CONCEPT OF OPTIMIZATION AND DESIGN OF A TESTING DEVICE FOR TESTING SEPARATING GRILLES

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The paper deals with a basic design of testing device for testing of separating grilles. It describes a physical principle of particle separation using this grille. It deals with a basic physical-design solution of this device. The device simulates environmental conditions while driving a vehicle and provides a customer with data on separation efficiency of the tested grille.
Principally, similar tests can be carried out in aero or automobile aerodynamic tunnels where environmental impacts (rain, snow, dust particles, formation of an aqueous aerosol) cannot be applied. Any application of these effects in the test would result in aerodynamic laboratory pollution and a large financial increase in a course of the test.

KEYWORDS

testing device, force sediment separator, separating grilles, principle of testing, CAD/CAM, simulation, structural 3D modellers

1 INTRODUCTION

The separation grille serves for the separation of water, coarse impurities and, in part, dust and aerosol from ventilation holes (air conditioning of buildings, cooling of electric power equipment of rail vehicles, buses - suction of engines, etc.).
Air or automobile aerodynamic tunnel situationally complemented by a suction fan of the grille are usually used in sophisticated development of separating grilles. They all imitate an aerodynamic situation when driving, wind blows, and so on. With these laboratory devices, it is very problematic to apply water and other pollution such as ash and the like for testing separating properties of the grille. Under standard laboratory conditions, this is practically impossible or disproportionately expensive in view of the need to apply a wide range of additional protective devices to prevent contamination or moistening the laboratory. [Daneshjo 2017]
The subject of the paper is a study of possibilities of creation of stationary or mobile testing device with the closest possible physical-operation situation of the separating grille of rail vehicle which should result in several design options other than the aerodynamic tunnel solution. We can realize an optimal selection of the most appropriate concept, with critical comments on shortcomings, benefits, economy, and so on from basic options in the study. The selected concept should be developed into an initial project solution where it is necessary to make basic physical calculations and to describe attributes of the solution from a point of view of engineering, instrumental and possibly also software equipment (verbal, block, flow diagram, etc.). In the engineering part of the solution, it is necessary to design a basic construction solution of the main unit of the device by some structural 3D modellers.

The test of the grille in real simulated conditions is important because the efficiency of the device of the separating grille needs to be verified before social losses occur. The quality management system ISO 9001 does not enable certification and introduction on a market an inadequate device. In a case of rail vehicles, the grille serves as an entry to cooling system of the electric power equipment which has definitely prescribed electrical cover (electrical standards). The electrical power equipment is sensitive to moisture and dust coatings on insulators which become subsequently damp and become conductive.

2 DESIGN OF THE TESTING DEVICE FOR SEPARATING GRILLES

The solution is a design of a new testing device to measure under the required physical, realistic and environmental conditions, with a more economical measurement than a classic aerodynamic tunnel. The requirements for the test device:
- The testing device should be independent of type of tested grille.
- The device should work in a dusty environment in a rain and snow.
- Mobility of the device in exterior (external conditions).
- Economic efficiency.
- Control of air flow velocity and suction pressure of air.
- Safety.
- Environmental considerations.

The testing device should be independent of the type of tested grille. The tested grille is not a part of the device. The grille input parameters are dimensional a × b × c - so that the grille enters a tested hole. The hole of the testing device can be variably configurable but this is not a prerequisite because the size a × b × c is abiding by an order from the manufacturer of the grille. The required dimension will be ordered for the test. If necessary, an adaptation construction is made for laying of the grille. The air flow rate is essential - make sure that suction fan velocity is adjustable according to test plan and measuring program. The cooling air flow is requested by the customer, the proportion to the tested part of the grille will be calculated. A relatively low intake air velocity 3 m^3/s +/- 0.5 m^3/s is substantial for the right working – if possible, even less. A proposed actual grille size on the vehicle will be verified in a preliminary calculation is large enough (Fig. 1). This will be verified subsequently or confirmed by the test. [Fabian 2015]
From the methodological point of view, the main measured indicator of the testing device is an amount of water that the grille passes proportional to an amount of water captured by calibration tank. The result of the test will be a ratio of a mass of particles captured in the calibration tank (m_{kal}) to mass of the particles that have passed through the grille directly + aerosol in sum.
Rounded input profiles allow air to flow with minimal losses. The layers of the grid create labyrinths that curve (change) the direction of the air jets with particles of water or, respectively, dust. As a result of the centrifugal force generated and the different mass of particles and air, different trajectories result in the subsequent movement of particles and air.

