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The noise study of ceiling swirl diffuser with serrated adjustable blades

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Abstract In this study, measurements of the aeroacoustic properties of air terminal devices (ATDs) control room ventilation. As a study object the ceiling swirl air diffuser with adjustable blades was chosen. These are mechanical devices designed to control fluid flow and create a swirl to supply air into rooms. They are also the source of the noise in rooms. In this work, the new construction of blades was proposed based on the owl's wings. The blades were printed on a 3D printer from ABS and polished. The two positions of attached blades to the front panel of the diffuser were studied - when the serrated and unseratted edge was leading edge. The front panel of the diffuser with blades was installed on the plenum box with a side entry without the damper. The measurements were made in the reverberation room according to ISO 5135 to find the blade's position with lower noise parameters.

Keywords: HVAC, noise, ceiling diffuser, owl's technology.

1. Introduction

The indoor air is distributed by heat, ventilation and air-conditioning systems [1, 2]. Understanding the behaviour of flow in the ventilation pipes [3] and indoor airflow is essential for architects and designers of such systems. Supplying fresh air to an enclosed space to refresh/remove/replace the existing atmosphere can be accomplished by natural means (e.g., opening a window or door) or mechanical means (e.g., fans or blowers). Natural ventilation effects are uncertain, unreliable and difficult to control. Mechanical ventilation provides constant temperature, humidity and air quality within the enclosed space and is used more often in modern buildings. In such systems, control of the amount and quality of air in the human-occupied zone is necessary. This can be achieved by air diffusers (ATD's - air terminal devices) of different kinds, like exhaust or transfer diffusers and grilles. The ceiling swirl air diffusers are mechanical devices designed to control the characteristics of fluid at the entrance to the rooms. Such diffusers are very common in heating, ventilating and air-conditioning systems [4-7]. There are usually connected to the HVAC (Heating, Ventilation, Air Conditioning) systems and ventilation duct by a plenum box or sometimes directly connected to the duct. Such diffusers have got adjustable blades influencing air diffusion into the room. Directions of air discharge depend also on altered by adjustment of the control blade settings. The connection between the different construction of swirl diffusers and their blades and aerodynamical parameters and noise generation is studied in theme literature [8]. According to Polish standard PN-B-02151-2 [9], it is very important that the construction of each element of the HVAC system should provide a low level of noise.

In this work, an adjustable-blade swirl diffuser was tested taking into account his acoustical parameters. The diffuser was equipped with a plenum box and the diffuser front with 8 slits for blades. As the "base" diffuser with adjustable blades, the commercial one was taken shared by a friendly company. The prototype blade was designed and altered in a swirl diffuser. The prototype blade was made using a 3D printer. The reverberation room was used in these studies. The measurements were made according to ISO 5135. The sound power level (the value important for designers of the building) of the swirl diffuser with "base" and prototype blade were determined.

2. Experimental study

Experimental acoustical studies were performed during the airflow generated by the swirl diffuser front with adjustable blades in the reverberation room Institute of Power Engineering. The measurements were made on a test stand built following the norm ISO 5135 [10]. The reverberation room has got a volume of 237.0 m^3, an area of 231.5 m^2 and non-parallel walls. The tested object was connected to the centrifugal fan through three absorption silencers and a noise source outside the chamber as shown in Fig. 1.This diffuser comprises a square diffuser front with 8 slots, Fig. 2. Each slit (dimension 20mm×105mm)) had blades on the inside. The blade (grey colour) seen in Fig.3. was used as the "base" - a commercially blade, often used in such diffusers. The commercial blade - "base" was designed as a rectangular flat plate with chamfer edges and three semi-circular guides on the top of the blade. The underside of the blade has got one long guide in the middle directed perpendicular to the airflow.

