Aeroacoustic Optimization of a Metacage to Block the Noise Emitted by an Exhaust Fan

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1 Introduction

The recent pandemic showed the importance of well ventilated areas to preserve safety of the occupants. For that reason, the addition of Heating, Ventilation and Air Conditioning (HVAC) is needed to exchange air. However, these systems can be noisy and have a negative effect on people such as sleep disturbances, cognitive problems or influences on heart diseases [1]. Recent research in acoustics has proven the effectiveness of sonic crystals in blocking some of the ventilation noise without adding too much restriction to the flow [2–4].

The aim of this study is to reduce noise transmitted from an exhaust fan by replacing the conventional grill, shown in Figure 1, by an optimized metagrill (acoustic metacage made from sonic crystals). The original noise level of the fan was measured at 55.2 dBA, at an operation point of 0.1 inH2O at 110 CFM. The objective is to maximise noise reduction while maintaining ventilation performance in the same conditions.

FIGURE 1 – Exhaust fan

2 Method

2.1 Sonic crystals

The strategy here is to implement sonic crystals (SC) inside the grill, between the fan and the air inlet. SC are arrays of scatterers. Ideally, it consists of a unit cell of size H with a scatterer (example solid cylinder of diameter D) in its center. The unit cell is infinitely periodized and the SC shows a band gap where no transmission of sound is possible. The central frequency f_c of the band gap is given by the Bragg condition, $\lambda/H = 2$ or $f_c = c/2H$, where λ is the wavelength, and c is the speed of sound. For a finite number N of periodicity along the wave propagation direction, the sound transmission loss is typically proportional to the filling ratio D/H.

In reality, the SC must fit into the available envelope. In the case of the exhaust fan, the envelope is limited and the scatterers must be distributed radially up to a maximum external radius. In addition, to minimize head losses, the azimuth distance between scatterers should not be too small. Note that the flow of air over a scatterer can generate noise. Thus, the metagrill to be designed must attenuate more noise than it could generate while allowing air to flow with a minimum of pressure drop. This reality therefore forces us to proceed with an optimization of the various design parameters of the metagrill, while adding geometric, acoustic and flow constraints.

2.2 Optimization

The optimization is conducted with open source software. Sandia Dakota®is used to perform a numerical design of experiment (NDOE), EDF Salome®to CAD and mesh, EDF Code_Aster®to simulate, with the finite element method, the acoustics, OpenCFD OpenFOAM®to compute head losses, and development platform ERICCA MAGiC to obtain sound transmission loss (TL).

Due to the limited space, only two rows of scatterers will be used along the radial direction. The parameters to optimize are shown in Figures 2 and 3. The constraints are given in Table 1. The NDOE optimization will use a 25 samples Latin Hypercube Sampling (LHS).

TABLE 1 – NDOE of the metagrill. A 25 samples Latin Hypercube Sampling (LHS) was used.

Parameters	A1/A0 (%)	H1/H0 (ratio)	Entry Height (inches)	Mid Height (inches)	Nb.crystals radially
Lower	0.4	0.5	1	1	20
Upper	0.7	0.8	3	3	28

3 Results and discussion

The result coming out of the LHS was then fed to the Efficient Global Optimization (EGO) to find if there was an optimal solution within the response surface of the LHS. The final metagrill consist of 28 rows of two sonic crystals, with a $H1/H0$ of 0.7, $A1/A0$ of 0.6, an entry height of 1 inch and a

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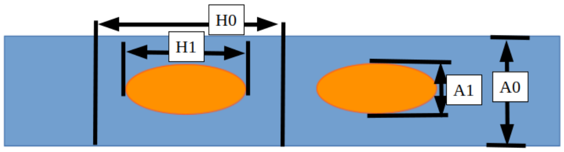

FIGURE 2 – Design parameters for the sonic crystals

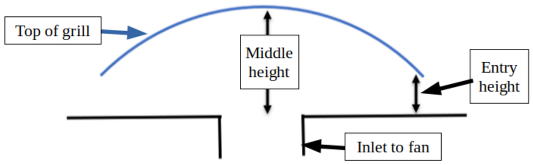

FIGURE 3 – Design parameters for the dome shape of the cover

middle height of 3 inches. A photo of the prototyped optimal metagrill is shown in Figure 4

