EXHAUST AIR REGULATING CONE
FOR OUTLET SPEEDS OF AT LEAST 7 M/S

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SUMMARY

According to the guidelines VDI- 2280: 2005 and VDI 3781: 2017 Part 4 an exit velocity of at least 7 m/s vertically upwards should be aimed for a better distribution of the corrosive exhaust air such as from laboratories. This speed ensures sufficient dilution and undisturbed removal of the exhaust gases with the free air flow. The corrosion-resistant mechanical regulator, developed for this purpose, is an automatic regulator for flow speeds that are constantly above a specified minimum speed using minimal aerodynamic forces (pressure and friction) and the spring force. Initially, analytical calculation and CFD analysis with OpenFoam are examined. The graphic evaluation shows velocity fields at different volume flow, the pressure fields and streamlines.

INTRODUCTION

According to technical guidelines an exit velocity of at least 7 m/s perpendicular to the roof should be observed when discharging laboratory exhaust gases. For this intention an increased outlet speed will be set for the nominal volume flow often with electrical driven volume flow regulators.

This effect can also be received by an automatic mechanical regulating cone. One important advantage is that the blow-out speed does not have to be increased in the case of nominal load by ramp up the speed of the fan. This avoids increased pressure losses and therefore less power consumption which results into an environmentally friendly solution. In addition to reducing the ventilator drive power, the sound power level of the exhaust air will be reduced by the regulating cone at the outlet.

GATHERING OF IDEAS

The extract air out of a laboratory is often conducted by a piping system through a multi-story building. On top of the building the exhaust air must be guided vertical above the roof surface into the horizontal blowing wind profile. Different volume flow rates result into various outlet velocities and distinct mixing heights. In the market are a lot of exhaust air towers available, most of them made of stainless steel or aluminum to look flashy on top of the structure. To bring the exhaust air sufficient up into the blowing off wind area, the height of such a passive component must be much higher than an active intelligent unit. These tall towers result in strong wind loads with retaining jigs and much more material consumption which is not resource-protecting. The target is to go easy on resources by using a mechanical part without any electrical power consumption. In 1999 a German patent DE19731332A1 [1] was published, which shows the basic idea of such an element.

The **exhaust air regulating cone (EARC)** is a perfect building component to guarantee a high vertical outlet velocity airstream far away from the roof top.

