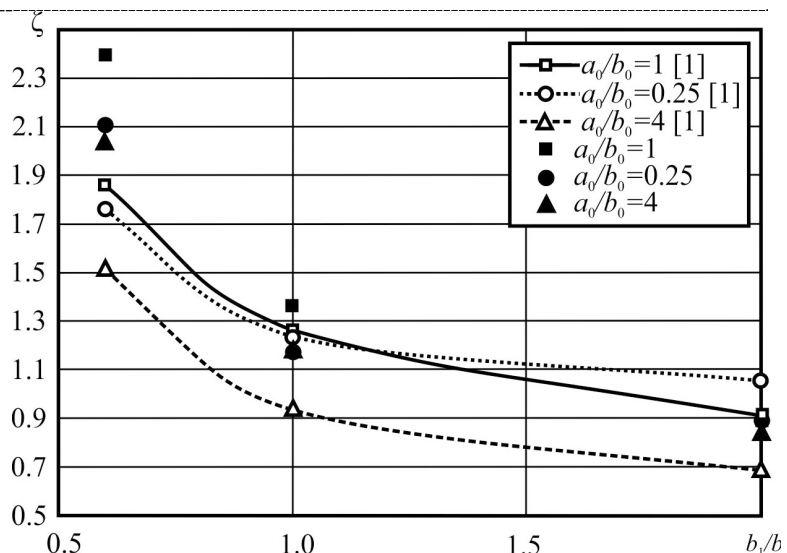


Figure 2. Dependence of the LRC of "sharp" elbow on the dimensions b_1/b_0 and a_0/b_0 .

Figure 2 shows the dependence of the LRC of "sharp" elbow on the dimensions b_1/b_0 and a_0/b_0 . The obtained results allow to make a conclusion about the decrease of elbows LRC with the increase of the channel area after the elbow, which agrees well with the data of [1] (the difference from them is within 1% -26% for different b_1/b_0). This is explained by the fact that in a such bend the flow velocity in the outlet section of the elbow reduces, and respectively reducing loss of pressure in the disturbing element.

Based on the results of the numerical calculation, the minimum value of the LRC is obtained for the maximum investigated depth $a_0/b_0 = 4$, and it decreases with increasing b_1/b_0 . This also agrees with [1] and is explained by a decrease in pressure loss in the local resistance due to a decrease in the flow velocity in the outlet section of the elbow. In [1] are mentioned two factors that affect the LRC in such elements with increasing channel size after the elbow: increase of the vortex zone, which is

accompanying with an increase in energy losses, and a simultaneous decrease in the velocity, which leads to a decrease of the LRC. It should be noted that for $a_0/b_0 = 1$, for larger values of b_1/b_0 , the LRC is somewhat larger than for a smaller in depth elbow with $a_0/b_0 = 0.25$, although the vortex zone increases with decreasing the depth of channel (Figure 6).

Results and Discussion

Influence zones

In Figure 3, the icons show the lengths of the influence zones (IZ) before (l_b) and after (l_a) the elbow, depending on the size of the channel after bend and the depth of the channel.

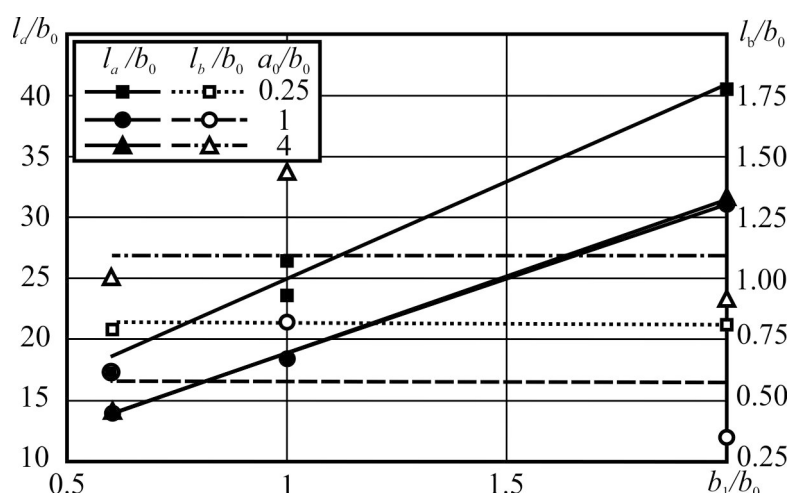


Figure 3. Dependence of the lengths of the IZ on b_1/b_0 and a_0/b_0 for the "sharp" elbow.

