Noise silencer of air exhaust

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***Abstract*—**The actual noise silencer of a strong air exhaust of more than 50 m^3/s is too noisy for the surroundings. The aim of this paper is to propose effective measures of noise suppression. The next complication are some sticky particles in the air volume, which obstructs the air exhaust.

***Keywords*—**Flow numerical simulation, Noise silencer.

I. Introduction

USING the method of the flow numerical simulation, several following designs of noise silencer were tested.

Due to the large extent of received results, the presented flow fields do not contain actual scales of parameters of the flow field (velocity etc.). Actual values are not important here, but important are characteristic fields of tested parameters of flow fields, only. For better understanding - the used scales are standard, the highest value is red and the lowest value is blue, according to the wave lengths in the spectrum of visible light.

II. Tested Silencer Designs

A. Actual design

This system was presented in [1], here it is repeated as initial information. The exhausted air is flowing up through the bent tubing, set on the fan outlet, into the free surroundings, where it is subsequently fading out. The horizontal part of the system is probably the chamber of the former filter, which is empty today, because due to the sticky part in transporting air the system was quickly obstructed, and must have to be frequently closed down and cleaned.

Illustrative results of the flow numerical simulation are presented in Fig. 1 as velocity field (left) and field of the turbulent kinetic energy (right). Added surroundings (up) are very long to represent the very long dissipation of the exhausting flow. Inside the horizontal chamber (former silencer or filter?) the flow is very turbulent, due to the sharp bends of the flow. Turbulences, pressure pulsations and turbulent boundary between the free flow and the surroundings are the sources of aerodynamic noise. The walls are made from thin sheets, which is vibrating and the noise from it is spreading into the surroundings. Hereat, it is well-known that for noise damping, the walls should be made massive. Sharp direction changes induce the flow turbulization, the result is an uneven velocity profile, high turbulence values and pressure fluctuations.

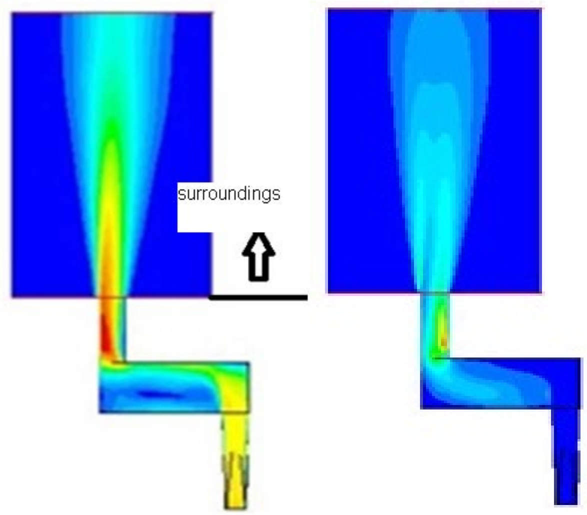


Fig. 1 Former air exhaust layout: velocity (m/s) - left, turbulent kinetic energy (m^2/s^2) - right

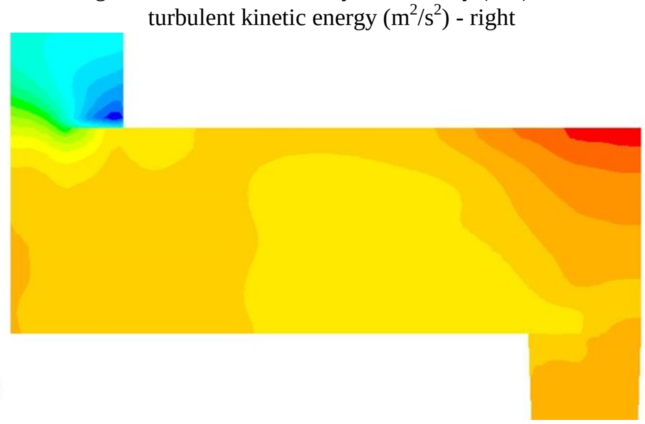
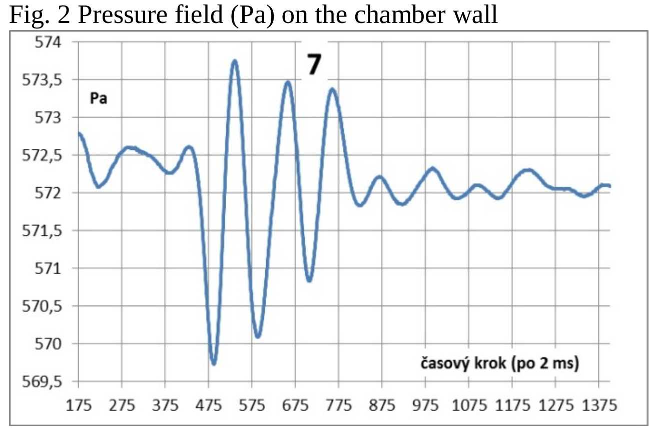