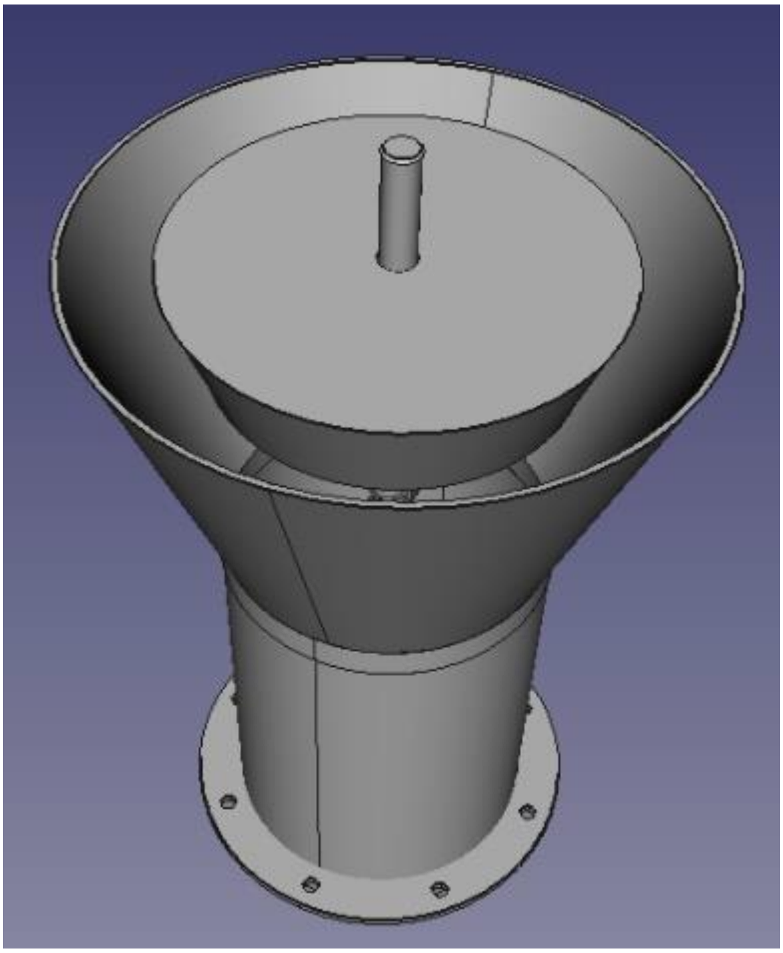

Figure 1: schematic construction

This effect operates without any supplementary drive units, only the sum of buoyancy force, weight force and a rebound spring force hold the cone in suspense.

