Concept of Global Noise Control in Cabins

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Introduction

Protection from high sound pressure levels in low frequency range is of great concern in order to meet health and safety regulation for working environments. An example is a propeller driven aircraft, where the propellers induce periodic noise within the cabin. Several methods for the attenuation of unwanted sound like passive absorbers have already been applied. But the capabilities of passive methods decrease in the low frequency range, because the wavelength of a sound wave becomes large compared to the thickness of a typical absorber. Therefore active approaches could be superior in the low frequency range. Nevertheless, to reach an acceptable noise level in a large cargo bay with a high density of acoustic modes, a large number of actuators and sensors are required and have to be distributed globally in the cavity. As a consequence, such system has high computational load and unwanted mass.

In order to reduce the number of components, unwanted sound radiated into the cabin by fuselage segments can be reduced by controlling the radiated sound power in the vicinity of the propeller. The capability and first experimental results of local placement of actuators and sensors in the vicinity of a radiating structure are shown in this research for tonal excitation. Furthermore a numerical calculation is presented to illustrate the experimental results.

Global Noise Reduction by Acoustic Barrier

As noted below, the fuselage segments in the vicinity of the propeller can be assumed as main radiation part of unwanted noise in the low frequency range (f < 500Hz) for propeller driven aircraft. It is known that a secondary noise source which is placed in the vicinity of a primary noise source with the same radiation pattern is able to attenuate the sound pressure level by destructive interference in a global manner [1]. First experimental and numerical investigations, which analyzed the local placement of actuators have been presented in [2,3]. It can be seen that the local placement of the actuators seems to be a viable option in order to achieve a global noise reduction. The main results are picked up and combined in the concept called acoustic barrier.

The aim of the acoustic barrier is to produce a secondary noise field which destructively interferes with the primary noise field in order to achieve a noise reduction in a global manner due to local minimization in the vicinity of the radiating structure. Figure 1 shows an experimental setup with six loudspeakers which are placed close to an aircraft panel. The error sensors are based on acoustic pressure measurement. Furthermore six microphones are placed on the left of the actuators. For the excitation of the structure a BR-25 MONACOR exciter (diameter: 130mm, weight: 1.24kg) is used. The ANR components in laboratory 1 (lab-1) and the primary exciter in laboratory 2 (lab-2) are shown in figure 1a) and figure 1b).

a) lab-1 b) lab-2

Figure 1: Aircraft panel installed between two adjacent laboratories

Numerical Analysis of the Acoustic Barrier: Model

To illustrate the capability of the acoustic barrier a numerical calculation is performed. By means of the numerical analysis physical phenomenon can be discussed.

Figure 2a) shows a simplified numerical model of lab-1. The dimensions are approximately 18m x 5m x 4.5m. The volume represents roughly the cavity of a transport aircraft. It can be seen that the model is divided into two regions by the blue area. The right part shows the primary noise source (green box), the six loudspeakers and the original room allocation. The primary noise source is modelled simplified as area with normal acceleration boundary condition.

The dimensions of the left region are 13m x 5m x 4.5m. Within the left cavity the sound pressure level of the uncontrolled and controlled noise field is detected by means of a sensor array with a spacing distance of 0.1m in each of the three coordinate directions.

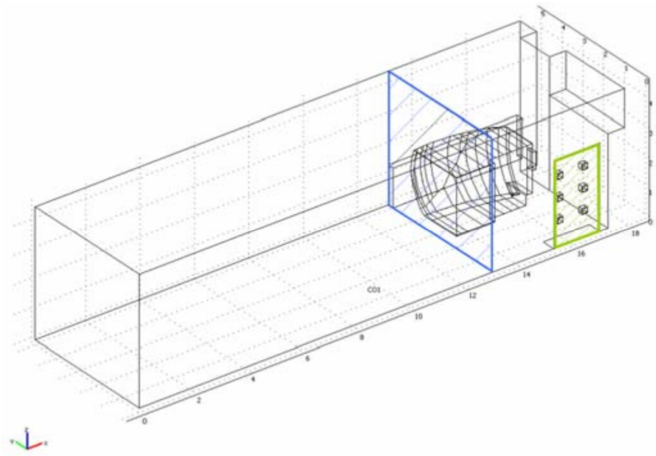
The arrangement of the six loudspeakers (grey box with grey circle) and six microphones (black point) is shown in figure 2b). The distance between the primary source (green box) and actuators is 0.2m. The error sensors are placed on the right of each loudspeaker. The distance between actuator and sensor is 0.03m. The numerical calculations are performed using COMSOL and MATLAB. The acoustic model is discretized by FE with Lagrange-Quadratic shape functions. Triangular elements are used for meshing and the maximum length of element is 0.45m. All boundaries are assumed to be sound hard. To simulate a net energy flow the fluid is damped with regard to equation (1), where c_0 is the velocity of sound (343m/s) and β is the damping factor (1%).