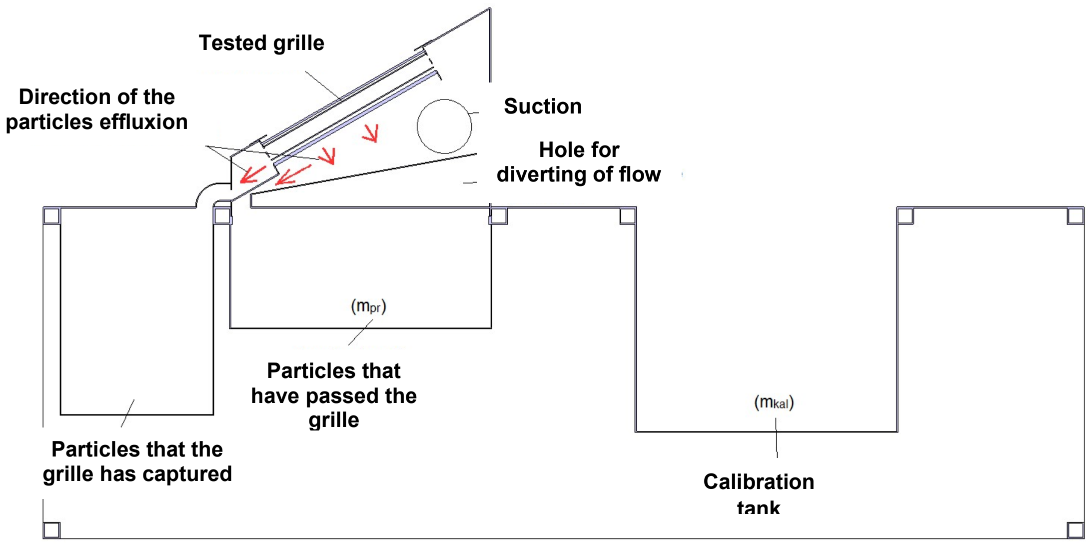

Figure 1. Principle of testing

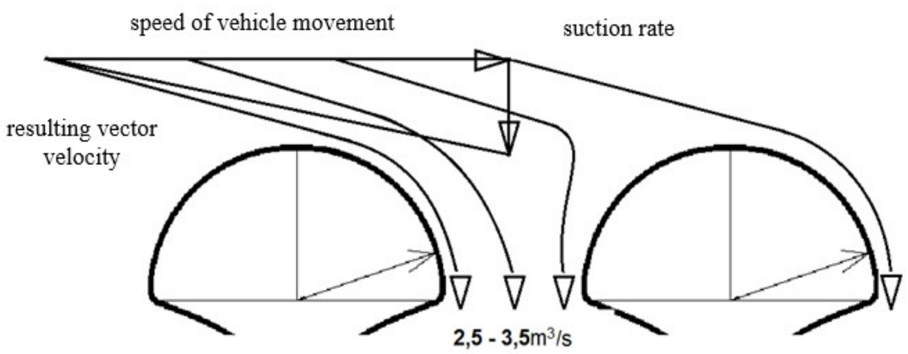

Figure 2. Changing trajectory of suction

Particles of impurities are directed into the collected areas of the jelly where they are captured and vertically climb to the lower edge - applies to the oblique and vertical grid. The horizontal grid must have a small real slope so that the water rises to the collecting point or, outlet. The collecting part is equipped with an anti-brick so that the entrapped dirt does not re-enter the air flow due to the transverse acceleration of the vehicle. The individual air flow profiles must meet the conditions of the continuity equation so that losses are as low as possible.

The trajectory of the particulate stream which is driven by the air flow is modified by suction, which is necessary for proper cooling function. When ingested, the particle is pulled by the air jets. Since it has a greater weight than the air, the effect of centrifugal force passes on another trajectory and is carried to the retaining part of the grille profile (Fig. 2) where it captures and slides in the profile direction. It is carried away by gravitational force. Self-cleaning effect requires a minimum gradient.

The weighable quantity of m_{pr} will be obtained as a sum of a weighable quantity that passes through the tested grille (m_{pr1}) directly and the quantity that has leaked out in a form of the aerosol that a cyclone separator will capture (m_{pr2}). This sum is the amount that the passes through the grille (Fig. 3).