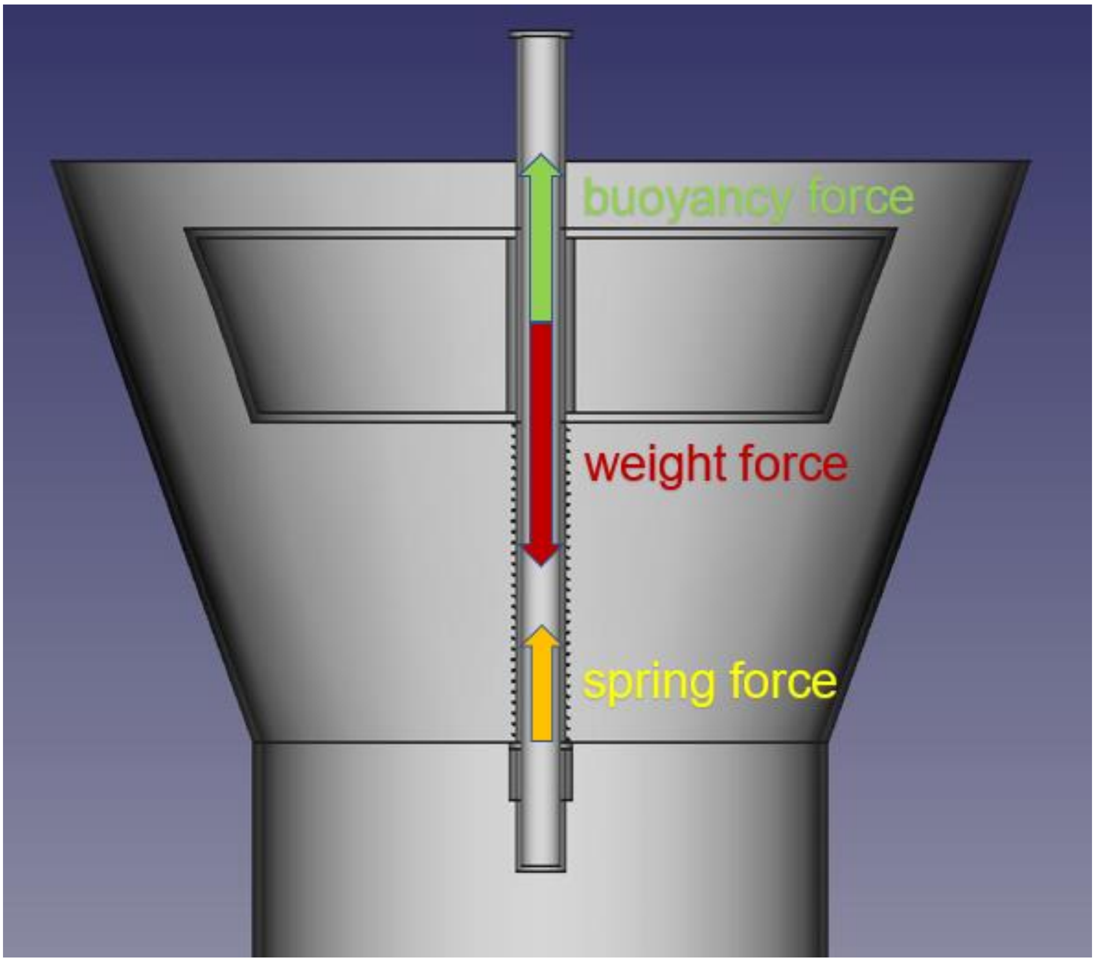

Figure 2: main forces

The different heights are adjusted by varying the volume flow rates. A strong flow results in high buoyancy force with a constant weight force and therefore in a superior cone. The bigger outlet area between inner and outer cone gives a similar outlet velocity compared to a smaller outlet area with a lower located inner cone; the lower cone is bound up to a smaller volume flow rate.

ANALYTICAL 1-D CONTEMPLATION

To be able to calculate the balance of power for different volume flow rates it is necessary to calculate the weight force as a constant first. Together with the spring force and the resistance force (mainly buoyancy effect by the stagnation pressure and a little bit of friction at the side walls) amount them to the equilibrium.

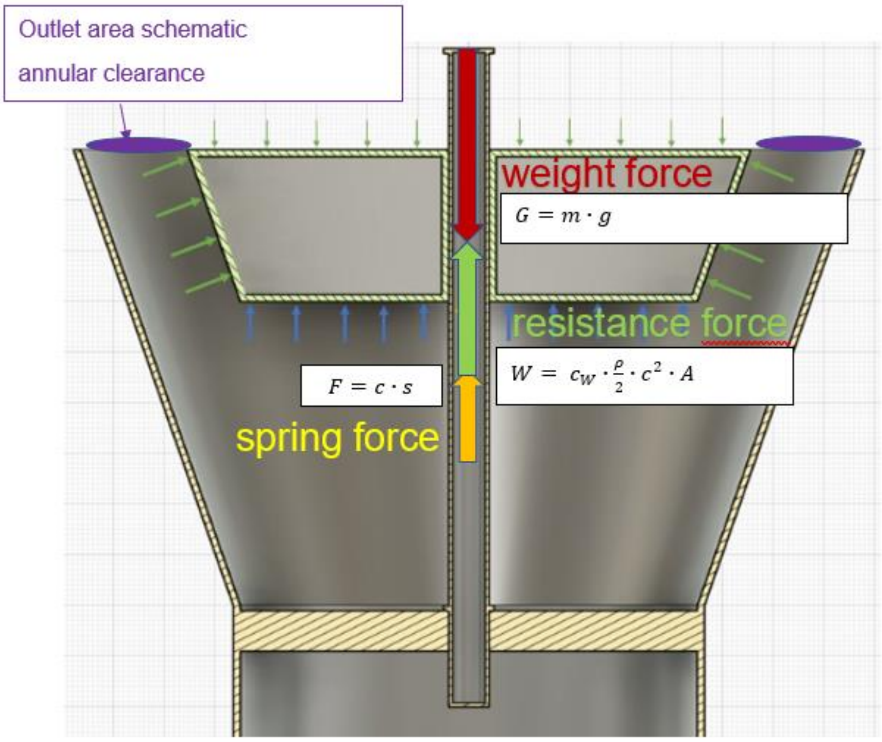

Figure 3: force formulas

Our challenge is now to determine the height of the inner cone for two different volume flow rates. As mentioned before the weight of the cone is constant for one pipe size and the pressure spring force varies in length with its fixed selected suspension rate. As higher the volume flow rate as greater the velocity of the flow and therefore the resistance of the inner cone. All other parameters stay constant like c_w value and projected area of the shape or density of the air. So an increased speed will result into a high flying cone or vice versa.

