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Simulation of Processes of Ventilation in the Confined Area of Trapezoidal Form

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Abstract: By using of non-stationary discrete vortices, now is possible to build a mathematical model of air flow in the closed area of the trapezoid shape, containing exhaust port, an open outlet at the entrance to which can be installed directing slim profiles. Such areas correspond to the premises with a sloping roof, at the top of which the exhaust air is produced and in the openings of windows air enters. Ventilation was regarded in different sizes of open apertures and by the presence in them directing profiles. The results can be used to arrange the ventilation in the industrial premises.

Key words: Method of discrete vortex · System of industrial ventilation · Vortex fluxes

INTRODUCTION

Simulation of circulating flows in a confined space [1] is necessary for the proper organization of ventilation. In some industrial premises there are restrictions by the amount of air velocity. The main purpose is to determine on the basis of the developed mathematical model and the numerical experiment the most rational scheme of ventilation in these premises.

Part and Parcel: The physical formulation of the problem is to determine the velocity field of the vortex structure of the flow inside the confined space of non-rectangular form, the top of which there is a suction port and containing open apertures from where comes air from the outside (Fig. 1).

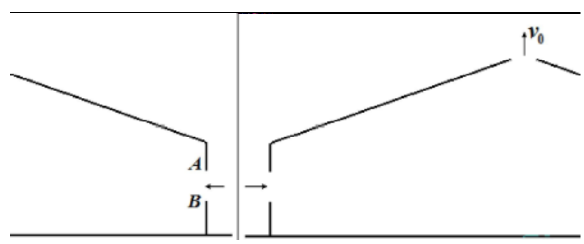

Fig. 1: By the statement of the problem

Because the flow is symmetric relative to the vertical axis, we shall consider only one part of the computational domain (Fig. 2), in the open outlet of which may also contain a thin profile.

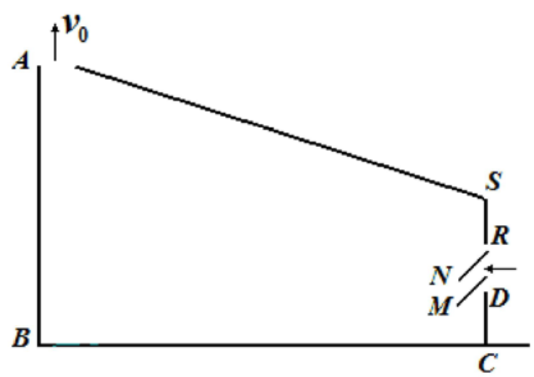

Fig. 2: The estimated flow domain

We assume that the environment is ideal, incompressible.

For constructing mathematical model was used the method of singular integral equations, which is widely used in the aerodynamics of the dust ventilation [1-14]. The mathematical statement of the problem consists in solving of the Laplace equation for the potential function φ at each calculated moment of time:

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$\Delta\varphi = 0$

With given values of the boundary normal velocity component $\partial\varphi/\partial n|_S = v_n(x) - U_n$, where x - point boundary S. The function represents the effect of available vortices in the flow, converging with from sharp edges at each calculated moment of time, along the direction of the outward normal. Assume that the boundary of the area is composed of z lines, which is discretized a set of added vortices and control (calculated points). On fractures and its ends of the lines should be located vortices. In the middle, between two attached vortices are located control points. Then, if the attached vortices N, the control points N-z. At $z = 0$, the algorithm is simplified and corresponds to simulation of vortex flows in a simply connected region.

Let us consider the initial moment of time $t = +0$, when the suction port is activated. At this moment of time the area contains only attached vortices. Influence of these vortices at the reference point along the direction of the normal is determined from an expression:

$$v_n(x^p) = \sum_{k=1}^{N} G(x^p, \xi^k) W(\xi^k) \tag{1}$$

Where

$$G(x^p, \xi^k) = \frac{(x_1 - \xi_1)n_2 - (x_2 - \xi_2)n_1}{2\pi\left[(x_1 - \xi_1)^2 + (x_2 - \xi_2)^2\right]}$$

(x_1-x_2) coordinates of the point $x^p, (\xi_1, \xi_2)$ - coordinates of the bound vortex with circulation $W(\xi^k)$, located at the point ξ^k; $\{n_1,n_2\}$ -oordinates of unit vector of normal n to the boundary of the region; $v_n(x^p)$ - velocity at the point x^p ong the direction n that is known in formulating the problem.