Fig. 2 Pressure field (Pa) on the chamber wall



. Fig. 3 Record of pressure pulsations on the chamber wall, time step of 2 ms

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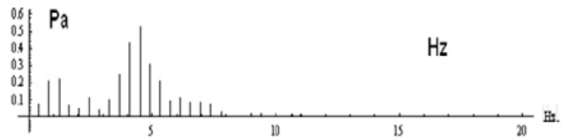


Fig. 4 Frequency analysis of signal from the Fig. 3

The pressure field, how the flowing air is acting on the chamber wall, is presented in Fig. 2 for one time moment of the used unsteady solution. Its time evolution in the middle of this surface for unsteady simulation with time step of 2 ms is presented in Fig. 3 and its frequency analysis is presented in Fig. 4. The maximum acoustic pressure was detected at a frequency of 4.5 Hz - this value corresponds very well with the real field measuring on the actual equipment [2].

The next numerical simulation proved that such pulsation was going to zero after installing the fluent shape of the exhaust tubing [1], [3]. Finally, the only straight vertical tube was designed because it is not any reason for the former S-shaped tubing.

B. Design of cleanable silencer

For the suppression of the above mentioned high noise level, the standard labyrinth silencer was designed, containing several shaped channels. The exhaust is oriented down to the roof surface and/or in the circumferential direction. The total bend angle of the flow is 810°. Due to the noise damping, the silencer is designed as a squared body of thick walls (boards). The design made from thin sheets can be circular, too, but the damping effect of such a system of thin sheets is lower and it is subject to operational vibrations, too.

The channels of the labyrinth are designed large enough to be able to enter into and to clean sticky layers on the inner surfaces. So the system must be demountable, for instance with a removable upper part.

But the large channels are not suitable as the noise silencing. Therefore, it should be better the cleaning (blasting) of the silencer walls by dry ice [4]. In such case, in the channel it is inserting the blasting nozzle with an extension, only, so that the channels can be narrow and more effective for noise silencing.

Remark: It is not clear, why in the exhausted air are included sticky parts, when at the exhaust inlet are installed filters, water shower walls etc., which could catch all sticky parts.

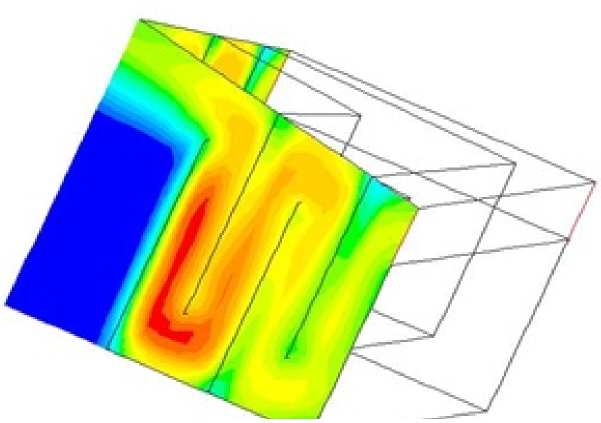


Fig. 5 Field of turbulences in vertical plane of symmetry

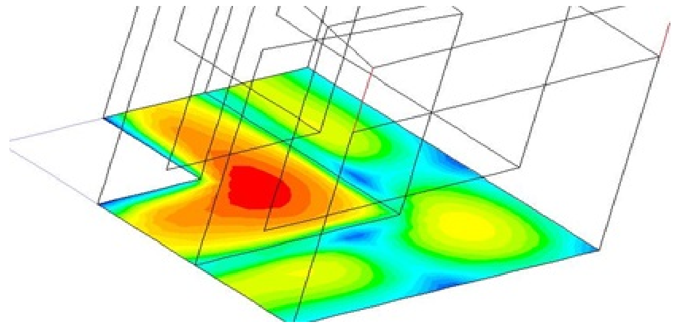


Fig. 6 Field of turbulences in the ground plan

The used numerical model has two symmetry planes, therefore, it is solved as a one-quarter model. As an illustration, there is presented the turbulence field in the vertical symmetry plane (Fig. 5) and in the ground plan, too (Fig. 6). The local maxima in the areas of sharp bends are here visible again.