The lines shows the results of approximation - solid for l_a/b_0 , dotted for l_b/b_0 . Dependences of the lengths of the IZ and approximating formulas for their calculations are given in the table 1.

Table 1. Dependence of lengths of influence zones for the "sharp" elbow.

a_0/b_0	l_a/b_0	l_b/b_0
0.25	$12.596b_1/b_0+6.218$	0.583
1	$12.212b_1/b_0+6.513$	0.8
4	$15.962b_1/b_0+9.013$	1.1

It follows from Figure 3 that when the channel size after elbow (b_1) increases, the IZ after the elbow is lengthened due to the increase in the diffusive effect, which increases the flow separation and vortex formation [1]. In addition, it should be noted that the greater the depth of the channel a_0 , the more length of IZ after elbow. Dependences of the IZ length before the elbow on the change of the channel size b_1/b_0 , for the number of numerical experiments carried out, are not observed (Figure 3). However, it can be noted that as the channel depth a_0 increases, the IZ before the elbow becomes longer.

Vortex zones

To study the dependence of the vortex zone length on the flow regime, three tasks were solved in the self-similar modes with velocities: 10 m/s ($Re = 6.7 \cdot 10^4$), 80 m/s ($Re = 5.3 \cdot 10^5$) and 1000 m/s ($Re = 6.7 \cdot 10^6$) for the channel with $a_0/b_0 = 0.25$ and $b_1/b_0 = 1$. The outlines of the obtained vortex zones are shown in figure 4, where the two-dimensional case ($a_0/b_0 = \infty$) is shown with a solid line. It can be

seen that with the Re increases, the size of VZ changes insignificantly - on the main line the outlines completely repeat each other; some difference is observed in the area where the VZ is touching the wall of the elbow.

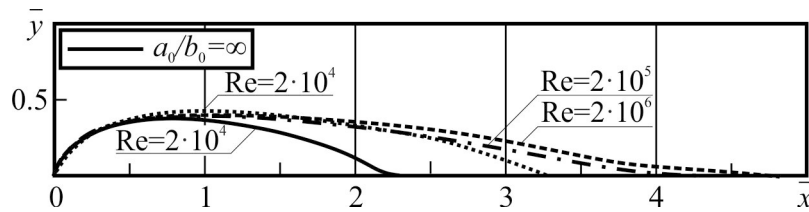


Figure 4. The lengths of the vortex zones for elbow with $a_0/b_0 = 0.25$, $b_0/b_1 = 1$ for Re from $2 \cdot 10^4$ to $2 \cdot 10^6$.

Figure 5 shows the dependence of the dimensionless length of the vortex zone x_0/b_0 on the channel depth a_0/b_0 . In this figure the lengths of the vortex zone for a depth $a_0/b_0 = 0.25$ for a different Re number are shown as individual icons.

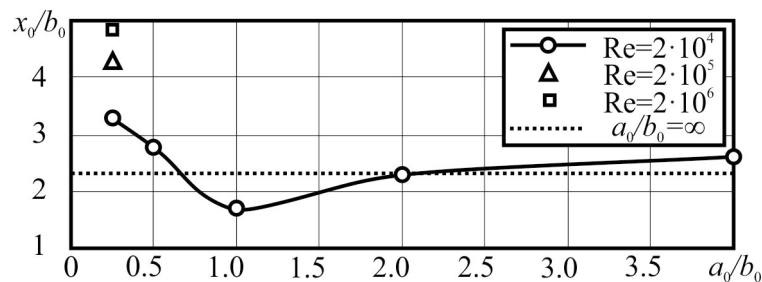


Figure 5. Dependence of the dimensionless length x_0/b_0 of the vortex zone on a_0/b_0 .