By varying p from 1 to N-z in (1) we get a system of equations N-z with N unknown circulations $W(\xi^k)$, where $k = \overline{1,N}$. We supplement considered system z equations, which are discrete analogues of the Thompson - invariance circulation of the liquid contour, surrounding the profile and trace (the amount of circulation bound vortices that are located on the line and free vortices coming down from it, is equal to zero). Then we obtain a closed system of linear algebraic equations:

$$\begin{cases} \sum_{k=1}^{N} G(x^p, \xi^k) W(\xi^k) = v_n(x^p); \quad p = \overline{1, N-z}, \\ \sum_{k=1+n_{c-1}}^{n_c} W(\xi^k) = 0, \quad c = \overline{1,z}. \end{cases}$$

Here $\sum_{?=1}^{z} n? = N; \quad n_0 = 0$; $n_0 = 0$: n_c the number of bound vortices on a c-d line.

After determining the unknown circulation, velocity at any point of the area along any given direction is determined from the expression (1), wherein x^p is substituted in place of point under consideration is. At the time $\underline{t} = 1$. Δt gap occurs L - L of free vortices with sharp edges of the border. Strictly saying, the vortices lying on these edges, were already free, because it was proved in [15] hypothesis of Chaplygin-Zhukovsky-Kutta, attached vortex layer on the profile from which veil is coming off and free vortices disappear. Gathering of free vortex is performed in the direction of flow velocity. Their new position is computed of an old by the formulas:

$$x' = x + v_x \Delta t, \quad y' = y + v_y \Delta t$$

Where v_x,v_y - components of the velocity that are calculated by formulas (1) for n {1,0 и n = {0,1}, respectively and instead of (x_1, x_2) substitute into coordinates (x, y). The circulation of free vortices with over time is not change. Taking into account coming down free vortices, the system of equations for the unknown circulations of bound vortices assumes the form:

$$\begin{cases} \sum_{k=1}^{N} G(x^p, \xi^k) W(\xi^k) + \sum_{l=1}^{L} G(x^p, \varsigma^l)\gamma(\varsigma^l) = v_n(x^p); \quad p = \overline{1, N-z}, \\ \sum_{k=1+n_{c-1}}^{n_c} W(\xi^k) + \sum_{l=1+L_{c-1}}^{L?} \gamma(\varsigma^l) = 0, \quad c = \overline{1,z}, \end{cases} \tag{3}$$

Where ς^l - point of location of a free vortex that came down from the l-th sharp edge. L_c- the number of vanishing points of a vortex sheet with a line c; $\sum_{?=1}^{z} L? = L; \quad L_0 = 0.$

In the next time will come down more L - free vortices, previous ones will acquire their new position defined by the formula (2), where the velocity components are determined based on the availability free vortices in the flow:

$$v_n(x) = \sum_{k=1}^{N} G(x, \xi^k) W(\xi^k) + \sum_{l=1}^{L} G(x, \varsigma^l)\gamma(\varsigma^l)$$

At the moment of t = 2. Δt the system (3) becomes:

$$\begin{cases} \sum_{k=1}^{N} G(x^p,\xi^k)W(\xi^k) + \sum_{\tau=1}^{2}\sum_{l=1}^{L} G(x^p,\varsigma^{l\tau})\gamma(\varsigma^{l\tau}) = v_n(x^p); \\ p = \overline{1, N-z}, \\ \sum_{k=1+n_{c-1}}^{n_c} W(\xi^k) + \sum_{\tau=1}^{2}\sum_{l=1+L_{c-1}}^{L_c} \gamma(\varsigma^{l\tau}) = 0, \quad c = \overline{1,z}, \end{cases}$$

Where $\varsigma^{l\tau}$ - point the location of a free vortex came down from the l-th sharp edge at the moment τ [tau]; $\gamma(\varsigma^{l\tau})$ - its circulation.

At an arbitrary instant time, the system of equations for the unknowns circulations bound vortices will take the form:

$$\begin{cases} \sum_{k=1}^{N} G(x^p,\xi^k)W(\xi^k) + \sum_{\tau=1}^{m}\sum_{l=1}^{L} G(x^p,\varsigma^{l\tau})\gamma(\varsigma^{l\tau}) = v_n(x^p); \\ p = \overline{1, N-z}, \\ \sum_{k=1+n_{c-1}}^{n_c} W(\xi^k) + \sum_{\tau=1}^{m}\sum_{l=1+L_{c-1}}^{L_c} \gamma(\varsigma^{l\tau}) = 0, \quad c = \overline{1,z}, \end{cases}$$

And the speed at any given point is determined from the expression:

$$v_n(x) = \sum_{k=1}^{N} G(x,\xi^k)W(\xi^k) + \sum_{\tau=1}^{m}\sum_{l=1}^{L} G(x,\varsigma^{l\tau})\gamma(\varsigma^{l\tau})$$

If the free vortex is approaching to an impermeable boundary at a distance of less than λ [lambda] (distance between adjacent bound vortex and control point), it moves away from it at along a normal distance λ [lambda]. If the free vortex was approaching to suction port on the same distance, the vortex was removed from our consideration. In the case of approximation to the vortex at a distance $x < \lambda$, they induced magnitude of the velocity determined from the formula:

$$v(x) = xv/\lambda$$

where v - velocity caused by the vortex, which is located at a distance λ [lambda].