$$c = \frac{c_0}{1 - j\beta} \qquad \text{[m/s]} \qquad (1)$$

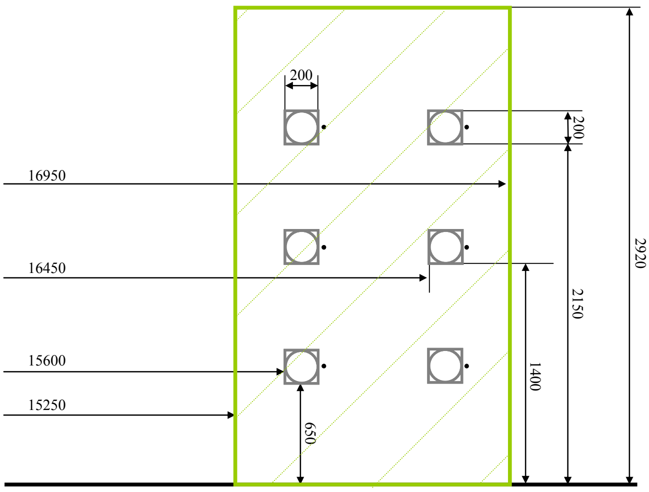
The optimal complex strengths of the secondary sources $\underline{\mathbf{q}}_{\text{opt}}$ can be calculated by

$$\underline{\mathbf{q}}_{\text{opt}} = -\underline{\mathbf{Z}}^{-1}\,\underline{\mathbf{p}}_{\text{prim}} \qquad \text{[m/s}^2\text{]} \qquad (2)$$

where $\underline{\mathbf{Z}}$ is the (6x6) transfer matrix between all actuators and all microphones and $\underline{\mathbf{p}}_{prim}$ is the (6x1) vector of the acoustic pressure of the uncontrolled field.



a) Numerical model of lab-1 (green area = primary noise source, blue area divides the two regions)



b) Arrangement of loudspeakers (grey boxes with grey circle), microphones (black points) and primary noise source (green) [all dimensions in mm]

Figure 2: Numerical model and arrangement of the acoustic barrier

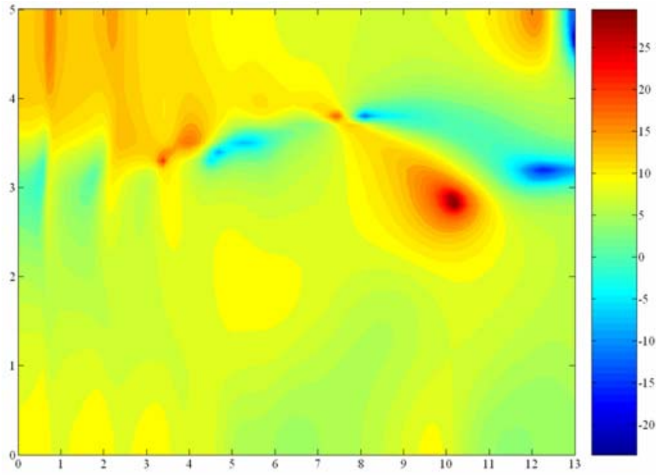
Numerical Analysis of the Acoustic Barrier: Results

In figure 3a) and figure 3b) the SPL reduction for 125Hz and 136Hz for a monitor plane above ground 1.5m is shown. Note that only the SPL in the left region is measured, refer to figure 2a).

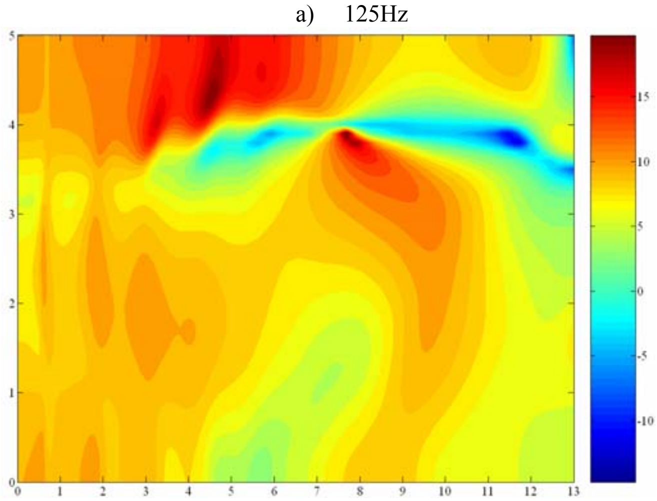
The maximum SPL reduction is approximately 30dB for 125Hz and 20dB for 136Hz. Furthermore it can be seen, that for both frequencies some points show an increase of the SPL. An increase of approximately 20dB is shown for example in the upper right corner for 125Hz.