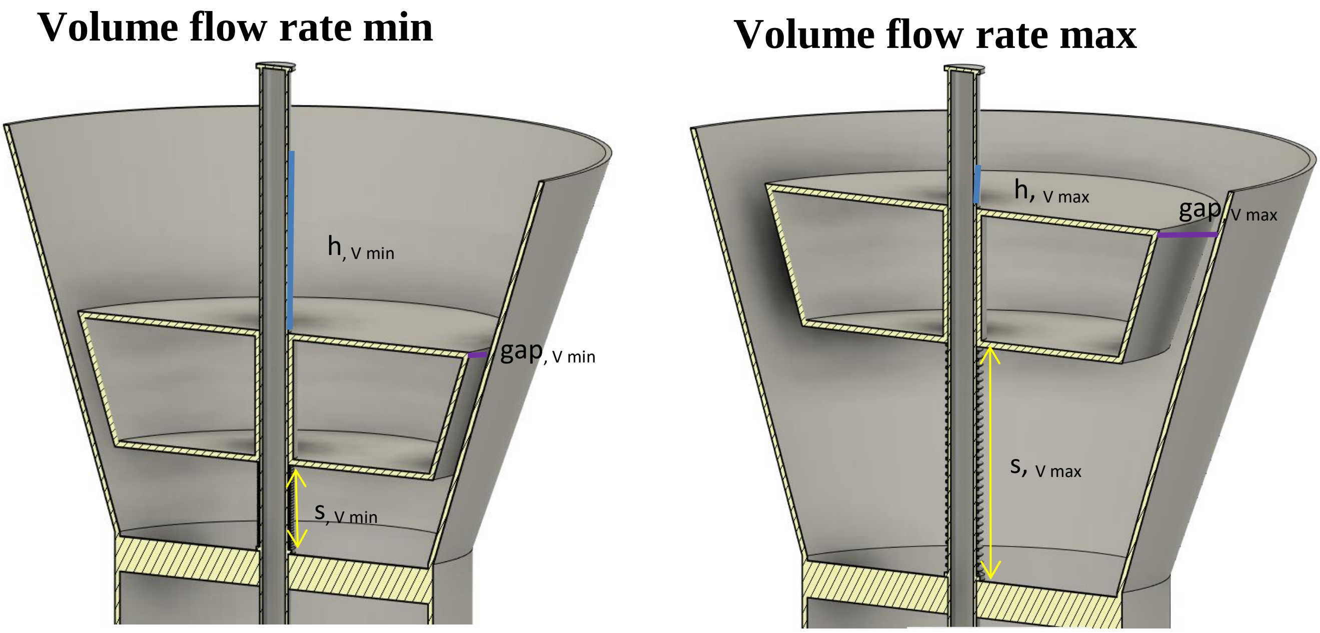

Figure 4: Different heights at different volume flow rates [2]

As an example of the EARC with a pipe inlet of 200 mm the following table shows the analytic results calculated for a rough too simplistic one-dimensional approximated Excel calculation:

Table 1: analytic solution of $\dot{V}$min and $\dot{V}$max through a DN200 exhaust air tower

	Weight [N]	**Spring [N]**	**Flow resistance [N]**
$\dot{V}$ min = 300 [m^3/h]	-3.5	0.6	2.9
$\dot{V}$ max = 1 000 [m^3/h]	-3.5	0.8	2.7

The flow resistance appears smaller at $\dot{V}$ max compared to $\dot{V}$ min because the inner obtuse-cone is hovering in a wider cone area at lower speed.

NUMERICAL 3-D CALCULATION

The EARC is mainly built with a pipe as an inlet, on top an outer taper and a guiding rod for the inner cone at the center of the outlet. To be able to calculate the flow through this area and the discharge area we have to increase the upper sector by a huge cylindrical field.