Based on the mathematical model, we developed a computer program that allows us to make the calculation of the velocity field, to build flow lines and monitor the development of vortex structure in confined and open multiply connected domains, containing thin profiles.

CONCLUSION

Modeling was done at different heights of open aperture (a window): 1.2 m (Fig. 3), 0.8 m (Fig. 4) and 0.4 m (Fig. 5). The distance between two adjacent bound vortex (discrete step) h = 0.1 m; step time $\Delta t = h. AB/(v_0.1\text{m})$. Flow lines are constructed in the longitudinal and the horizontal profiles component of the velocity scale.

At the height of the window in the range of 0.8-1.2 m stagnant (vortex area) is located in the lower part of the premises (Fig. 3, 4). In the case of reducing the size of the window height to 0.4 m stagnant zone is moved to the upper part of the room (Figure 5). However, in this case, we have observed increased values for the velocity in a fairly narrow region, adjoining to the bottom of the premises. This area can be extended if the fully open aperture of window to set slim profiles, for example, in Fig.6, two profiles of 20 cm under an angle of 45 degrees (Fig. 6). By the found velocity profiles may be found the required for the safety of animals exhaust velocity v0. From calculations (Fig. 3 to 6) we can assume that the magnitude of v0 should be reduced by half, i.e. should be 0.5 m / s.

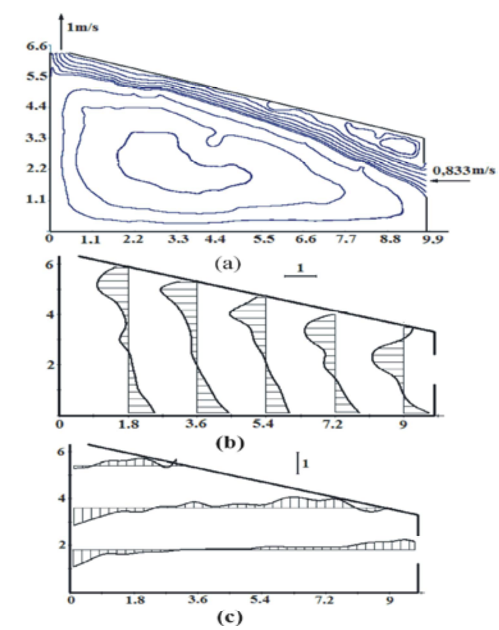
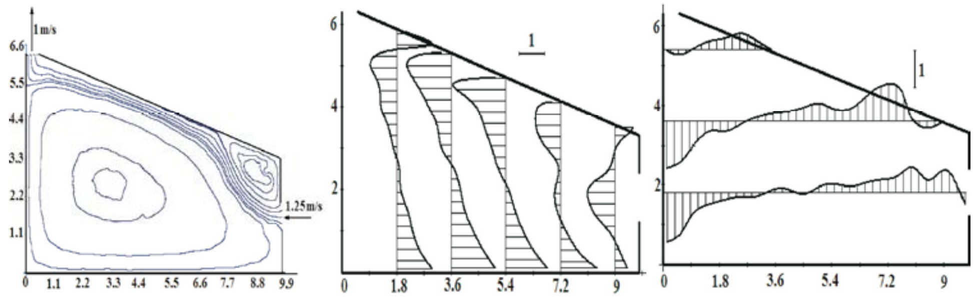
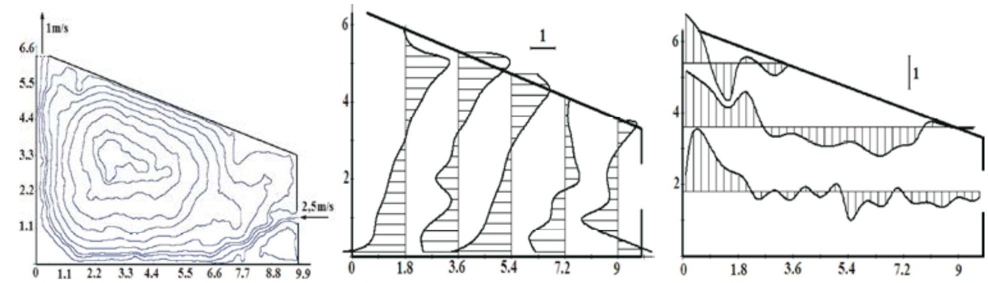


Fig. 3: Structure of the flow at full window height of 1.2 m: a) flow lines; b) the horizontal profile of the component of the velocity (pictured single segment corresponds to speed of 1 m / s); c) the vertical profile of component of the velocity (the model at time t = 448.8; number of free vortices - 2321, the time step = 0.12).