To validate the prototype, sound and ventilation measurements were taken. The sound measurements were carried out according to the ISO 9614-1 standard at the Venmar Ventilation ULC laboratory on the fan equipped with the conventional grille and the metagrill. The results showed that the overall fan sound power with the metagrill was reduced from 55.2 dBA to 49.7 dBA. Also, to verify the type of attenuation provided by the metagrill, its transmission loss was measured at Mecanum Inc on a small reverberation chamber. Figure 5 shows the measured TL. The result demonstrates the broadband attenuation of the designed metagrill.

For ventilation measurements, ISO 5167-1 was used on the ventilation test bench of Venmar laboratory. The results obtained were similar to the simulated ones. The designed metagrill does not offer more resistance to flow than the original grill.

4 Conclusion

To conclude, a metacage optimization approach, with sonic crystals, was presented as a solution to reduce noise transmitted while keeping good ventilation. The optimized design has achieved a noise reduction of nearly 6 dBA by blocking the transmission of ventilation noise over a wide frequency band.

Acknowledgments

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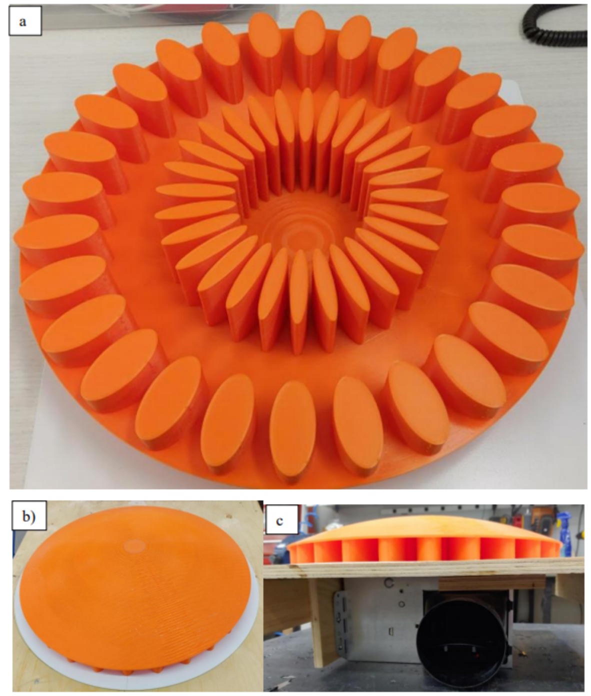

FIGURE 4 – Prototype of the optimized metagrill. a) Inside view. b) Outside view. c) Side view with wood representing the ceiling

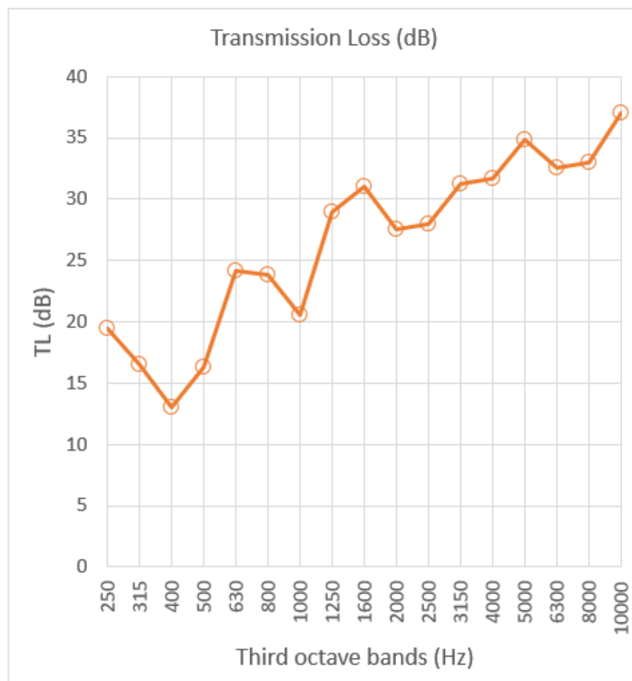

FIGURE 5 – Transmission loss measurements at Mecanum

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