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INFLUENCE OF PROTECTIVE GRILLES ON THE PRESSURE-SIDE ACOUSTICS OF A COOLER-FAN-ASSEMBLY USED IN CONSTRUCTION SITE MACHINERY

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Abstract

The fans in the cooling system contribute significantly to the noise emissions of heavy construction equipment such as rotary drilling rigs. Protective grilles are used to prevent people and animals from coming into contact with the rapidly rotating fan blades. It is known from the relevant literature that such protective grilles on axial fans can increase the fan's radiated sound power by several decibels. In this study, we therefore systematically investigate the acoustical influence of protective grilles mounted on the pressure side of the fan of a cooler-fan combination used in construction machinery. Four typical protective grilles with significantly different geometries are used. The grilles are first acoustically characterized in an aeroacoustic wind tunnel under low-turbulence flow conditions and then mounted on the pressure side of the cooler. The cooler, which is installed in an axial-fan test rig, is acoustically measured at various operating points of the axial fan. It is found that the grilles have no significant influence on the sound emissions of the overall system at any of the feasible operating points. A similarity analysis leads to the hypothesis that pressure-side protective grilles primarily influence the emitted sound spectrum in low-pressure axial fans.

Keywords: *heat exchanger, axial fan, installation effects, protective grilles, construction site*

1. Introduction

Heavy construction machinery, such as rotary drilling rigs, requires enormous drive power -often several hundred kilowatts- to perform their tasks at full capacity on the construction site. These tasks include, among other things, soil mixing and drilling holes for concrete foundations [1]. To adequately cool the equipment under these high drive power conditions, multiple coolers are required to cool the hydraulic circuits, water circuits, or the turbocharger.

Coolers usually consist of a heat exchanger and a suction-type axial fan. To prevent the rapidly rotating fan from coming into contact with people or animals during operation, protective grilles are required; these can be installed in various geometries and at different distances from the fan blades. An example of such a device is shown in figure 1.

Figure 1: Example of an axial fan as part of a cooler-unit in a rotary drilling rig protected by a grille.

In the past, it has been shown that the coolers of such a device can play a decisive role in emitted sound power and perceived psychoacoustics [2]. Therefore, the search for measures to reduce noise emissions from such devices is of particular interest.

In the axial fan research community several studies have shown that installing protective grilles on the pressure side of axial fans can lead to a significant

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increase in radiated sound power of up to 6 dB. In all documented cases, broadband increases around a center frequency of approximately 1000 Hz were observed in the frequency spectrum. In all of the studies, the greatest increases in sound power with the use of a protective grille were observed when operating points with high airflow rates on the fan's characteristic curve were examined [3], [4], [5].

2. Methodology

In this paper, we aim to investigate the influence of geometrically different protective grilles on the radiated sound power of a fan-cooler assembly.

2.1. Examined Protective Grilles

Four typical examples of such protective grilles, which are also the ones examined here, are shown in figure 2. Grille 1 and Grille 2 are made of steel. These

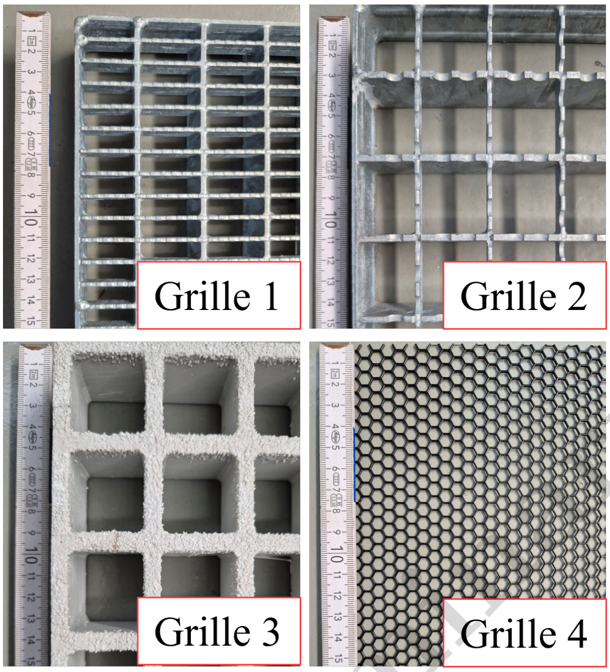

Figure 2: Photograph with close up of the four protective grilles.

are standard protective grilles. Grille 3 is made of fiberglass-reinforced plastic. Grille 4 is like a wire mesh with a honeycomb pattern. The grilles also differ in terms of their thickness (relative to the drawing plane, as shown in figure 2). The thicknesses are: 3.0 cm for grille 1; 3.0 cm for grille 2; 3.9 cm for grille 3; and 0.1 cm for grille 4. These grilles are all used in conventional rotary drilling rigs, depending on the cooler's mounting position.