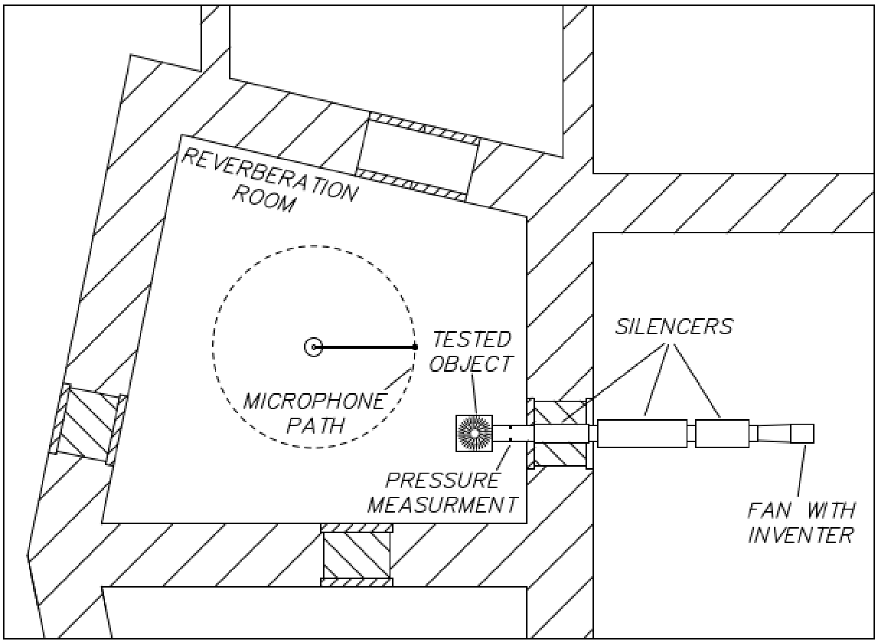

Figure 1. Scheme of reverberation room with studied object - diffuser in experimental setup and front panel.

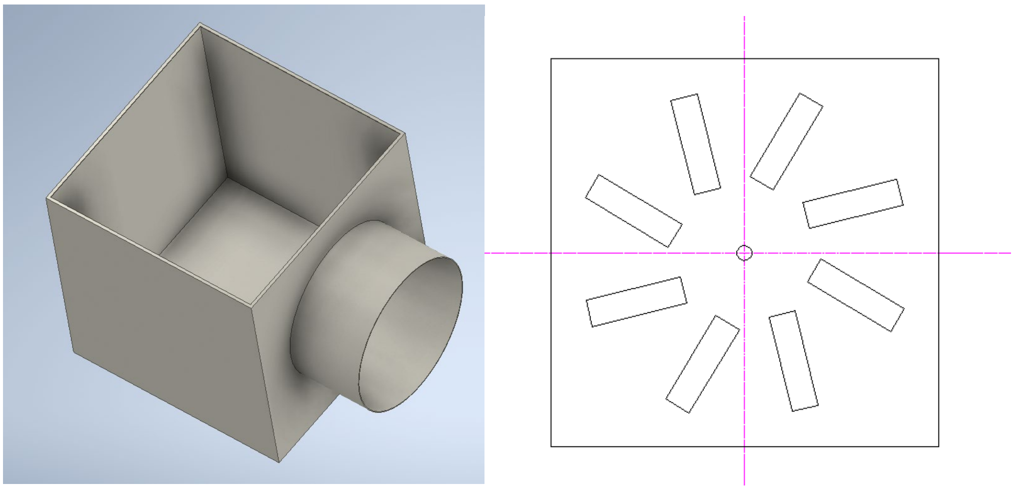

Figure 2. Studied object - diffuser in experimental setup and front panel.