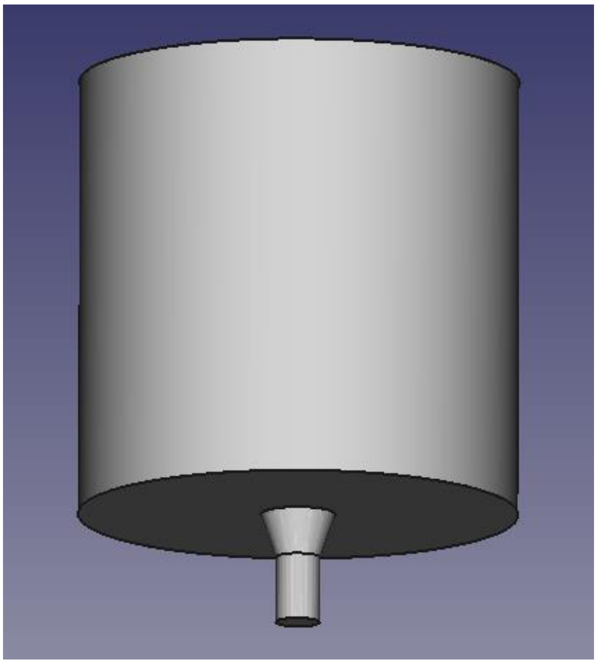

Figure 5: CAD geometry design by FreeCAD v0.19 [3]

Because of the lack of commercial CFD software at our company we reduced our geometry to a quarter of the range and kept the number of nodes less than 200,000. Nevertheless, we refined our mesh near the inner cone to be sure to get the right information about the flow.

We wanted to see the jet stream effect of the outflow as well, so we must put a huge cylinder over the complete flow area with a closed ground, except the round inlet section of the pipe.

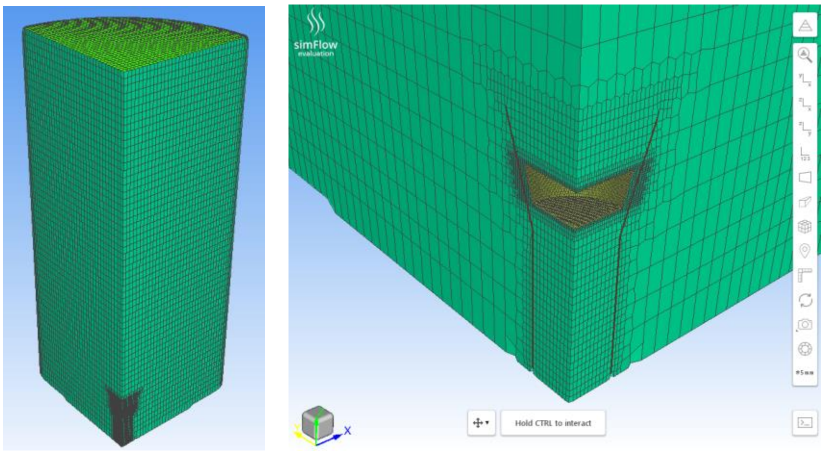

Figure 6: simFlow mesh field [4]

At this inlet we fixed the velocity to a surface normal value and at the outlet we used a zero gradient of the pressure. We used the basic steady-state incompressible simpleFoam solver with a RANS k-ω turbulence model. Calculations were done without any influence of a spring.