2.2. Investigations in the aeroacoustic wind tunnel

In the first step, the four different protective grilles are acoustically characterized in the aeroacoustic wind-tunnel under low-turbulence flow conditions. In this case, the fan and heat exchanger are omitted, and only the characteristics of the grilles are to be determined. The tests were conducted in the aeroacoustic wind tunnel at LSTM in Erlangen. Figure 3 shows the test setup used for this purpose.

Figure 3: Measurement set-up and localisation of the microphones within the aeroacoustic wind-tunnel.

The grilles are attached to the outlet lip of the wind tunnel nozzle using screws. An elastic sealing tape is located between the grilles and the outlet lip, which prevents air from escaping at the sides. We measure the sound pressure on a hemisphere with a radius of 1.06 m using four microphones (M1–M4). We use 1/2-inch free-field microphones from Microtech Gefell (MTG), consisting of MK250 microphone capsules and MV210 preamplifiers. An S-Quadriga II from HEAD-acoustics is used here as the A/D converter and recording system. The recording time is 30 seconds at a sampling frequency of 48 kHz.

In order to later compare the sound emitted by the grilles with measurements taken at the cooler under real installation conditions, we calculate the distance-independent sound power from the measured sound pressure. Since these flow-through cross-sections differ at the wind tunnel nozzle and behind the fan, we also correct for the area ratio $A_{ref,fan}/A_{nozzle}$, assuming that the sound intensity is constant across the grille surface. This yields the following formula for the sound power, based on [6]:

$$L_W = \overline{L}_p + 10\log\left(\frac{2\pi r^2}{1m^2}\right) dB + 10\log\left(\frac{A_{ref,fan}}{A_{nozzle}}\right) dB \quad (1)$$

Here, $\overline{L}_p$ stands for the sound pressure level energetically averaged across the four individual microphones (M1-M4).

2.3. Fan and Heat Exchanger

The cooler used in these studies is shown in figure 4. It consists of a microchannel heat exchanger measuring 530 × 580 × 84 mm. It is capable of dissipating 24.1 kW of heat under full load. The plenum is connected to an electric fan with 11 impeller blades and an outer diameter of 0.5 m, that rotates at a maximum speed of 3050 rpm. It is an axial fan with a tip shroud. At the design point, approximately 1.4 m^3/s of air is transported.

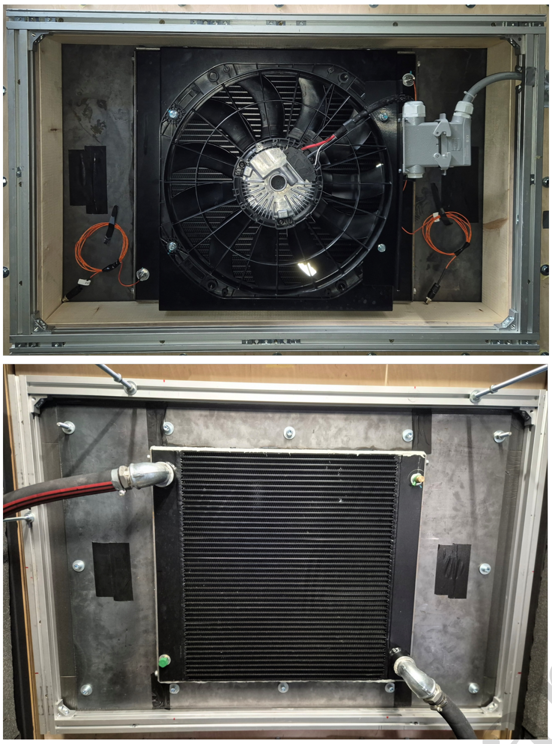

Figure 4: Photographs of the cooler used in this study. Top: fan side, Bottom: heat exchanger side.