The reason seems to be the spatial shifting of the acoustic modes. Due to local minimization of the acoustic pressure in the near field of the primary source the SPL in the far field can't be reduced at each point. Furthermore it can be observed that the points where an increase of the SPL is captured are minima in the uncontrolled case.

Nevertheless only a small region with an increase of SPL can be seen and hence the capability of the acoustic barrier seems to be a good option considering the size of the regarded region and the small number of ANR components.



a) 125Hz



b) 136Hz

Figure 3: Calculated noise reduction in the plane z=1.5m

Experimental Analysis of the Acoustic Barrier: Setup and Measurement

The ANR system is shown in figure 1a). Six loudspeaker and six microphones are placed close to a radiating structure. The arrangement and the distances between the ANR components are shown in figure 4 where the loudspeakers (LS 1..6) are presented as grey boxes and the microphones (MIC 1..6) as black points.

The filtered x least mean square (FxLMS) algorithm is used. The algorithm calculates, under consideration of the primary signal x and the error signals $\mathbf{V}_{MIC}$, the optimal actuation of the six secondary sources $\mathbf{V}_{LS}$ by minimization of the following cost function

$$J = \mathbf{e}^H \mathbf{e}, \qquad (3)$$

where $\mathbf{e}$ is the (6x1) vector of the measured error sensor signals. The control loop is shown in figure 5. Due to destructively interference of primary and secondary noise field, noise reduction is obtained. For more details on the control algorithm see [4].

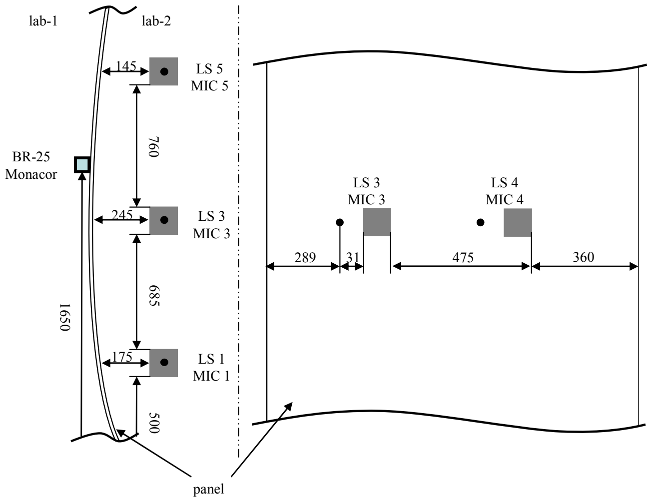


Figure 4: Arrangement of the six actuators and sensors [all dimensions in mm]

For the evaluation of the achieved noise reduction the measurement hardware consists of a monitor microphone (MM) and a Phonic PAA3 spectrum analyzer. The measurement setup is shown in figure 5. The monitor microphone is placed in the upper right corner of lab-1, because the corners of a reverberant room represent the maximum pressure of the most modes. Furthermore, the noise reduction is captured at 20 arbitrarily picked points, refer to figure 5. The structure is presented as green square in figure 5, too.

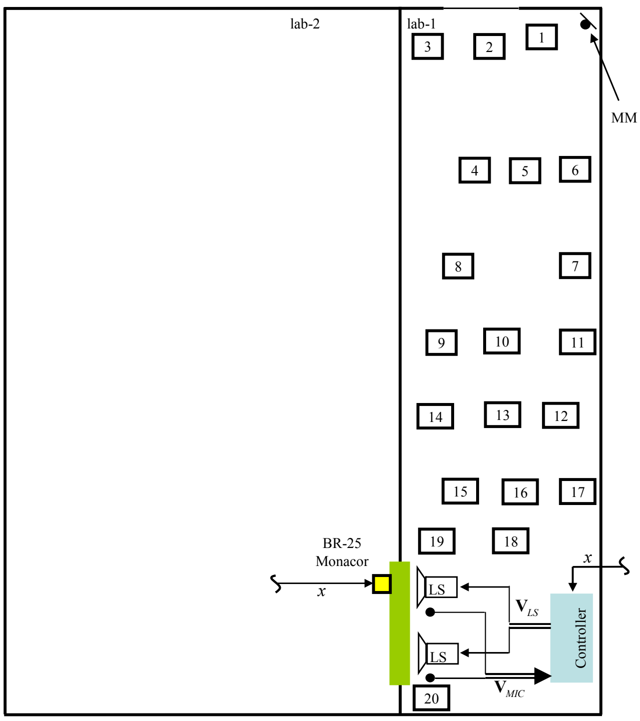


Figure 5: Measurement setup

Due to the panel excitation by means of the BR-25 MONACOR a primary noise field is produced within lab-1. The sound pressure levels (SPL) of the uncontrolled field are measured at the 20 points and in the corner (MM). Afterwards the SPL of the controlled noise field is measured at the points. The noise reduction at the monitor microphone can be calculated by