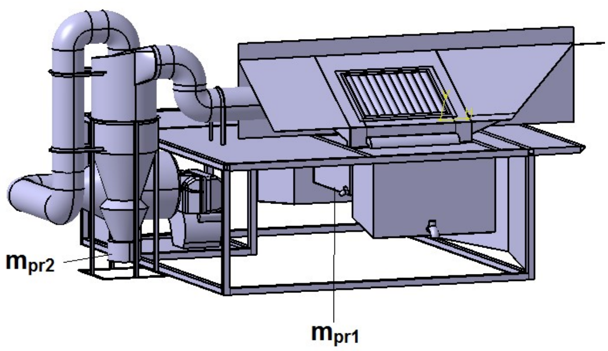

Figure 3. Containers for capturing the weighing quantity m_{pr}

The result of the test will be obtained by comparing the mass m_{pr} and the mass m_{kal}. The formula can be written as:

$$\varphi = \frac{m_{pr}}{m_{kal}} = [\%] \qquad (1)$$

Factor of the penetration Through the grille in the dimension - either as dimensionless or × 100 as percentage expression:.

$$m_{pr} = m_{pr1} + m_{pr2} \qquad (2)$$

Factor of grille separator ψ= 1- ϕ [1], or Ψ=100- ϕ [%] and the result is in [%]

The particles that the grille will capture, they will drain into a separated container. The particle ratio in this container to the particle ratio in the calibration tank should show an approximate efficiency of the grille. A length of the test will depend on the generation of a measurable amount of penetration of fluid.

For easier of handling and transport, the device could be divided into four basic parts:

1. Measuring container.
2. An elimination grille for the arrangement and stabilization of the external flow field.
3. Propulsion turboprop unit.
4. Controlling and metering board.

These parts will bind together to form one unit that will be firmly secured against movement and dynamic flow pressure. As a turboprop engine has high performance, it is important to take into account torque and to ensure stiffness of the whole device against oscillation. [Hovanec 2015]

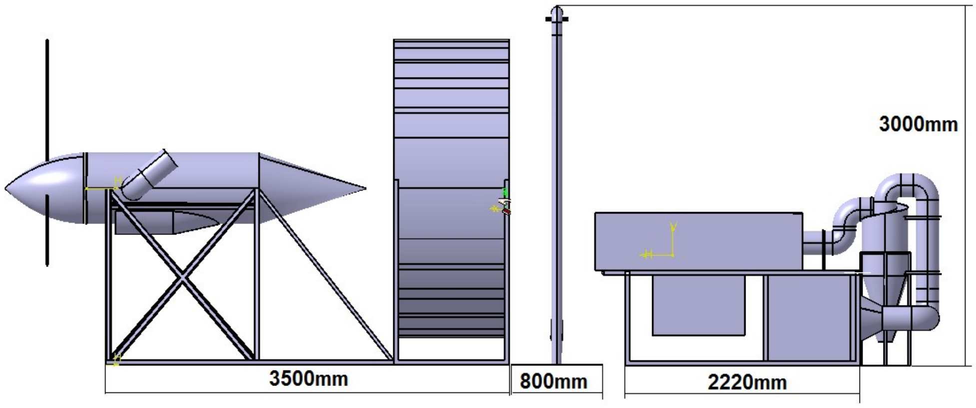

Figure 4. Dimensions of the testing device

Due to the transport option, it is important to adhere to maximum permissible width of 2500 mm for transportation on roads. This dimension exceeds a size of a shower but it can be dismantled and transported in parts, like a protective railing (Fig. 4). The distance of container location from the shower will have to be experimentally tested to create optimal environment for the test.

When constructing the testing device, it is also necessary to consider the control and measuring board. The board will serve to control the turboprop drive unit, a small combustion engine that powers the fan. The flow rate of the water is controlled by the tank and valves on the ramp. The entire device has to meet safety and ergonomic requirements. The device has to meet requirements for simple transportability in separating purpose individual blocks.

Fig. 5 shows the entire device with all the elements for carrying out the measurement. For safety, it is located around the turboprop drive unit. This must not hinder service activities and communication.