2.4. Axial Fan Test-Rig

For our tests, we use the axial fan test bench at LSTM Erlangen in accordance with DIN EN ISO 5801; this is described in detail in [7].
The figure shows a close-up of the test bench, highlighting the installation of the heat exchanger and the protective grilles. Using the test bench, we can study the combination of fan and heat exchanger across a wide range of the fan's performance curve. To enable reproducible acoustic measurements on the outside of the test bench, a measurement chamber was constructed using movable partition walls lined with acoustic foam on the inside. The floor is also completely covered with convoluted foam to prevent reflections of the floor. As shown by the red double-headed arrow in the figure, we can adjust the distance between the trailing edge of the fan blade and the protective grille using an extension made of aluminum profiles. Here, we are examining distances of 6 cm and 30 cm. The microphones described in section 2.2 are used again, with a measurement duration of 30

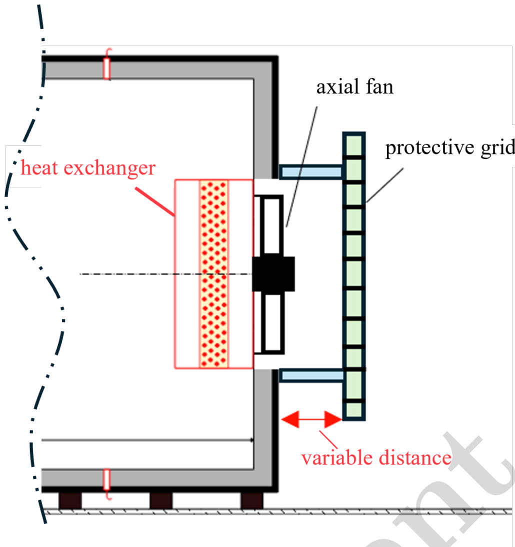

Figure 5: Partial Sketch of the test-rig used with special focus on the mounting situation of the heat exchanger and the grilles, modified according to [8].

seconds at a sampling rate of 48 kHz. The recording is made using a measurement chain of National Instruments devices that is part of the test bench. Figure 6 shows a photo of the test setup and the position of the microphones. To minimize wind interference, the microphones in this set-up are placed on a hemisphere with a radius of $\sqrt{2}$ m centered on the fan's hub.

3. Results

3.1. Aeroacoustic Wind-Tunnel

First, we will examine the results from the aeroacoustic wind tunnel, where the various protective grilles, hereafter abbreviated as G1–G4, were exposed to flow velocities of 7.5 and 11 m/s. These two flow velocities roughly correspond to the maximum flow velocities that occur behind the grilles when the fan is operated at flow rates of 1.0 m^3/s and 1.4 m^3/s. Figure 7 shows the results of the measurements. Here *Off* (and also in the other figures in the next section) refers to the measured sound power level with the fans and auxiliary blowers turned off. *no* stands for *no grille* and indicates that no grille was used and that the wind tunnel nozzle or fan can operate without pressure side obstructions. The total sound power level Lw_{tot} is determined here by logarithmically summing the values of the individual frequency bins [9]. Moreover all the spectra are A-weighted. The following can be observed from the two diagrams: First, the four different protective grilles emit very different sound spectra. In Grille 1 and Grille 2, dominant tonal components are present, which shift proportionally towards the higher frequency range as speed increases. Furthermore, higher flow velocities are accompanied by a significant increase in measured sound power. Finally, it can be observed that Grille 4 exhibits by far the lowest sound power at both velocities, with a

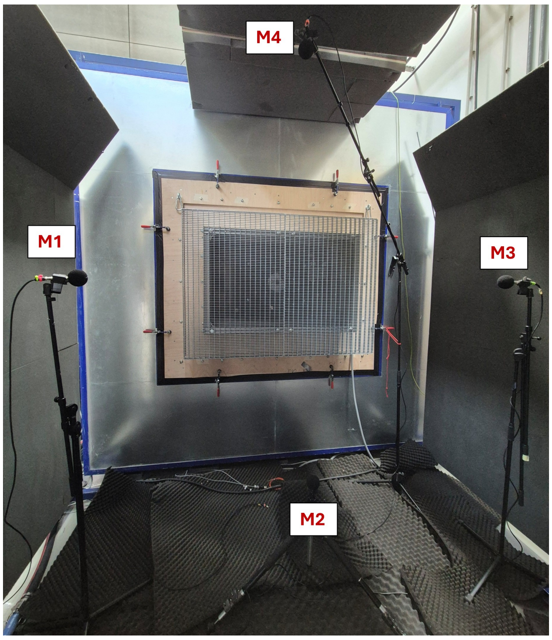

Figure 6: Measurement set-up and localisation of the microphones on the pressure side of the cooler outside the test chamber.