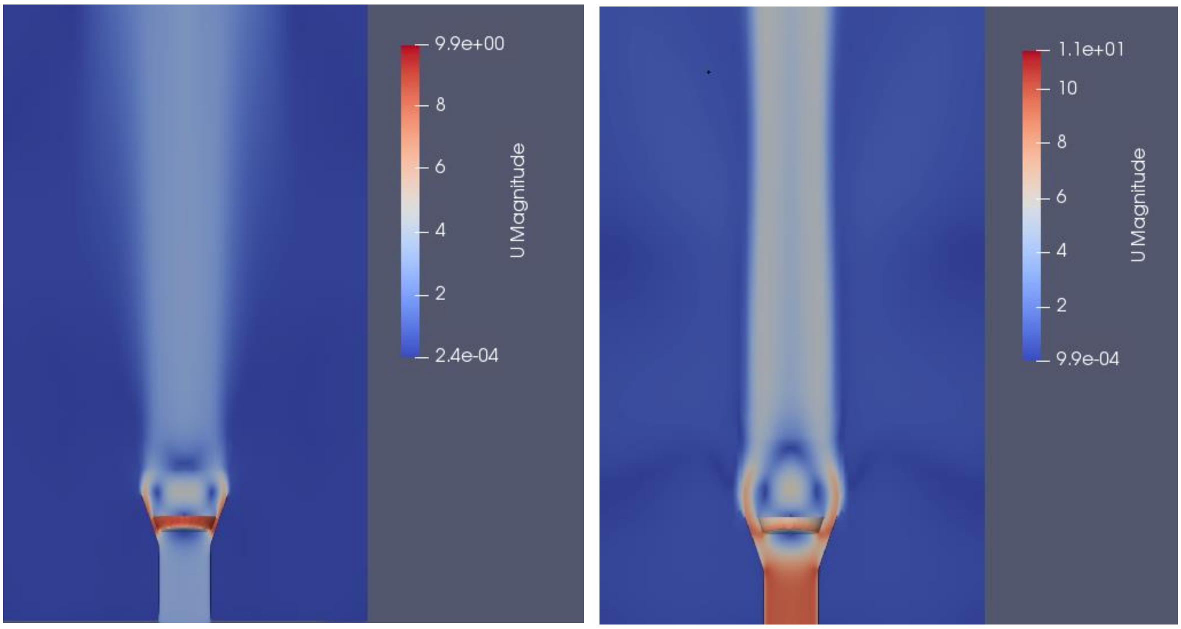

Figure 7: velocity field [m/s] plotted by Paraview [5], left side: $\dot{V}min$ = 300 m^3/h, right side: $\dot{V}max$ = 1,000 m^3/h

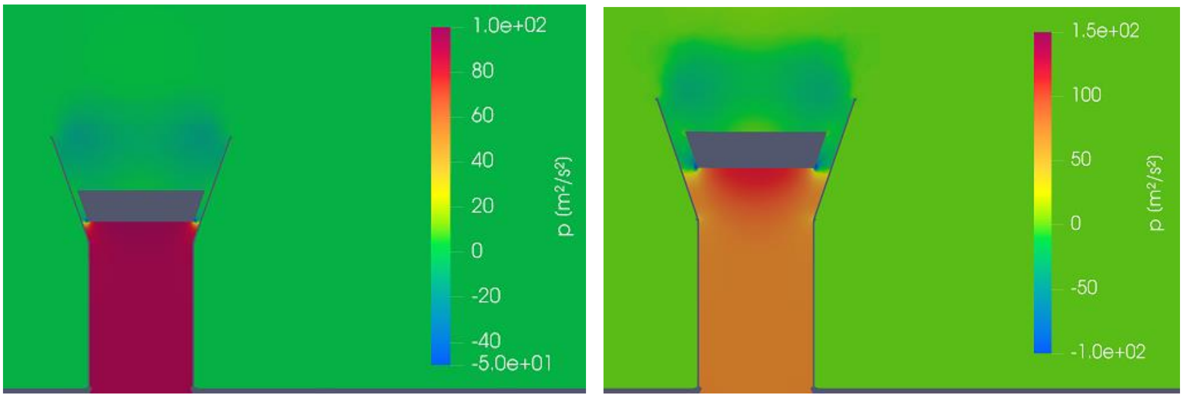

Figure 8: pressure field [m^2/s^2] (density 1.2 kg/m^3), left side: $\dot{V}min$ = 300 m^3/h, right side: $\dot{V}max$ = 1,000 m^3/h*

The figure 7 shows us the high velocity through the annulus between outer and inner cone and the stagnation area in the middle of the inner cone-bottom. A positive pressure field (see Figure 8) at the bottom of round about 100 Pa and a negative pressure above the cone was calculated.

Much better is a graph which combines the velocity vector in size and direction with the colored magnitude. In figure 9 from the bottom the $\dot{V}$ min of 300 m³/h gives an inlet speed of 3 m/s (left) and the $\dot{V}$ max of 1,000 m³/h gives an inlet speed of 9 m/s (right). In the middle of the bottom of the inner cone you find the stagnation point. Above the outlet of the EARC the airflow builds an annular vertical jet-stream with 2 separation vortices (in the two-dimensional sectional plane) at the lee-side of the inner cone.