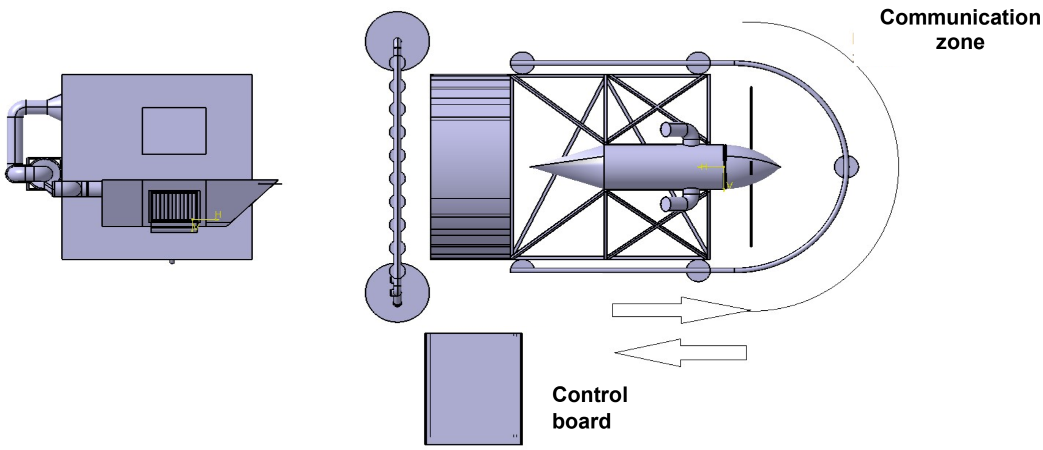

Figure 5. Trajectory of the security zone

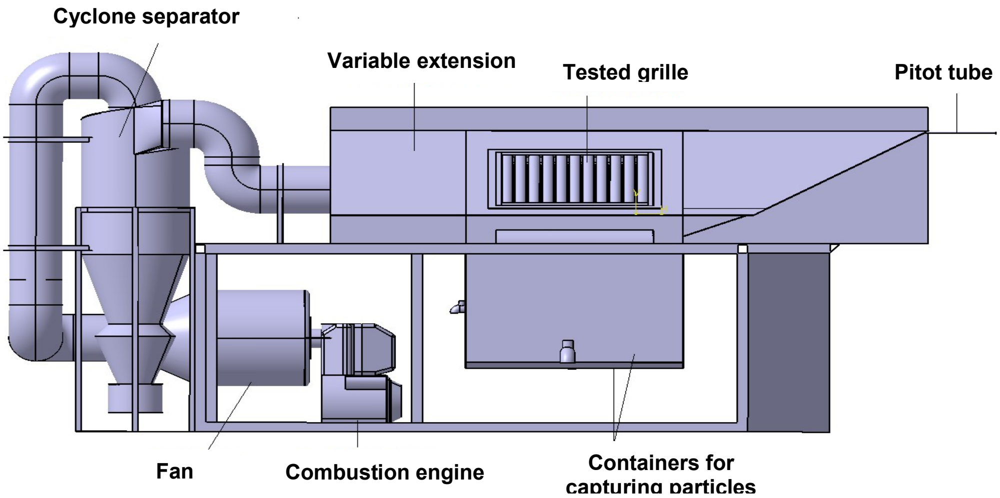

Figure 6. Basic construction parts of the measuring container

Basic parts of the container: Cyclone separator, Variable extension, Fan, Combustion engine, Containers for capturing particles (Fig. 6).

2.1 Containers for Capturing Particles

When constructing containers, a volume of the vessel and an area which a real volume of liquids or particles will fall on. The volume of containers will affect a length of the test. There is an attempt to achieve the shortest measuring section in the test due to a limited level of water in the tank which has to be provided into the considered tests location. [Králik 2011]

The area (hole size) is important for correct conversion of test results. It affects a selection of the fan as well as the engine that drives it. The selected size of this area is 0.5 m^2 in this testing device proposal. Since the grille size may vary depending on the customer, it is necessary to adjust the hole to maintain the correct test course, i.e. the flow rate of air through the grille and the amount of impurities that falls in the same area as the grille and the calibration vessel. The air flow is controlled by the velocity of a small combustion engine driving the fan. When testing different types of grilles, there may be two situations:

- If the grille is larger than 0.5 m^2.
- If the grille is less than 0.5 m^2.

If the first case occurs, a variable extension has to be used. In the latter case, it is necessary to adjust the area of the calibration container. The area is reduced by adding and fixing the bars.

The containers have an oblique shape to obtain more easily a measurable amount of captured particles and classic water taps for their simple draining into portable containers. We shall perform weighing and shall evaluate state of Netto (Fig. 7).

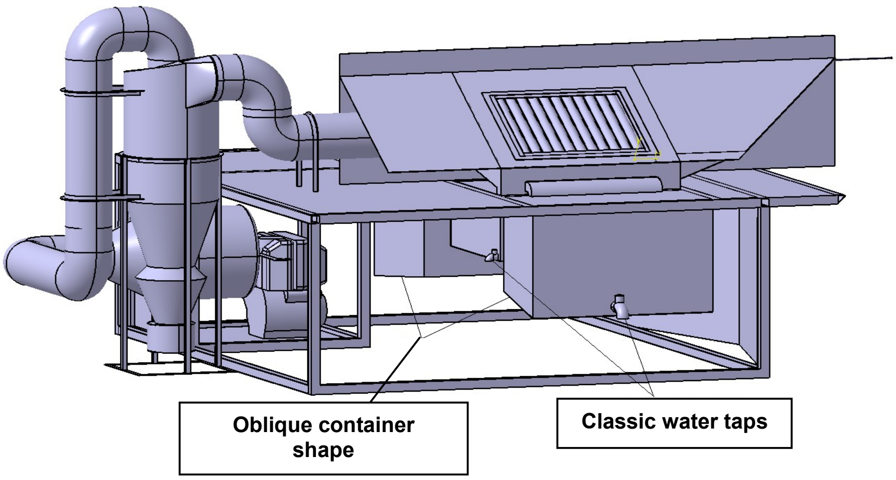

Figure 7. Containers for capturing particles

2.2 Variable Extension

When designing the extension, it is necessary to consider location of the grille and its size. The extension has to be manufactured to test each type of grille location (Fig. 8). For the correct working of the grille, it is necessary to have at least a minimum slope (self-cleaning), that is referred to a horizontal location. The extension will be need to manufacture for the grille test, the production of the extension will be cost for the test itself.