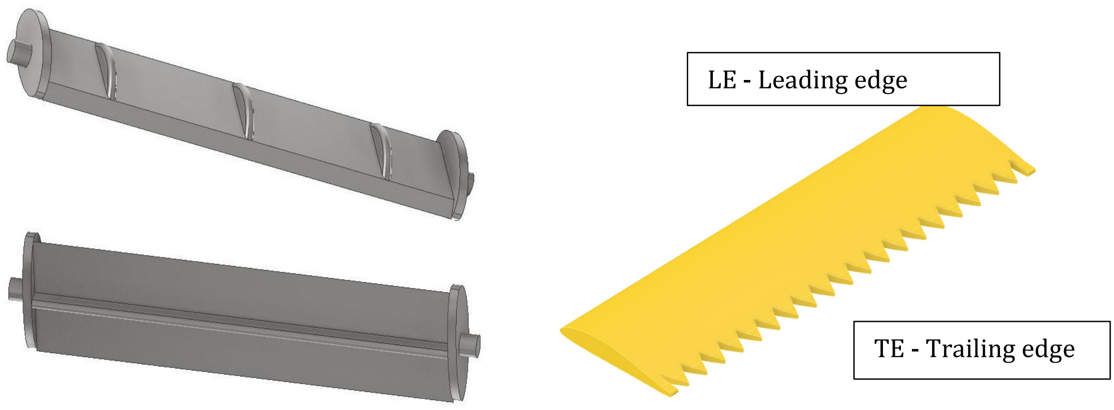

Figure 3. The both side of commercial blade treated as a base model (grey) and prototype blade (yellow).

The prototype blade (yellow colour) was design base on the unsymmetrical profiles with modifies edges as we see in the Fig.2. and it was created by authors. The maximum thickness of prototype airfoil was around 12%. The 8 blades were made by the 3D printer from ABS. Models of airfoils were suited to slit in the front panel of the diffuser (and also to the applied fixing), so they had got the same length and width as a base blade.

The measurements were carried out for three-volume flows: 200, 300 and 400m^3/h. The volumetric flow was set by changing the rotation frequency of the fan motor. For this purpose, a three-phase inverter is connected to the motor. Flow velocity was measured using the Testo 420 balometer. The static pressure drop on the expansion box together with the front plate was measured 300 mm on the channel in front of the plenum box in four evenly located points around the circumference and the environment. A differential pressure transducer was used for this.

The two-positions of blades were studied according to Fig. 4. Discharge directions of air can be altered by adjustment of the blade angle. For this study, the swirling blades were set to 45º (as a left-turned) and oriented so as to create an external swirl. During the measurements the prototype blade was turned to obtain always the left-turned airflow. The inflow of airflow was directed to the leading edge of blade ("1 prototype") or to the trailing edge of blade ("2 prototype") because of unsymmetrical build of blade.
The generated noise was determined by sound power level, measured and calculated under PN-EN ISO 3741 [9]. The Nor 140 measuring set with the Nor850 software and the Nor265 rotary table were used for the measurements. The sound pressure was measured at twelve uniformly spaced points in a circle with a radius of 1.7 meters (circumference 10.7 m). Measured in 1/3 octaves in the range from 100 Hz to 10,000 Hz. The measurement time is set to 15 seconds and in the case of background measurement to 30 seconds. Reverberation was measured for four omnidirectional loudspeaker settings with three microphone settings every 120 degrees. All calculations of the sound power level were made using a previously made calculation sheet. Before and after all measurements were made, the background level was measured and calibrated using the Bruel & Kjaer 4231 calibrator. After measuring each setting, the temperature, relative humidity and atmospheric pressure necessary for calculating the sound power were recorded.

"1 prototype" -
inflow to the LE of airfoil (blade)

"2 prototype" -
inflow to the TE of airfoil (blade)

Figure 4. Scheme of inflow between studied prototype blade and front panel of the diffuser.

3. Discussion of the results

For the studied prototype blade, noise reduction was observed regardless of the direction of the inflow of air. As can be seen, the prototype blade gave lower values of the acoustics spectrum in the whole studied range at 200m^3/h - Fig. 5. Especially, it can be seen for "2 prototype" at 100-2000Hz frequency, where we see lower values of A-sound power level in the acoustic spectrum. From this, we can assume, that the inflow to the blade with the serrated edge is acoustically better than for the uniform edge what is confirmed also by studies at higher airflow - Fig. 6 and Fig. 7.