$$\Delta L_{\mathrm{MM}} = L_{\mathrm{MM,uncontrolled}} - L_{\mathrm{MM,controlled}}, \qquad [\mathrm{dB}] \qquad (4)$$

where $L_{\mathrm{MM,uncontrolled}}$ and $L_{\mathrm{MM,controlled}}$ are the SPL of the uncontrolled and controlled noise field. The overall noise reduction of the 20 points can be calculated by means of the logarithmic average

$$\Delta L_{\log} = 10 * \log_{10}\left[\frac{1}{20}\sum_{i=1}^{20} 10^{\frac{\mathbf{L}_{i,\mathrm{uncontrolled}}}{10}}\right] - 10 * \log_{10}\left[\frac{1}{20}\sum_{i=1}^{20} 10^{\frac{\mathbf{L}_{i,\mathrm{controlled}}}{10}}\right] \qquad (5)$$

where $\mathbf{L}_{\mathrm{uncontrolled}}$ and $\mathbf{L}_{\mathrm{controlled}}$ are 20 x 1 vectors of the uncontrolled and controlled noise field at the 20 measurement points. Furthermore the difference of the maximum SPL for the uncontrolled and controlled case can be evaluated by

$$\Delta L_{\max} = \max(\mathbf{L}_{\mathrm{uncontrolled}}) - \max(\mathbf{L}_{\mathrm{controlled}}) \cdot \qquad (6)$$

Experimental Analysis of the Acoustic Barrier: Results

The experimental investigation is performed for tonal excitation at 125Hz and 136Hz. Figure 6 shows the first experimental results of the acoustic barrier.

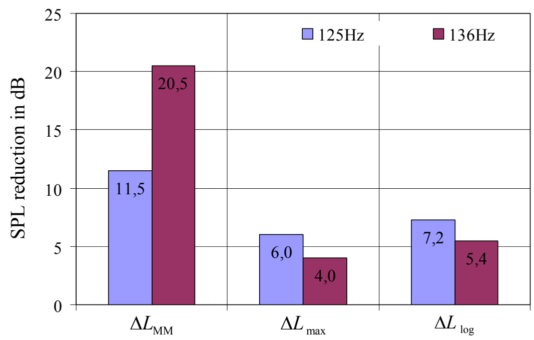


Figure 6: Achieved noise reduction in dB for the monitor microphone ΔL_{MM} and for the 20 measurement points $\Delta L_{\max}$, $\Delta L_{\log}$

The SPL reduction is shown for the three described evaluation criteria as presented in equations (4), (5) and (6). At the monitor microphone a noise reduction of at least 11dB for 125Hz and 20dB for 136Hz can be achieved. These results show that the local minimization of the acoustic pressure by means of the ANR system seems to have a global effect on all modes, under consideration that the corner of a reverberant room presents the maximum acoustic pressure of the existing modes.

The maximum SPL reduction $\Delta L_{\max}$ of the 20 measurement points shows a noise reduction of 6dB for 125Hz and 4dB for 136Hz. The logarithmic average SPL reduction shows a noise reduction of 7dB for 125Hz and 5dB for 136Hz. The difference between the maximum values is similar to the results of the averaged data, but both results seem incomparable to the SPL reduction in the corner of the lab-1. Eventhough for 136Hz a higher noise reduction can be seen for the corner of lab-1. This is the not the case for $\Delta L_{\max}$ and $\Delta L_{\log}$. The evaluation of each measuring point shows that the SPL reduction is mostly between 7.5dB and 17.5dB for both frequencies. However, at some positions an increase of the SPL is measured. As already observed by the numerical calculation the reason seems to be the spatial shifting of the acoustic modes.

Conclusion

This paper shows first experimental and numerical results with the acoustic barrier concept. The primary noise field is produced with a vibrating panel. The aim of the acoustic barrier is a global noise reduction with a local placement of actuators and sensors in the near field of the primary source. In this research six loudspeaker and six error microphones were placed in the vicinity of the vibrating panel. The numerical model and experimental setup are presented. Furthermore, the numerical and experimental results are discussed for two frequencies (125Hz and 136Hz).

The acoustic barrier seems to be a good option for global attenuation of noise, because it can be seen that the noise reduction in the cavity is at least 7dB for 125Hz and 5dB for 136Hz. Note that no optimization of actuator and sensor placement was done. The work is still in progress and further improvements will be show in future investigations.

The numerical and experimental results show an increase of the SPL at some positions. The reason seems to be the spatial shifting of the acoustic modes.

References

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