Different variable extensions would be for various types of grille location. When designing a testing device, the grille will be described in the oblique location, due to this location there is the most physical principles for describing and most implementation in practise of railing vehicles. Thus, oblique location is the most common option and therefore it is a subject of a more detailed solution.

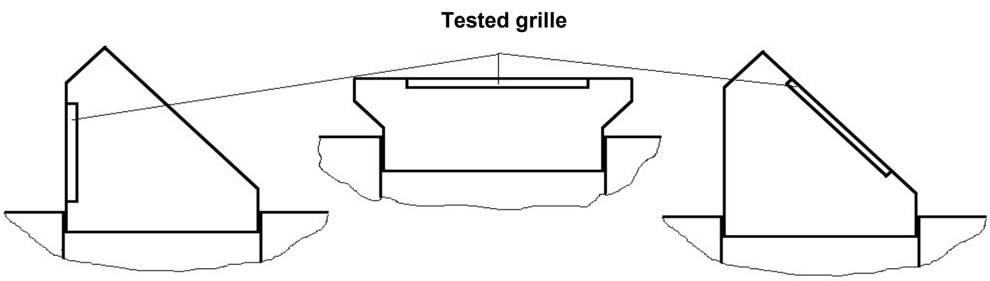

Figure 8. Construction options of variable extension for different location of tested grille

Figure 9 shows model solution for the oblique location of grille:

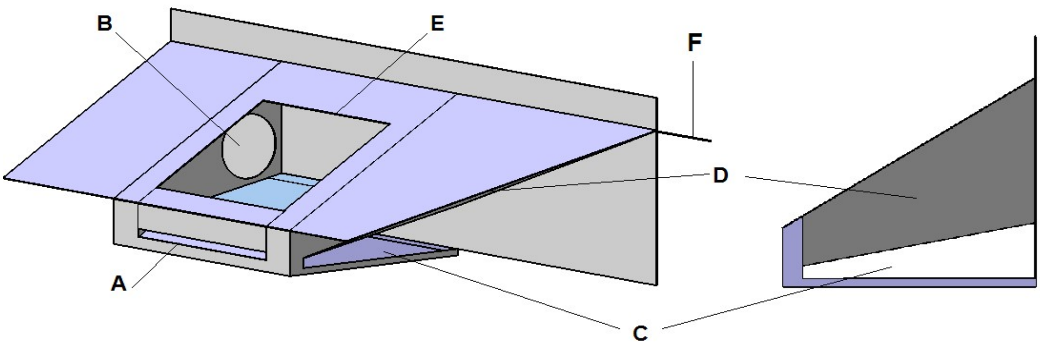

Figure 9. Model of solution for variable extension with description

- A- Hole for effluxion of particles captured by the test grille
- B- Suction hole
- C- Hole for cut and diverted trays
- D- Plate for isolating trays between the grille test and calibration
- E- Hole for the tested grille
- F- Pitot tube

A hole for flow diverter and flow isolator and guide plate are parts that reduce a vortex flow in order to avoid biased or inaccurate results, see Fig. 10.

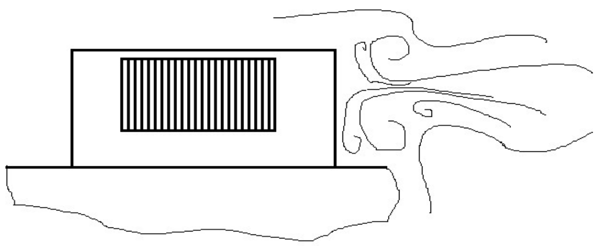

Figure 10. Influence of the vortex flow on the variable extension

To reduce this effect, the front part of the measuring container on which there is a "knife" for cutting off and diverting the undesired flow will be adjusted (Fig. 11).