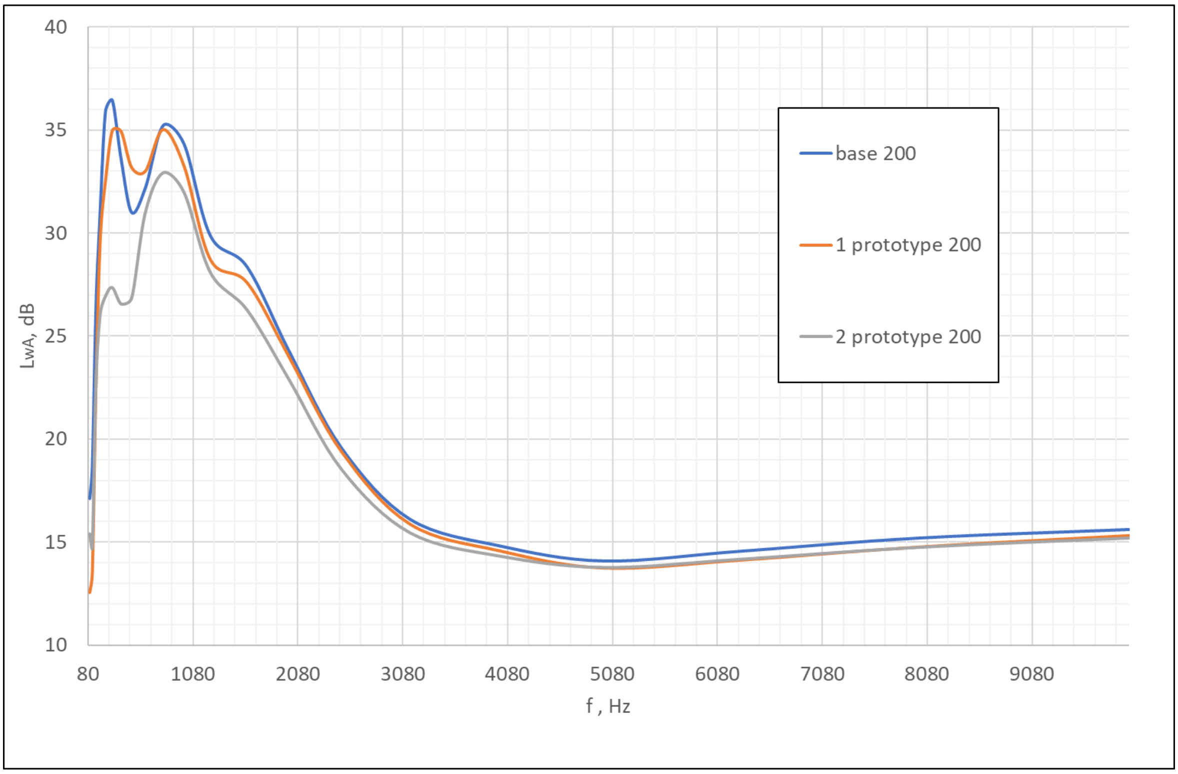

Figure 5. The 1/3 octave band A-sound power spectrum of studied "base" and prototype blade at the flow of 200 m^3/h.

What is interesting, is that occur of the characteristic peaks at the acoustic spectrum. At 200 m^3/h we can see two peaks at 315 Hz and 800 Hz for the "base" blade and "1 prototype". But for "2 prototype" one significant at 800 Hz is observed. The peak at 315 Hz disappeared for the "base" and "1 prototype" blades with flow velocity increases. The peak can only observed at 800 Hz, but for the "2 prototype" this peak also decreases causing a slight increasing the values of the acoustic spectrum above 4000 Hz.

The sound power level with A corrections for the studied blades is presented in Table 1. As can be seen, from Table 1 there are positives differences between the "base" blade and the studied prototypes. The values of static pressure for the studied blades are also given in Table 1. The lowest values of static pressure is observe for "2 prototype" blade.