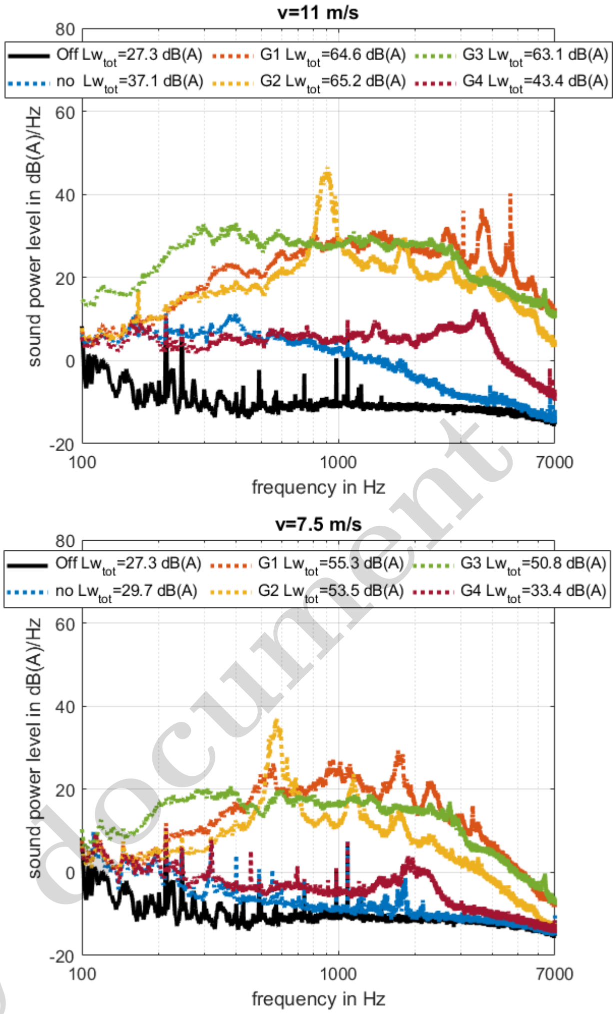

Figure 7: Measured sound power for the four different grilles in the aeroacoustic wind tunnel at an effective flow velocity of 7.5 m/s at the bottom and 11 m/s at the top.

difference of 17 dB(A) from the second-quietest grille at 7.5 m/s and 20 dB(A) at 11 m/s.

3.2. Axial Fan-Test-Rig

Below are the results of the acoustic measurements taken on the pressure side of the fan on the test rig.

3.2.1. Design point

The figure shows the measured sound power levels at a distance of 30 cm from the trailing edge of the fan at the top and at a distance of 6 cm at the bottom. The diagrams also show the blade passing frequency (BPF) and its first higher harmonic marked with dashed red lines. Upon first glance, the results show that the grilles have no effect on the calculated total sound power level Lw_{tot}. The total sound power levels for all variants tested are within 1 dB of each other. On the one hand, this indicates a high degree of repeatability in the experiments; on the other hand, it clearly shows that the protective grilles have no acoustic effect. This applies to both the larger and the smaller distance between the protective grille and the fan. A comparison of the spectra measured here with the wind tunnel results for 11 m/s suggests that the fan noise is at a higher level than the flow noise in the wind tunnel across the entire frequency range under consideration.

3.2.2. Reduced fan-speed and volume flow

It seems reasonable to test the fan at a reduced speed using the highest possible volumetric flow rate at the same time. The fan was therefore operated at the lowest possible speed of 1020 rpm. The fan was supported by the auxiliary fan of the main test bench in such a way that a maximum airflow of 1.0 m^3/s could be achieved. The acoustic results obtained are shown in figure 9. It is clear that, even at this operating point of the fan, the protective grilles have no measurable acoustic effect on the sound power level. This time, the measured total sound power levels are within 0.5 dB(A). This applies both when the distance between the fan and the protective grille is 30 cm and when it is 6 cm.