C. Realization

It is a pity that only a part of the above mentioned labyrinth from the section II-B was realized, with a total bend angle of 360°, only, i.e. with an open exhaust up. Reputedly, due to a mass reduction of the equipment on the non-bearing roof and due to misgiving from the possible back suction of the exhausted air, contaminated by volatile parts, into the hall. The resulting velocity field is presented in Fig. 7 left – for a more expressive display, the reduced scale is used (it is not displayed the area of maximum velocity at the outlet from the silencer). The detail of the directional field in the symmetrical half of the silencer body is shown in Fig. 7 right.

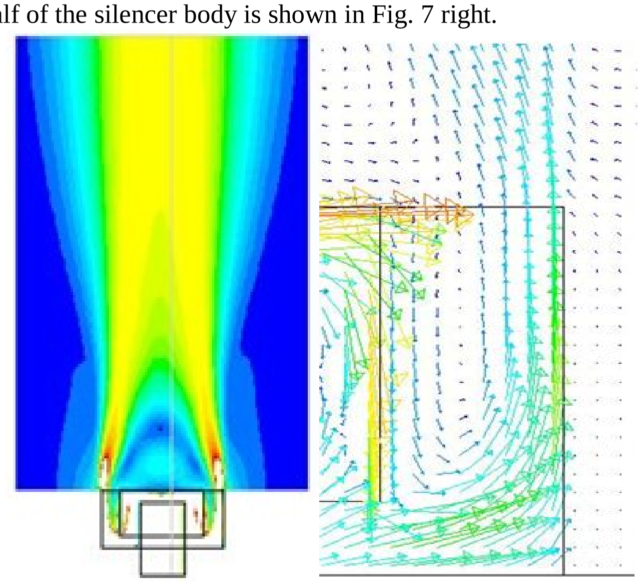


Fig. 7 left - velocity field after the realized silencer (suppressed scale) right – detail of the directional field in the outlet orifice

The next Fig. 8 shows the velocity field in the sharp bends (180°) of the labyrinth – the velocity field is deformed expressively, the velocity profile at the outlet is very uneven with maximum on the outer wall and minimum at the inner wall (with slight backflow). The shear area between both flows is the source of aerodynamic noise. The inserted partition in the last part after Fig. 9 makes the flow guidance better, but it must be rigid and demountable due to the inner cleaning. But its one-side fixing may increase the possibility of vibration.

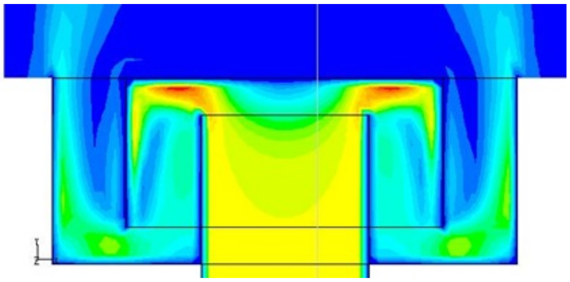


Fig. 8 Velocity field in the silencer

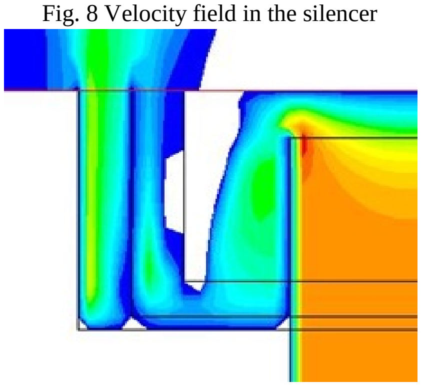


Fig. 9 Influence of the inserted partition (symmetric half)

This design does not bring any improvement because the high column of the free outflow (similar to Fig. 1) remains the source of noise. The additional partial covering of the exhaust orifice after Fig. 10 is operating as a narrowed nozzle, only, i.e. it increases the flow velocity, therefore the velocity field image is very similar and the decreasing of aerodynamic noise level is none.