The differences between the 1/3-octave level of sound power of the "base" blade and studied variant of blades were used to present, at Table 1, the results of noise reduction (ΔL_{WA}), using the equation:

$$\Delta L_{WA} = L_{WA"base"} - L_{WA"variant"} \quad (1)$$

where: $L_{WA"base"}$ - the level of the A-sound power in the frequency band considered for the "base" blade; $L_{WA"variant"}$ - the level of the A-sound power in the frequency band considered for the studied variant of blade. The graphs are presented in Figs. 8, 9.

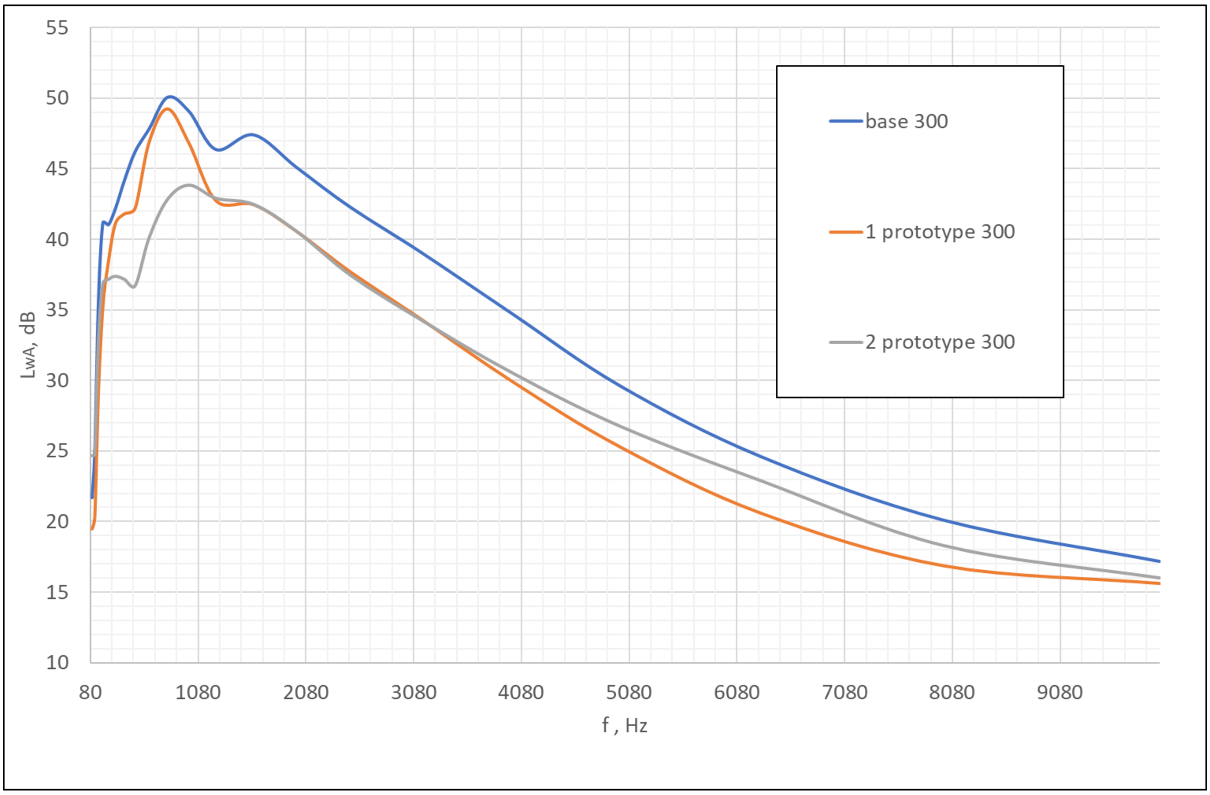

Figure 6. The 1/3 octave band A-sound power spectrum of studied "base" and prototype blade at the flow of 300 m^3/h.