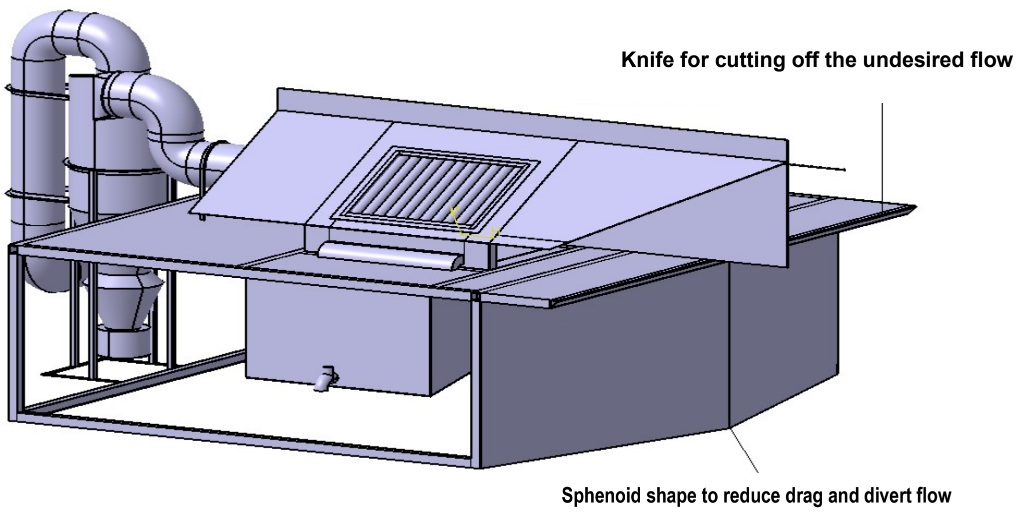

Figure 11. The construction part of the diverting container for diverting the undesired flow

The area in the circle in Fig. 12 is connected to the grille. The part that is captured by the grille is taken to a separate container (for the weight sum check and comparison with the result of the calibration). A trapezoidal shape of the channel under the test grille is related to the continuity equation to achieve a uniform airflow velocity over the entire area of the tested grille since the suction opening is located substantially to the right and to the rear. The passage trapezoidal channel at the bottom is related to the released cut off part of the flow diverted along the suction channel of the grille. [Kozuba 2015]

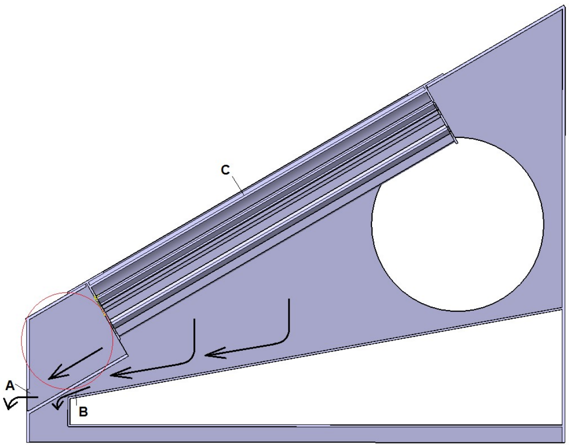

Figure 12. Transverse section variable extension with tested grille and description

A- the hole for effluxion of the particles captured by the tested grille
B- the direction of flow of the particles that have passed through the grille and have not been entrained by suction
C- tested grille

To complete the method, it is also necessary to capture that part of the liquid or particles which are entrained by flow in a form of aerosol. A cyclone separator is designed for this purpose.
Cyclone separators are used to separate condensate or dust from the air. Tangential input rotates a part of the incoming air into a rotary motion. Thanks to resulting centrifugal force, the more liquid and solid particles are thawed on the separator wall where they are connected to large drops that flow out or fall in into collection point for the condensate or dust. The separation process continues with the rounding of the trajectory in the lower part where the air is turned towards vertical drainage pipe. Exhausting air has not already contained a significant amount of condensate or dust. Only the finest fractions or aerosol are leaked. This is a source of a mild error of the method. The bottom of the separator (draining) is removable. Fractions or the liquid gets out for weighing at external weight in this part. The detected weight will be used to make the test result objectivity.

2.3 Fan

To select a fan, it is necessary to select a proposed suction velocity and determine the test volume flow with the customer request for the test. The initial proposed velocity is 3 m^3/s for the correct working of the grille. The suction hole area is 0.5 m^2. The factor of the grille thickening is around 65% (free space 35%). We shall select an appropriate fan from the given parameters and delivery options. Make sure that the suggested fan velocity corresponds to the combustion engine options. The fan drive will be modified - the original electric engine will not be used due to water, and the demand for regulation and autonomy for the work of the entire power-independent device from the public network. A small combustion piston engine will be used as a suitable solution. [Knežo 2016]

The minimum free flow area is ϕ=35% $\varphi = 35\%$

Minimum flow area Q:

$$Q = 0.5 \times 0.35$$

$$Q^{'}[m^3/s] = [m^2 \times m/s] = 0.175 \times 2.5$$

$$Q = 0.43\ m^3/s$$

2.4 Engine Selection

The engine is used to drive the fan. Important data for engine selection have been:
- Adjustable velocity.
- Power has been selected according to the original output of the electric engine of the fan.
- Air cooling.
- Remote control option.