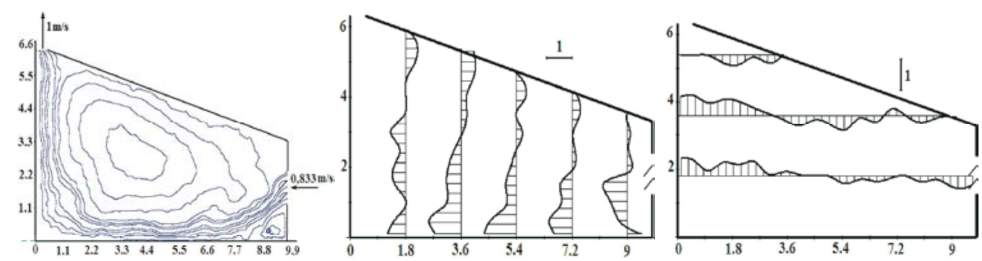
(a) (b) (c)

Fig. 4: Structure of the flow at partial open window height of 0.8m: a) flow lines; b) the horizontal profile of the component of velocity (the pictured single segment corresponds to speed of 1 m / s); c) the vertical profile of component of the velocity (the model at time t = 177, the number of free vortices - 2005, the time step = 0.08).



(a) (b) (c)

Fig. 5: Structure of the flow at partial open window height of 0.4 m: a) flow lines; b) the horizontal profile of the component of velocity (the pictured single segment corresponds to speed of 1 m / s); c) the vertical profile of component of the velocity (the model at time t = 48.96; number of free vortices - 2017, the time step = 0.04)



(a) (b) (c)

Fig. 6: Structure of the flow at full open window with direct air stream height of 1.2 m: a) flow lines; b) the horizontal profile of the component of velocity (the pictured single segment corresponds to speed of 1 m / s); c) the vertical profile of component of the velocity (the model at time t = 56.16; number of free vortices - 2599, the time step = 0.12)

CONCLUSION

Now were developed a mathematical model and a computer program for calculating circulating flows in areas of trapezoid form with the exhaust port and the open outlets, which can contain profiles. The most rational for the organization of ventilation is the installation of thin profiles in the open window outlets, pressing air flow to the underside part of the premises. We constructed streamlines and velocity profiles, according to which can be determined necessary volumes of exhausted air for providing the desired speed limits in air jets.

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REFERENCES

1. Averkova, O.A., 2007. Computer simulation of circulating currents in a confined area on the basis of discrete vortex / O.A.Averkova, V.Yu.Zorya, K.I.Logachev, R.Yu.Ovsyannikov / / Bulletin of the Belgorod State Technological University named after V.G. Shukhov. 3:129-137.
2. Logachev, K.I. and A.I. Puzanok, 2004. Computational Modeling of Air-and-coal Flows next to Suction Holes. ECCOMAS 2004 - European Congress on Computational Methods in Applied Sciences and Engineering, e-Book Full Papers, pp: 19.
3. Anzheurov, N.M. and O.A. Averkova, 2008. Software for computing dusty air flows in ventilation systems. Refractories and Industrial Ceramics. 49(3): 229-234.
4. Logachev, K.I.. A.I. Puzanok and V.U. Zorya, 2006. Numerical study of aerosol dust behaviour in aspiration bunker. ECCOMAS CFD 2006 - European Conference on Computational Fluid Dynamics, e-Book Full Papers, pp: 11.
5. Averkova, O.A., V. Yu. Zorya and K.I. Logachev, 2007. Behavior of aerosol particles in suction bunker of standard design. Chemical and Petroleum Engineering. 43(11): 686-690.
6. Logachev, I.N., K.I. Logachev and O.D. Neikov, 1995. Localization of dust generation during the pressing of powders. Powder Metallurgy and Metal Ceramics, 34(3-4): 203-206.
7. Logachev, K.I. and N.M. Anzheurov, 2003. Flow Analysis of Slit-Type Suction Ports Shielded with Slender Visors. Refractories and Industrial Ceramics, 44(3): 145-148.
8. Averkova, O.A., V.Yu. Zorya, I.N. Logachev and K.I. Logachev, 2010. Numerical simulation of air currents at the inlet to slot leaks of ventilation shelters. Refractories and Industrial Ceramics. 51(3): 177-182.
9. Averkova, O., A. Logachev, I. Logachev and K. Logachev, 2012. Modeling of gas separated flows at inlet of suction channels on the basis of stationary discrete vortices. ECCOMAS 2012 - European Congress on Computational Methods in Applied Sciences and Engineering, e-Book Full Papers, pp: 20.
10. Logachev, K.I. and V. N. Posokhin, 2004. Calculation of a Flow in the Vicinity of a Round Suction Pipe. Proceedings of the higher education institutions. Aircraft Engineering. 1: 29-32.