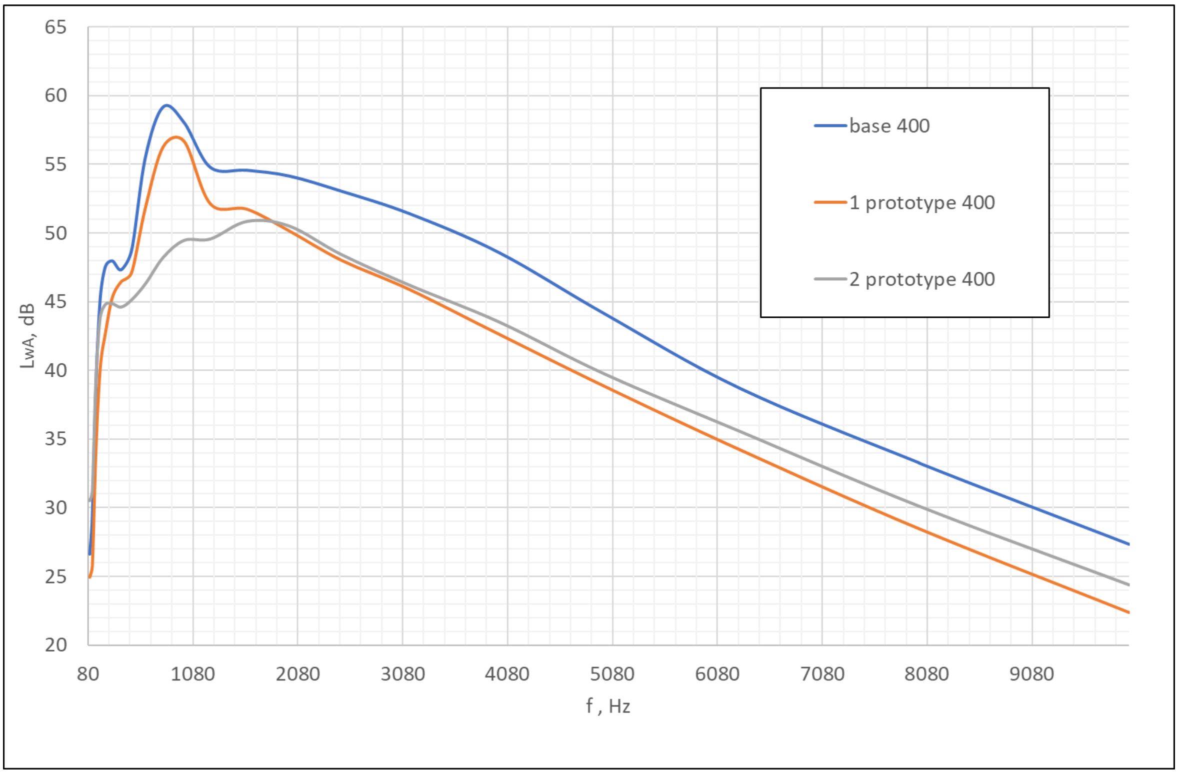

Figure 7. The 1/3 octave band A-sound power spectrum of studied "base" and prototype blade at the flow of 400 m^3/h.