4. Discussion

This study found no effect of the protective grilles on the acoustic emissions of the fan under investigation. We have seen that airflow through the grilles is a significant source of noise at the flow velocities under consideration. However, in our case, the noise from the grilles is masked by the fan noise across the entire frequency range under consideration. The following section will discuss why, contrary to the literature cited in the introduction, no effect was measured. One possible reason may be the precise geometry of the protective grilles. The literature consistently refers to

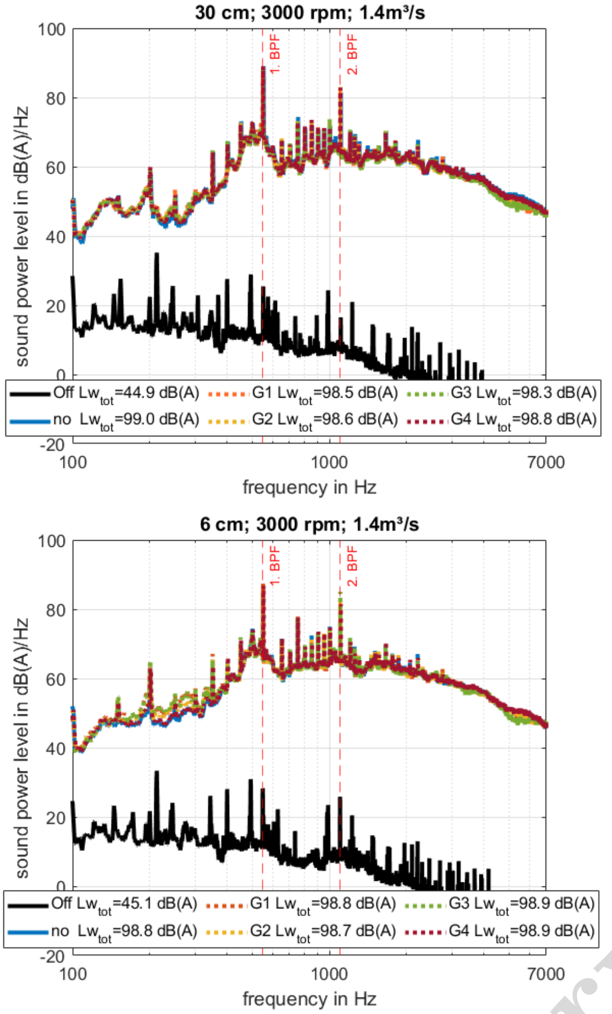

Figure 8: Results of the measured sound power levels at the fan's design point at a speed of 3000 rpm and an airflow rate of 1.4 m³/s. Top: results for a distance of 30 cm between the grille and the trailing edge of the blade, Bottom: results for a distance of 6 cm between the grille and the trailing edge of the blade.