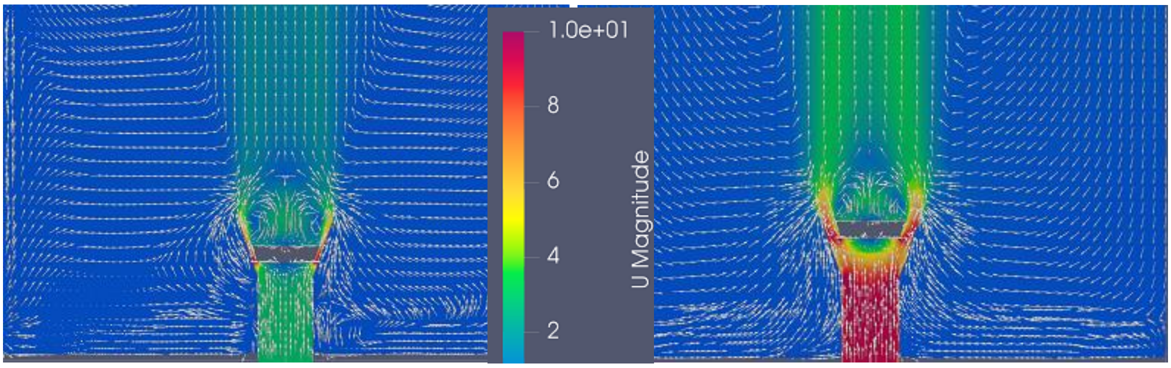

Figure 9: velocity field [m/s] plotted with speed arrows, left side: $\dot{V}min$ = 300 m³/h, right side: $\dot{V}max$ = 1,000 m³/h

This section of annular stream forms a long steady staying jet ring, especially at high flow speed:

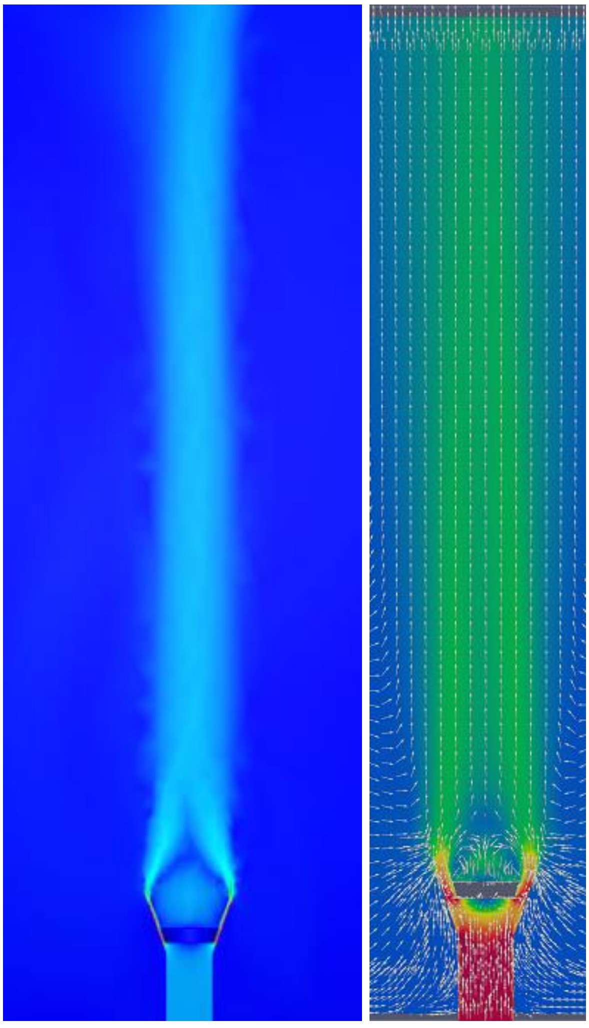

Figure 10: velocity field [m/s] plotted w/o (left) and with speed arrows (right), both sides at: $\dot{V}max$ = 1,000 m³/h

Special attention should be made to the lee side vortexes as well as to the bigger but less stronger whirls at the outer area beside the EARC driven by the vertical strong jet-stream.