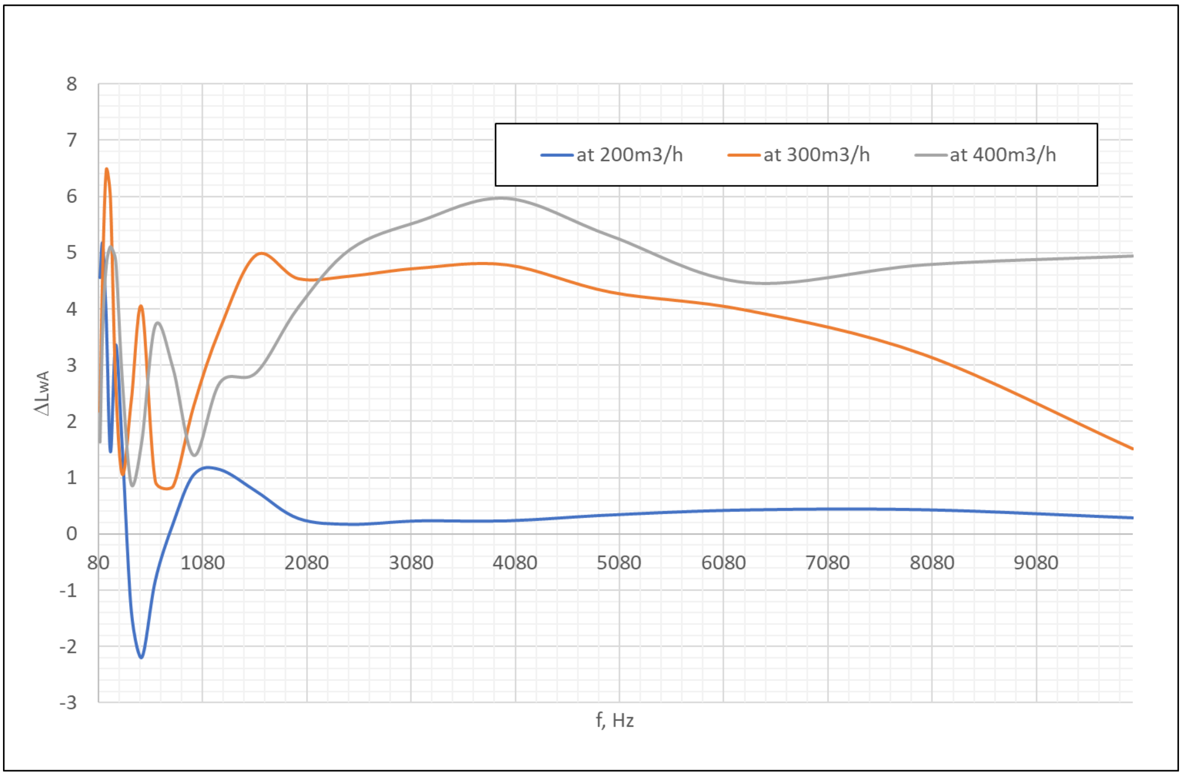

Figure 8. 1/3-octave differential A-sound power spectrum between "base" and "1 prototype" blade.