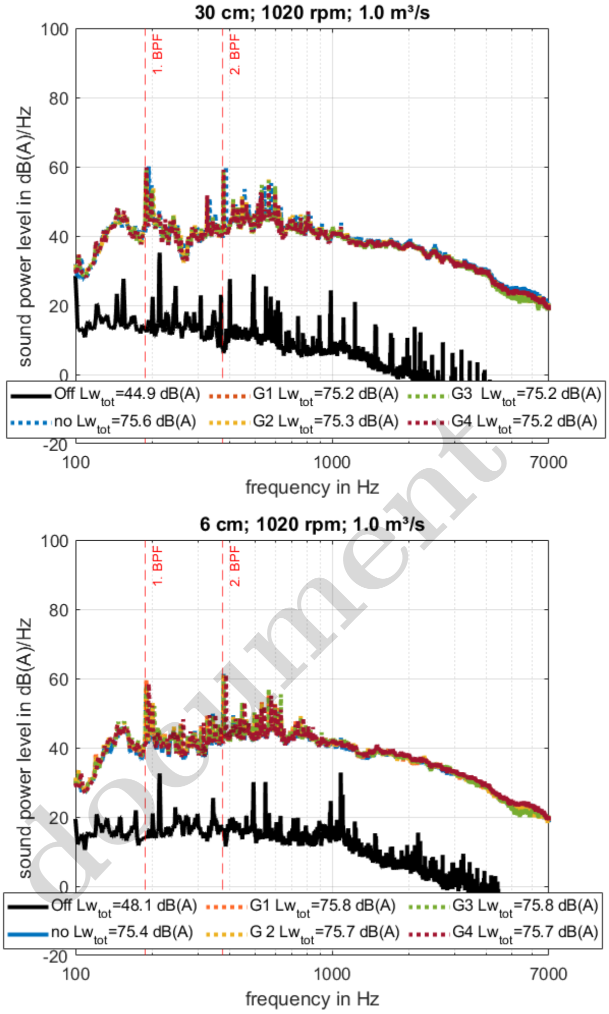

Figure 9: Results of the measured sound power levels at reduced fan speed of 1020 rpm and an airflow rate of 1.0 m³/s. Top: results for a distance of 30 cm between the grille and the trailing edge of the blade, Bottom: results for a distance of 6 cm between the grille and the trailing edge of the blade.

protective grilles consisting primarily of round rods. The acoustic effect is then attributed to the vortex streets that form in a cylindrical tandem arrangement. Another possible explanation lies in the performance curve of the fan used here. To compare the fans described in the literature with the one used here, we introduce the dimensionless parameters flow coefficient φ and dimensionless static pressure ψ with the following definitions [5]:

$$\varphi = \frac{4\dot{V}}{u_2 \pi D_2^2} \tag{2}$$

$$\psi = \frac{2\Delta p_{stat}}{\rho u_2^2} \tag{3}$$

Here, u_2 denotes the tip speed at the blade tip, D_2 denotes the outer diameter, $\dot{V}$ denotes the volumetric flow rate, and Δp_{stat} denotes the static pressure rise of the fan. The result is figure 10 , whereby some information must be reconstructed from the respective publications.

While the three fans described in the literature all cover a similar range in the performance map, the fan from the present study is located in the lower left corner of the diagram. The characteristic curve of the fan examined here is also extremely steep and does not exhibit a typical plateau. The advantage of such a characteristic curve is that the overall system is relatively insensitive to variations in counterpressure and can provide a relatively constant flow rate even as flow resistance increases.

For further explanation, two additional empirical formulas are provided here for estimating the sound power of grilles with airflow $L_w, grille$ and of axial fans L_w, fan [10]:

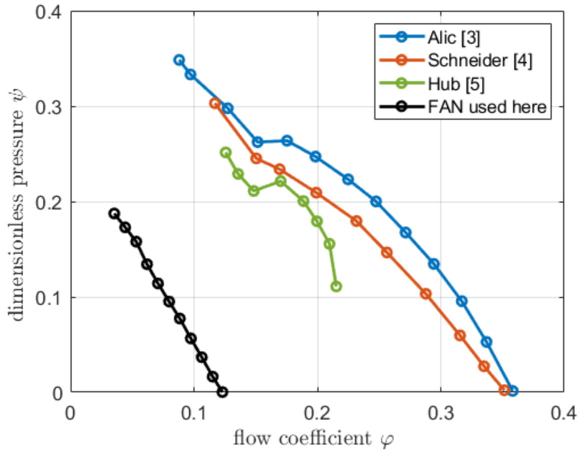

Figure 10: Dimensionsless reconstructed characteristic curves of the fans mentioned in the introduction [3],[4],[5] and of the fan studied here.

$$L_{w,grille}\,[\text{dB}] \approx 10 + 10\log A_G + 30\log c_w + 60\log v \quad (4)$$

$$L_{w,fan}\,[\text{dB}] \approx 40 + 10\log \dot{V} + 20\log \Delta p \quad (5)$$

Here, A_G represents the cross-sectional area of the protective grille through which the flow passes, v once again the flow velocity at the grille and c_w represents the pressure loss coefficient of the grille, both of which are constant in this case. In addition, we can substitute $\dot{V}$ for vA_G here. From these relationships, it can be concluded that protective grilles through which air flows have a significant acoustic effect on the radiated sound power of a fan-cooler-assembly, particularly when there are very high airflow rates associated with a given static pressure drop.

5. Conclusion

In this study, we investigated the acoustic impact of various protective grilles mounted on the pressure side of a cooling-system fan. While the protective grilles differed significantly when subjected to pure airflow without a fan in the aeroacoustic wind tunnel, no acoustic effect of the grilles on the overall system with fan could be demonstrated. We found that the dimensionless characteristic curve of the fan examined here differs significantly from those reported in the literature where acoustic effects occurred. In the future, we want to expand our research to additional fan-cooler-combinations.

6. Acknowledgments

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