Figures 4 and 5 shows that when the depth of the channel increases, the length of the VZ decreases. Perhaps this is due to the smaller turning radius of the flow: if the depth of the channel a_0 is several times greater than its width b_0 , then the change in the flow direction in the elbow will be smoother.

Figure 6 shows the outline of the VZ of elbows with different depths, determined along the center of the channel. As preliminary study showed, significant differences in the shape of the three-dimensional vortex zone along the channel depth are observed only near the walls [5].

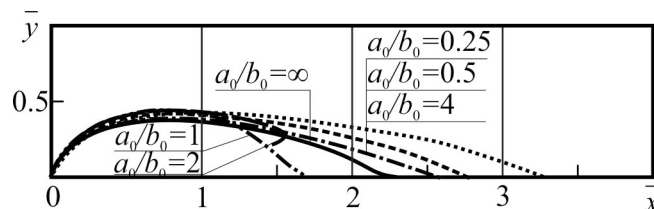


Figure 6. Outlines of vortex zones for elbows with depths $a_0/b_0 = 0.25 \div 4$.

It can be seen from figure 6 that for elbows with different sizes of a_0 practically along the entire length of the vortex zone its height and outlines agree well with the outline of the separation zone obtained for the two-dimensional model.

Modeling of efficient profiled elbow

The above-defined outlines of the vortex zones that forms due to separation of flow at the inner edge (taken from the two-dimensional model) were used to create computer models of the profiled

efficient elbows (Figure 7). Although profiling of the external elbow corner also leads to a decrease in the LRC, but it is less significant [1, 5], and therefore was not considered here.

At the next stage solved a number of tasks on the flow of air in a channel with a profiled "sharp" elbow with an angle 90° (Figure 7) for the same range of channel sizes b_1/b_0 and a_0/b_0 as for the unprofiled ones, and using those same boundary conditions and models.

Based on the results of the study, a graph of the LRC dependence on b_1/b_0 for various depth a_0/b_0 was plotted (Figure 8). The dependence of LRC on b_1/b_0 for the unprofiled elbow of one depth - $a_0/b_0 = 1$ and according to the known experimental data [1] is also given for comparison here. It can be seen that the resistance of the profiled elbow is significantly lower than the "sharp" one (reduction to 64%). It can also be concluded that, with an increase of the channel area after the elbow, a decrease of elbows LRC is observed, which agrees well with the data of [1]. This is due to the fact that at the outlet section of the elbow, the velocity of air decreases, reducing the pressure loss of the disturbing element. As the depth of the channel increases, the elbow resistance also drops. For three-dimensional elbows, the minimum LRC is also obtained for $a_0/b_0 = 4$. In addition, the plot of ζ for the two-dimensional model lies below the others, i.e. the LRC for this case is minimal. This indicates that the profile of the profiling insert, taken from the outline of the vortex zone in the two-dimensional elbow, is the best for two-dimensional model (i.e. $a_0 = \infty$) and slightly worse for the elbows with other depths.

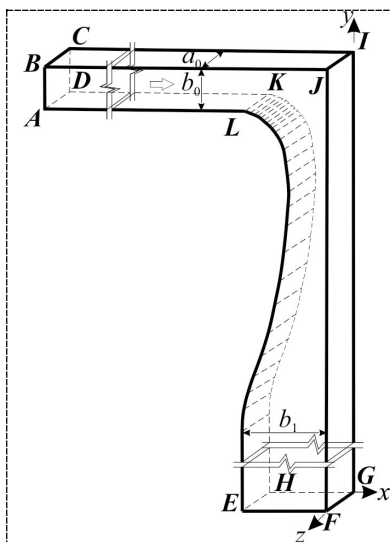


Figure 7. Geometry of the computational domain of the profiled elbow (for the case $b_1/b_0 = 2$ and $a_0/b_0 = 4$).