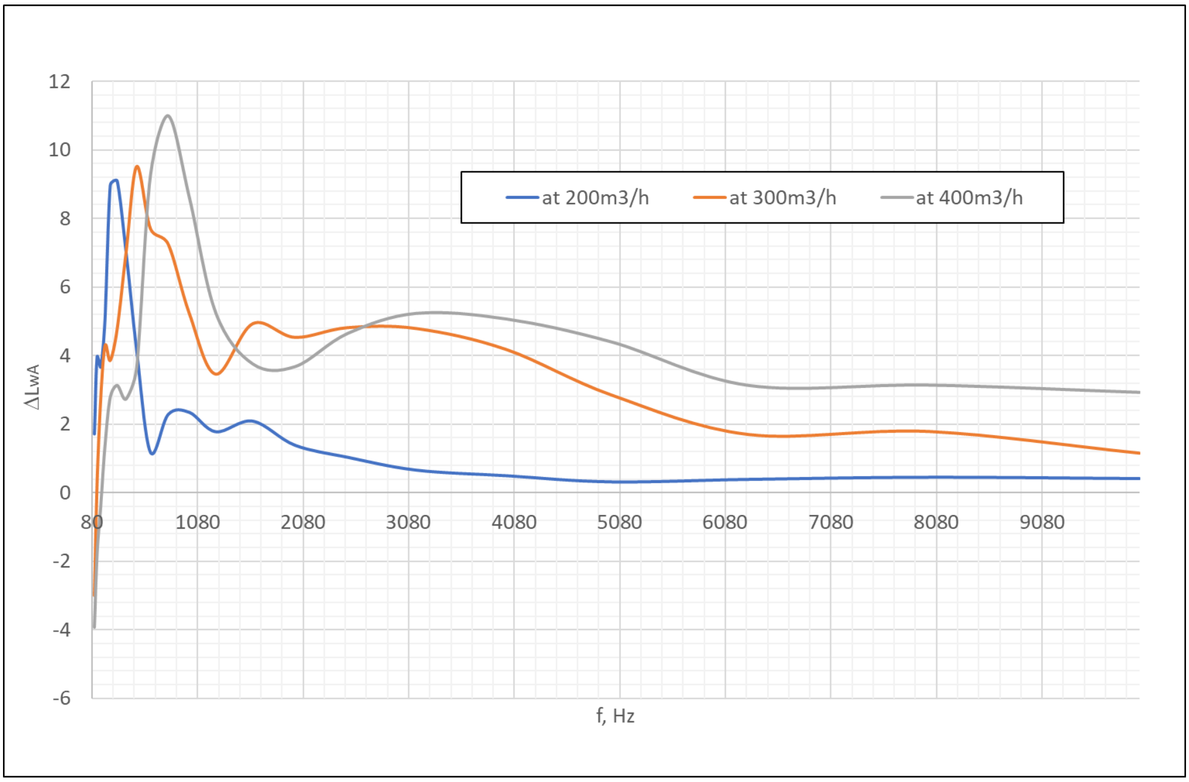

Figure 9. 1/3-octave differential A-sound power spectrum between "base" and "2 prototype" blade.

The positive values of the 1/3-octave differential spectrum tell about the noise reduction by studied blade in different inflow. The maximum difference is 6.2 dB for “2 prototype” blade at 400 m^3/h. The positive values can be seen for “1 prototype” but no bigger than 3 dB. For “2 prototype” blade the values of difference increase according to increasing the flow velocity. This may suggest, that the studied prototype blade generates lower noise than the commercial no matter which side is inflowing direction. For "1 prototype" can be seen a significant decrease in the differential acoustic spectrum at 500 Hz at 200 m^3/h. For this prototype, the serrated edge is near the diffuser panel - is based on it. That may suggest that serrated edges can take part in generating the “edge sounds” at low-flow velocity, but this requires next studies.

Table 1. For studied blades: the sound power level with A corrections - L_{wA}, the pressure differences - Δp and differences between the 1/3-octave level of sound power of the “base” blade and studied variant of blades - ΔL_{WA} , for volume flows: 200, 300 and 400 m^3/h.

Studied blades	L_{WA}	Δp	ΔL_{WA}
	dB	Pa	dB
Base 200	43.7	31.5	-
Base 300	57.1	52.8	-
Base 400	65.3	127.8	-
1 prototype 200	43.1	27.6	0.6
1 prototype 300	54.7	60.1	2.5
1 prototype 400	62.4	107.3	2.9
2 prototype 200	39.5	23.2	4.2
2 prototype 300	51.5	59.4	5.7
2 prototype 400	59.2	117.8	6.2

4. Conclusions

In this study, an adjustable-blade swirl diffuser with a plenum box and the diffuser front with 8 slits for blades was studied. As the “base” diffuser the commercial one was taken shared by a friendly company with adjustable blades. Order to find lower noise parameter of the swirl diffuser the blades were altered during these studies. The prototype blade, as unsymmetrical, was studied in two positions: the inflow of airflow was directed to the leading edge of the blade (“1 prototype”) and to the trailing edge of the blade (“2 prototype”). The acoustical parameters were measured in the three-volume flow and three positions of the blade. The 1/3-octave octave band A-sound power spectrum and 1/3-octave differences A-sound power spectrum show that the two types of positions of the studied prototype blade could be used to reduce the noise of the swirl diffuser. Thanks to this the noise power can be reduced by about 2 – 6 dB.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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