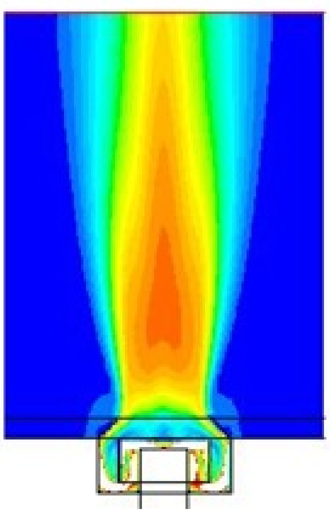


Fig. 10 Velocity field of the free flow after the narrowed outlet

D. Analysis of the silencer original design

The original design after the section II-B is slightly modified after Fig. 11 and fulfils well the requirements for an effective damping of aerodynamic noise. The exiting flow is spreading along the flat roof, where the drifted sticky parts, not caught sooner on the inner partition, are caught on the roof surface. Here it is not any intensive „column" of turbulent free air flow up, which is a significant source of the aerodynamic noise.

In this design, the flow velocity of the outgoing air, i.e. of dynamic pressure on the roof surface, is decreasing proportionally with the distance from the outlet, i.e. with an increasing circumference of the flow (Fig. 12 left). In Fig. 12 right, there is the ground plan of the same velocity field at the level of the upper wall of the silencer – in the middle par, the velocity on the wall surface is equal to zero, in the walls vicinity there is visible a slight backflow and along the outer walls the slower main flow is going out.

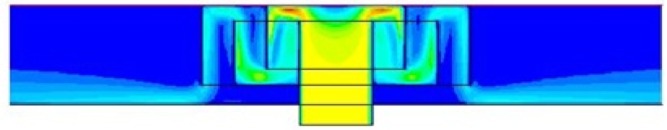


Fig. 11 Velocity field in the silencer body, exhaust down against the roof

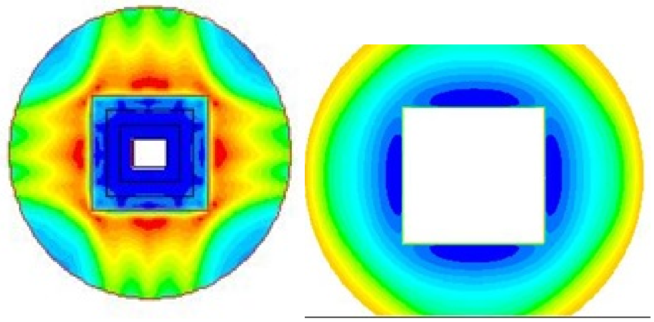


Fig. 12 Dynamic pressure on the roof surface (left)
Velocity field at the upper wall of the silencer (right)

Further, there are presented two next shape modifications, without any important influence on the global image of the flow field. In Fig. 13, the outer wall is shortened on one half, due to a weight reduction of the equipment – it realizes the last flow bend of the labyrinth, only, the main flow down remains. Fig. 14 presents the influence of the next low partition set-off on the roof to prevent possible flow spreading along the roof surface in the direction to the near-by air suction into the hall.

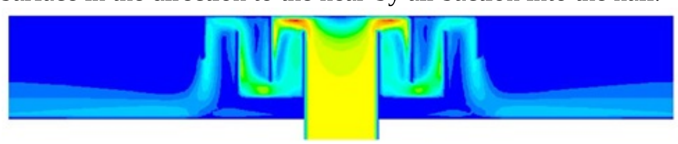


Fig. 13 Velocity field – the shorter outer wall

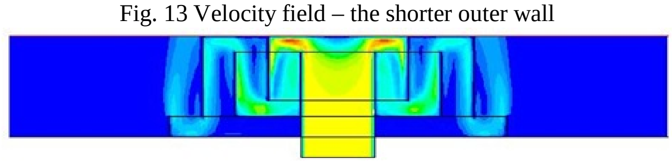


Fig. 14 Velocity field – the added low and set-off partition

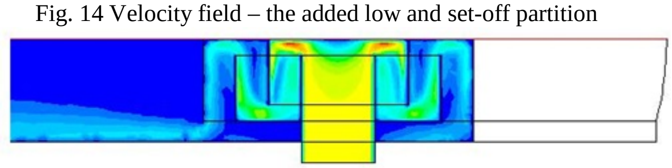


Fig. 15 Velocity field – the silencer just along the skylight

Fig. 15 simulates the flow field deformation when the silencer is situated just at the wall of the roof skylight. It has not an important influence on both flow through the silencer and air exhaust, too. In the ground plan, the flow outflow is constricted after Fig. 16 on a certain, not important part of the circumference, only.