Based on these data and the fan selection, a small combustion diesel engine from the firm Lombardini was selected (Fig. 13). The diesel engine is more favourable than a gasoline engine from a passive fire safety point of view.

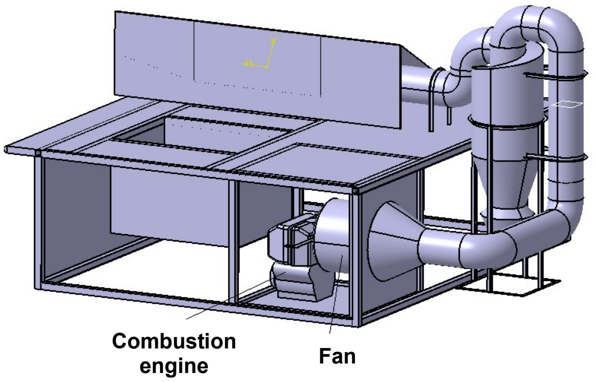

Figure 13. Transverse section variable extension with tested grille and description

3 ELIMINATION GRILLE FOR THE ARRANGEMENT AND STABILIZATION OF THE EXTERNAL FLOW FIELD

The grille serves to compensate for the vortex flow that is generated using the M601 turboprop unit and the V 508D propeller. The propeller unit also forms flow components that are undesirable for the course of the test. This flow has to be "offset" by the turboprop unit, i.e. eliminate these undesirable components for the correct course of the test.
The propeller gives a move in the direction of flight by accelerating the air that passes through its disk (its plane) - this air forms a flow tube. Its transverse section varies with the flow rate of the flowing air.
The task of the elimination grille is to arrange the flow profile in a maximum gauge to make it as parallel as possible. Since the device is designed to simulate air flow at a certain velocity, it is not necessary to achieve complete flow "offset". We do not consider inequality as a method error because the flow around

the rail vehicle is not ideal. The construction of the alignment grille model has been based on the rules for piping construction. The depth of the grille is 5×d, where d is the dimension of the girder profile of the grille see Fig. 14.

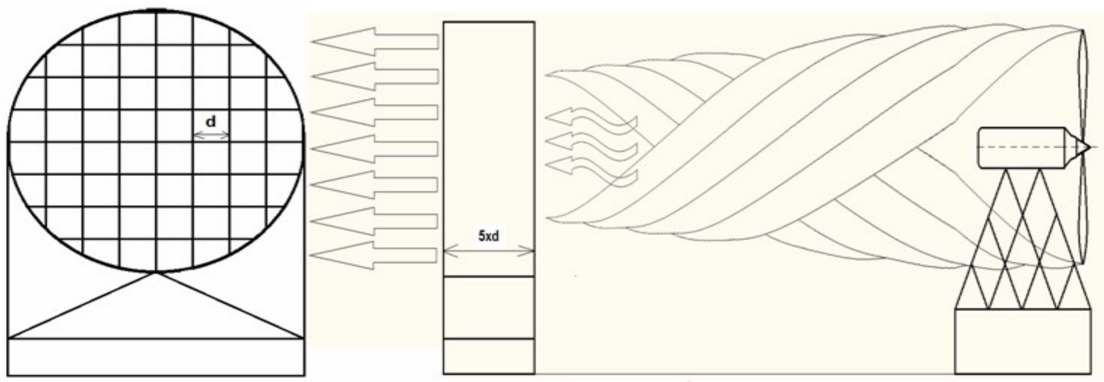

Figure 14. Schematic representation of the grille function

4 VELOCITY MEASUREMENT

A pitot tube will be used to measure the flow rate of air. We shall use it as an approved and proven method because pressure is measured more easily than velocity. Pitot tube or Pitot pipe is a sensing part of a measuring device that senses the velocity of fluid flow - liquids and gases based on the ratio of static and dynamic pressure of the measured fluid. The principle of the activity is based on the Bernoulli equation. [Tomko 2015]