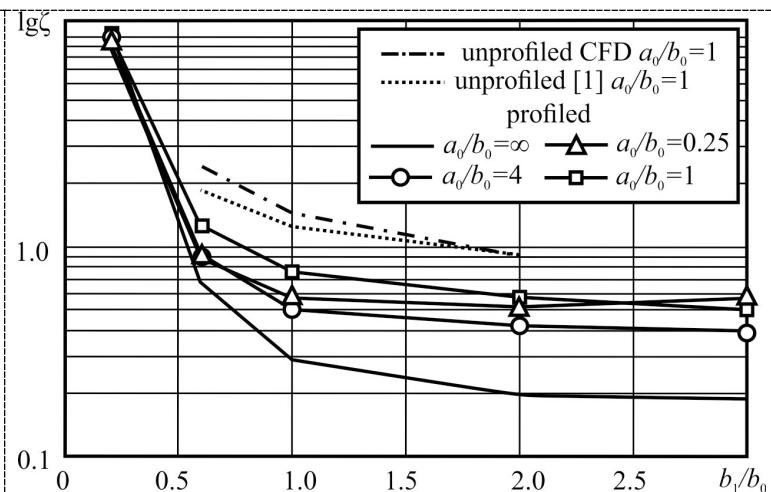


Figure 8. Dependence of LRC on the ratio of the sizes b_1/b_0 and a_0/b_0 for the profiled elbow.

Figure 9 shows the dependence of the lengths of the influence zones before l_b/b_0 (dotted line) and after the elbow l_a/b_0 (solid line) on the channel size after the elbow and channel depth for the profiled elbows. At this graph, for comparison, data for unprofiled elbow with depth $a_0/b_0 = 1$ are shown.

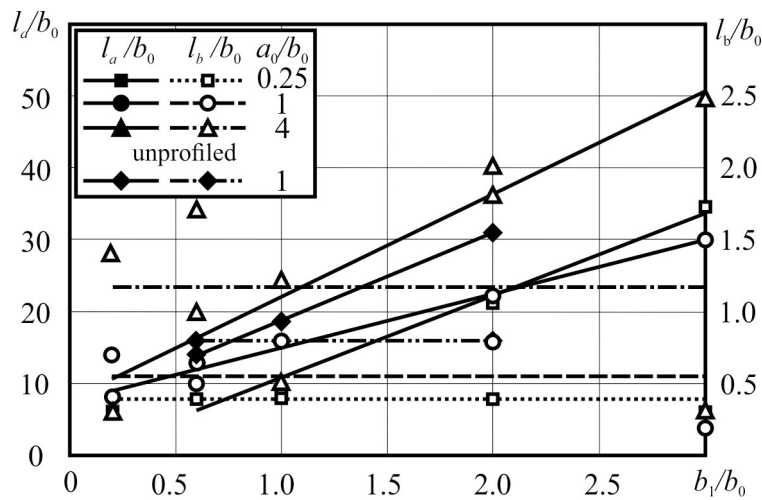


Figure 9. Dependence of lengths of the IZ on b_1/b_0 and a_0/b_0 for profiled elbows.

The results of IZ study in profiled elbows, approximating with formulas are given in the table 2.

Table 2. Dependence of IZ lengths for the profiled elbows

a_0/b_0	l_a/b_0	l_b/b_0
0.25	$11.434b_1/b_0 - 0.741$	1.18
1	$7.525b_1/b_0 + 7.339$	0.55
4	$14.251b_1/b_0 + 7.719$	0.4

The increase of the IZ length after the elbow occurs in the same way as for the unprofiled elbows, with the increase in the size of the channel after turn (b_1), and with increasing channel depth a_0 , the IZ after elbow lengthened. Dependences of the length of the IZ before elbow on the change of the size of channel b_1/b_0 are also not observed, while increasing the depth of the channel a_0 , the length of the IZ before elbow increases. Comparison of IZ of the unprofiled and profiled elbow showed that during profiling the IZ decreases to 45.5% before elbow and from 7.7 to 40.9% after it, depending of dimensions of elbow.

Conclusion

Thus, a detailed numerical investigation of the flow in the "sharp" elbow allowed to determine the outlines of the vortex zones formed when the flow is separate from the inner edge of the 90° elbow, the lengths of influence zone and the dependence of the local resistance coefficient on the wide range of its width and depth. Further, based on this data the numerical models of profiled elbows was created and the dependences of LRC and IZ on the dimensions of elbow were determined. Showing a significant reduction of pressure losses and a decrease in the length of the influence zones of such kind profiled elbows, which demonstrate their high energy efficiency.

Acknowledgments

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