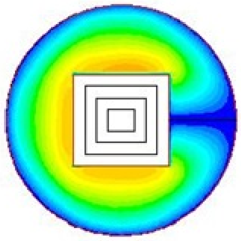


Fig. 16 Velocity field from Fig. 15 in the ground plan

The last Fig. 17 shows the modification with a classical slotted silencer at the outlet – it is effective, well accessible from the roof, simply demountable and cleanable, namely without operation interruption.

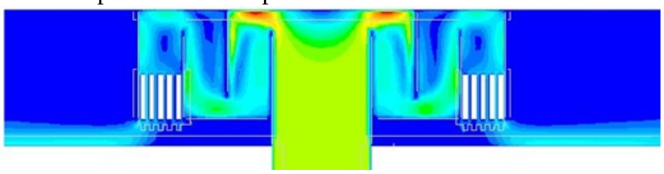


Fig. 17 Velocity field in the classical slotted silencer

E. Summary of the results

The main parameters influencing the level of the aerodynamic noise of exhausted air (velocity, flow kinetic energy, turbulent kinetic energy) are presented in the summary Tab. 1. For outlet directed down (section II-D), the values are of tens of percents lower, compared with outlet up (section II-C), all under the condition of the same air flow. It is evident that the realized partial solution after the section II-C is not good.

Remark: Simulating the acoustic field (levels of acoustic pressure etc.) needs much more effort and time of the solution. But in this study, it is not important to evaluate real noise levels before and after design changes, but to show the way to the improvement. Here the presented values of the flow field have sure the influence on the noise level in general, it is possible to judge that using the presented modifications, the noise level is decreasing.

Tab. 1 Overview of flow parameters influencing the noise level

exhaust		up	down	down+side
flow	kg/s	100%	100%	100%
outflow velocity	m/s	100%	47%	58%
turbul. kin. energy	m^2/s^2	100%	24%	40%
flow kinet. energy	J	100%	22%	34%

III. INFLUENCE OF THE SURROUNDING SOLIDS

Here it is evaluated the influence of the surrounding solids on the exhaust air flow from the silencer body. In Fig. 18, it is the actual situation after the section II-A – exhaust from the high chimney and suction under the low shed, with many skylights around.

Fig. 18 Situation on the roof – exhaust, suction, skylights

For this case, the outflow field was simplified after Fig. 19 – here it is not any influence of inner flow in the silencer, see the section II-D, i.e. here it is the constant velocity in the whole outlet cross section. In Fig. 20, there is presented the velocity field in the vicinity of the exhaust (section II-D) in the ground plan 0.1 m over the roof plane – its range is relative short.

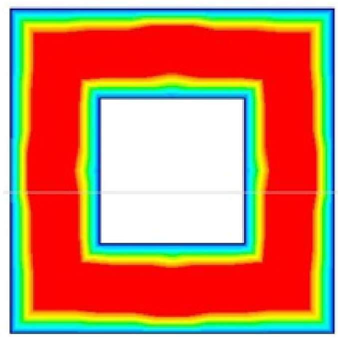


Fig. 19 Simplified (constant) velocity field at the silencer outlet

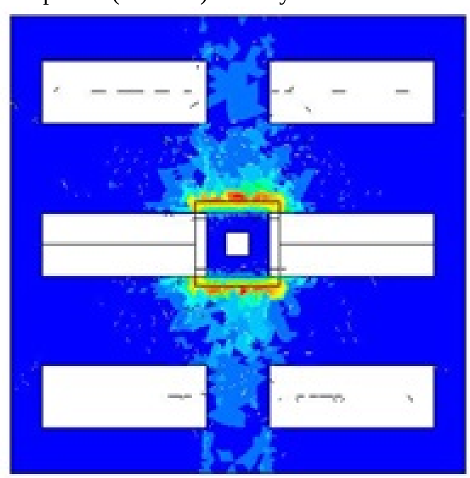


Fig. 20 Velocity field in the outlet vicinity

The velocity field on the roof in vertical cross sections is in Fig. 21 and Fig. 22 (at different velocity scales!). The vertical velocity is very low, maximum of 0.2 m/s, only. The horizontal velocity is of higher order, the maximum 10 m/s is in the outlet orifice, but with an increasing circumference of the flow it is decreasing quickly.