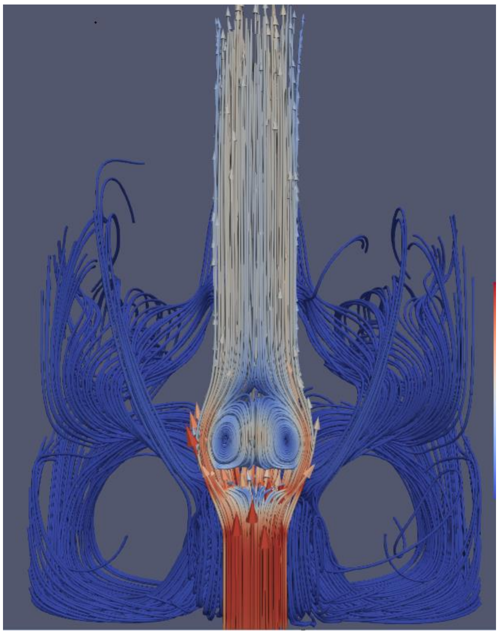

Figure 11: stream function [m²/s] plotted with speed arrows at $\dot{V}max$ = 1,000 m³/h

Numerical Results and Experiments

The calculation of the resistance force without consideration of the spring force displays the following table. This table indicates forces of a similar scale as the simplified Excel calculation.

Table 2: analytic solution of $\dot{V}$min and $\dot{V}$max through a DN200 exhaust air tower

	Weight [N]	**Flow resistance [N]**
$\dot{V}$ min = 300 [m³/h]	-3.5	1.7
$\dot{V}$ max = 1 000 [m³/h]	-3.5	1.2

Even measurements of a model size DN200 feature an almost permanent level between the minimal and maximal volume flow rate:

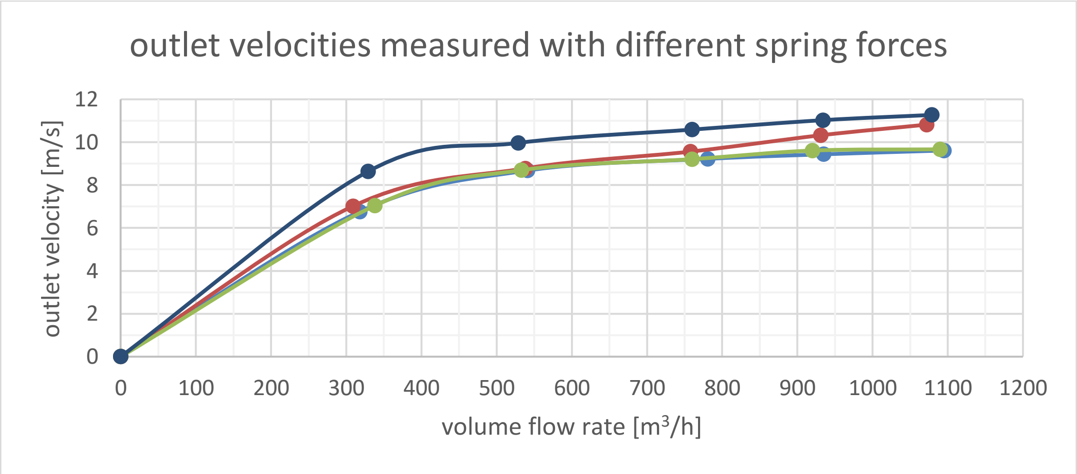

Figure 12: EARC outlet velocities measured with different spring forces at variable volume flow rates size DN200

CONCLUSION

The calculation of the resistance force (analytic or numeric) helps to preselect the magnitude of the necessary spring force. In this way the EARC is able to run at a minimum outlet speed ≥ 7 m/s between $\dot{V}_{min}$ and $\dot{V}_{max}$ as mentioned in the guidelines VDI 2280 and VDI 3781. This vertical guaranteed outlet jet stream gives the operator of the exhaust air installation the safety that corrosive exhaust air will not be pushed back to the roof of the building.

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[6] VDI 2280 ICS 13.040.20; 71.080.01 – *Requirements of discharge of organic solvents*, September **2011**

[7] VDI 3781 Part 4, ICS 07.060, 13.040.01, 91.060.40 – *Environmental meteorology, Discharge conditions for exhaust gases, small and medium combustion systems and other installations*, July **2017**