The Pitot tube consists of a pipe made of two hole systems. The open end directed against the flow direction serves to sense dynamic pressure and the holes in the housing serve for static pressure sensing. The fluid is in a real environment at a certain static pressure. At the same time, however, the dynamic pressure is produced by the kinetic energy flow of the fluid is created during its movement. The Bernoulli equation shows that:

total pressure p = static pressure p_1 + dynamic pressure p_2

In other words, the pressure at the inlet of the open pipe is the sum of the static pressure of the environment and the dynamic (kinetic) pressure of the moving molecules of the fluid (gas):

$$p = \frac{\varrho v_2^2}{2} + p_1 \tag{3}$$

Which of dynamic pressure is a difference between total and static pressure. The dynamic pressure is determined by the membrane in a closed container (Fig. 15). If the pressure on one side of the membrane is stable to static pressure, a deformation of the membrane is proportional to the dynamic pressure, this is recalculated (or mechanically converted) to the velocity indicator (the membrane deflection is electronically or mechanically transferred to the velocity indicator). Instead of static ports, Pitot's static tube (also known as Prandt's tube) can be used (Fig. 16). This has another tube on the same axis as Pitot's, with holes on the sides, out of the direct flow of air to measure static pressure. [Sabo 2015]

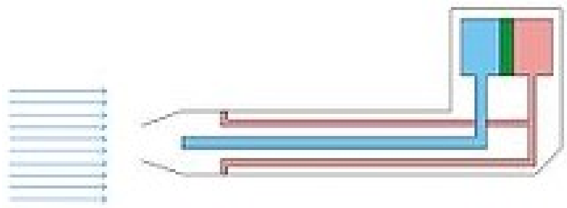

Figure 15. Scheme of Pitot's tube

blue: total pressure measurement
red: static pressure measurement
green: differential (proportional) pressure gauge

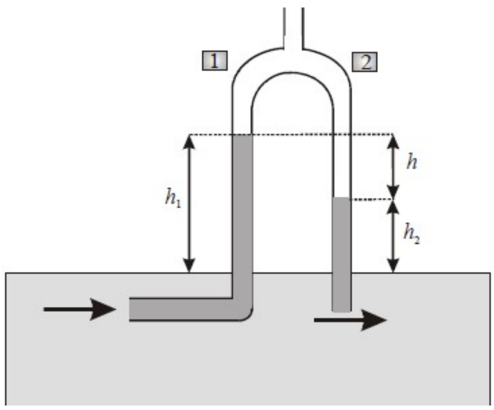

Figure 16. Principle of Pitot's tube

The velocity of fluid flow in pipelines and pipes are measured by this method where an anemometer cannot be used in industry. The Pitot tube enables for continuous measurement without changing the pressure in the pipeline. The difference in pressure causes a different height of the contrast fluid column which is directly proportional to the flow rate of the medium in the pipe. Flow rate measurement of flowing liquid (Pitot tube):

$$p_2 = p_1 + \frac{1}{2}\rho v_1^2 \tag{4}$$

$$p_1 = h_1 \rho g + p_0 \text{ a } p_2 = h_2 \rho g + p_0 \tag{5}$$

After substitution:

$$v_1 = \sqrt{2g(h_2 - h_1)} \tag{6}$$

We shall simulate various environments and produce noise during the test. We should select carefully a location where we can presume:

- Blowing swirling dust.
- Noise.
- Splash water.
- Take a snowdrop (for freezing).

The ideal location for the test is low-frequency airport. It is important that the location of the test is safe and environmentally friendly. These requirements are in line with aircraft engine tests where low-frequency aircraft engines are tested. Therefore, it would be optimal if the test went to the right location. This proposal assumes that this kind of grille testing will be realized at the engine line at Trenčín Airport. This is also the location of the customer of the theme of this paper. It has a relationship with the owner of the line so they can agree to cooperate.

5 CONCLUSIONS

The function of the tested object is described in detail, in this case the separating grille in this paper. It describes the physical principle of particle separation from the air at a certain volume flow as well as the basic formulas of the flow of ideal fluids, i.e. ideal liquids and ideal gases. The paper describes the design of the device for testing the separating grilles. It describes the advantages and disadvantages of the proposed concept critically. The final design is processed into a 3D form of CAD by program CATIA which was recommended by the customer. The measurement method is created and described and the basic physical principles of the correct design of the device itself are respected. It does not have a detailed design solution and its strength calculations. The paper is described as an optimal solution to the basic design and is only a basic selection of the whole issue with a possibility of further detailed processing.

The device can be used to test other features and objects by modifications, not just separating grilles. After modification, ventilation grille tests without ventilation, drainage roof grooves, windscreen wiper test and contact collector tests may be carried out after modification. It can be simulated, for example, how prototypes of road vehicles and so on will be contaminated. It is not known whether a similar device exists in Europe. This paper is a penetration of this undisturbed soil and therefore we evaluate it as socially beneficial and up-to-date, especially with regard to the effects of the last snow calamity in rail transport in the Czech Republic and Western Europe.

Sophisticated development of separation grilles is usually used by air or car aerodynamic tunnel, situationally complemented by a suction fan of the grid. They all imitate the aerodynamic situation when driving the car, blowing the wind, and so.

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