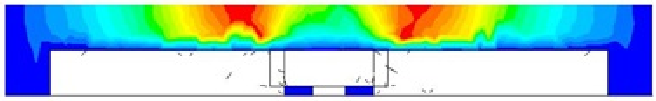


Fig. 21 Vertical velocity (max. 0,2 m/s)

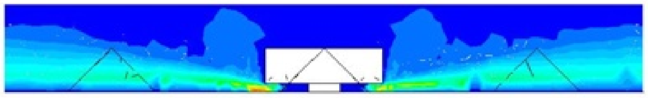
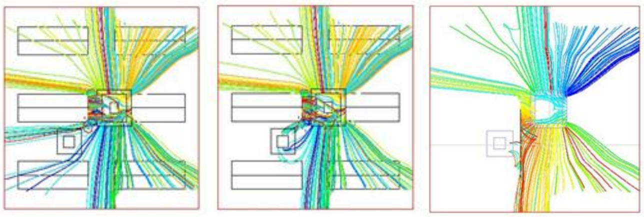


Fig. 22 Horizontal velocity (max. 10 m/s)

In the next Fig. 23 a-b-c, there are ground plans of streamlines for some operational cases.



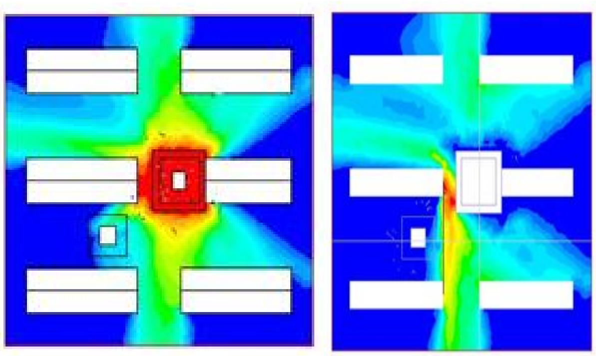
a) b) c)

Fig. 23 Streamlines in the ground plan

Fig. 23a - the suction is off, some streamlines from the silencer outlet are flowing to the suction inlet and around the suction body. In the exhaust there is some source concentration of impurities (for comparison below defined here as **100%**).

Fig. 23b - the suction is on, some streamlines from the silencer exhaust are drawn into the suction, but the concentration of impurities in the suction is **7.5%**, only, of the outlet concentration.

Fig. 23c - the suction is on, with inserted the partition on the roof. It reduces the direct (short-circuit) flow from the exhaust into the suction, the impurities concentration in the suction is **1%** , only, of the concentration in the exhaust.



a) b)

Fig. 24 Temperature fields in the ground plan

The impurity concentration is simply simulated here as the mixing of two air volumes of different temperatures – the outlet temperature is of 50 K higher than the temperature in the surroundings (and in the suction, too), the resulting temperature of the mixture corresponds to the impurities concentration.

Fig. 24a shows the temperature field in the ground plan – the maximum in the exhaust vicinity is defined as the scale of contamination. Fig. 24b shows the velocity field in the ground plan after inserting of the low partition on the roof to suppress the short-circuit flow from the exhaust in the suction. Fig. 25 presents the corresponding temperature field on the periphery of the simulated area – the local maximum of vertical velocity in the middle of the upper surface is the consequence of a declined horizontal flow in the vertical direction by the inserted partition.

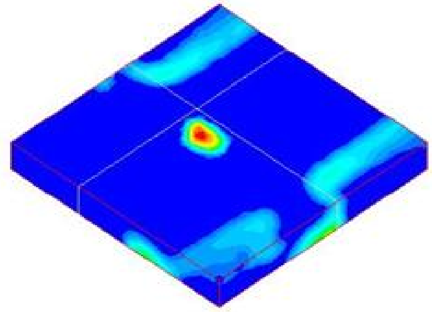


Fig. 25 Temperature field with the inserted partition

IV. Forces

From the realized simulation of the flow it is possible to simply state force (pressure) flow influences on the individual walls of the designed silencer for the right dimensioning of the whole construction. As an illustration, Fig. 26 presents the total pressure on the inner and outer surfaces of the inner partition. But here it is the stiffness more important than the fastness to be sure that the construction will not vibrate and so it will not be the secondary source of the noise.

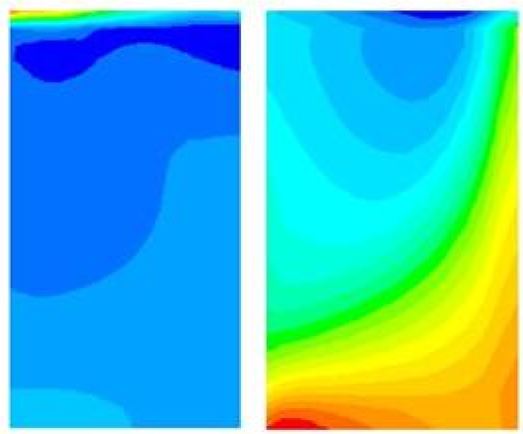


Fig. 26 Pressure on the inner (left) and the outer (right) side of the partition

The horizontal partition, inserted opposite to the inlet into the silencer, can decrease the extreme dynamic effect of the flow on the upper wall of the silencer. Fig. 27 presents the symmetric half of the velocity field, displayed with suppressed scale.

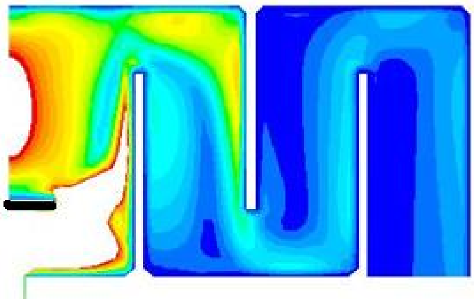


Fig. 27 Dynamic pressure suppressing on the upper side of the silencer by an insertion of the cross partition (suppressed scale)

V. CONCLUSIONS

After the removing of the thin-walled and bent exhaust tubing, the main source of the noise remains the strong and high turbulent air flow up. From the realized flow numerical simulations, it results the following recommendations for the next process. Simply said, those recommendations are well known, but oft not used - maybe the numerical simulation helps in their implementation. And more, numerical simulation can simply verify various hypotheses about the effectivity of noise damping, possible back suction of exhausted impurities etc.

1. The orifices in the labyrinth silencer should be as narrow as possible, but accessible for cleaning. A suitable cleaning method is the blasting by dry ice. But the primary should be the perfect capture and separation of sticky parts from the exhausted air before the exhausting fan, using an effective water curtain, exchangeable filtering elements etc. It is not clear the reason of a relative high portion of sticky parts, not caught before the exhausting system.

2. The wall of the silencer should be massive and stiff, with a reinforcement against vibrations – the designed partitions are fixed on one side, only!

3. The silencer ceiling is necessary, with the slope to the periphery - in an open design, rain and snow are falling in.

4. In the actual outflow – not suitable – to insert the next partition into the middle width of the outlet cross section. It must be simply demounted for cleaning, but at the same time, resistant against vibrations. By this, the outlet turbulences, as the source of secondary noise, are decreasing.

5. The outlet down is more suitable – the parameters of the flow field in the outlet, influencing the level of aerodynamic noise, are of tens of percents lower, compared with the outlet up.

6. The rugged roof of the hall (skylights) helps further to the aerodynamic noise decreasing of the air flow, blown down and dispersed along the roof surface.

7. The simulated impurity concentration in the suction from the roof back into the hall is 7.5% only of the concentration at the outlet.

8. The inserted partition on the roof between the outlet and the suction, the impurity concentration in the suction is decreasing on 1% only of the concentration in the exhausted air.

9. It is possible to situate the similar simple partitions around the next eventually opened skylights.

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[2] M. Pustka, V. Pulpan: "Noise emission reduction at the outlet from painting shop", report VUTS Liberec, 2012, unpublished.

[3] N. Mastorakis, V. Mladenov (eds.), *Computational problems in Engineering*, Springer Int. Publishing Switzerland, 2014

[4] www.pap-pe.cz : Blasting by dry ice (Tryskání suchým ledem) and many other references

Next references are not mentioned because in the paper there are presented own results of flow numerical simulation, only. It was used standard knowledge from the standard course of fluid mechanics, well known for professionals since many years ago. It is a pity that it was not applied at the original design and during the operation of the described equipment.