HIGH SOUNDPROOFING ABILITY OF POROUS MATERIALS UNDER STRESS USING 4S TECHNOLOGY

D. Rakov[1], J. Thorbeck[2]
[1]Institute of Engineering Science, Russian Academy of Sciences, 101990 Moscow, Mal. Haritonevskij per.4, Moscow, Russia
[2]Institute of Aeronautic and Astronautic, Berlin Technical University, Marchstr. 12-14, 10587 Berlin, Germany

OVERVIEW

Current R&D efforts to develop noise driven aircraft configurations feature, amongst other solutions, the relocation of engines above the wing respectively to the rear fuselage or fully or semi fuselage integrated engines. All of these imply a higher noise impact for the cabin. Effective solutions for improved cabin noise insulation technologies are therefore urgently required. One solution which has been developed based on empirical studies will be presented in that paper. The main aim of a series of experiments conducted has been to determine sound insulation properties of soundproofing panels employing porous materials under varying stress.

It is widely accepted, that it is basically impossible to get good soundproofing by use of thin-walled porous materials. However, investigations on noise insertion damping have shown that it is possible to achieve an extraordinary reduction of noise level using thin-walled porous, cellular and fibrous materials by simple vacuum bagging. In particular, for a technical foam panel of 30 mm thickness and with a specific area weight of less than 1 kg/m^2 the average reduction of the noise level can be up to 12 dB based upon the total noise level. That approximately corresponds to the characteristics of a 30 mm pine board with a specific weight of 20 kg/m^2 featuring that same sound damping capability of 12 dB. A unique opportunity for the provisioning of superior weight efficiency of noise insulation measures, which is necessary for aeronautical applications can be assumed.

That advantageous effect has been achieved by the new so-called 4S-technology (**S**teerable **S**ound **S**uppression **S**ystem). The creation of deformation zones on a surface and along the thickness of an insulating material, and also the interaction of that material with elastic membranes are the underlying principles of the effect. Varying the degree of deformations and, hence, the density of a sound insulation material, enables an adaptation to a desired degree of sound suppression, and also frequency band, which ultimately allows to create active and adaptive systems for sound insulation, alongside with passive ones.

1. INTRODUCTION

Active control systems are actively investigated [3, 4, 5]. The systems are based on acoustic emission from secondary sources. The outputs of the secondary sources are arranged so that they interfere destructively with the noise from the primary source. The performance of an active system is monitored by error sensors that measure the residual noise. Most efficient noise cancellation is usually achieved by the combination of active and passive methods [3].

The present work focuses on design, placement and change of mechanical characteristics of porous materials as used for smart adaptive systems.

It is widely accepted, that it is basically impossible to get good soundproofing by use of thin-walled porous materials. So, the well-known acoustician Rupert Taylor [1] in his book "Noise" writes, that «to fix (a) thin porous mat with the purpose to detain the sound going from one point to another, is simply loss of time. The maximum that can be achieved such way, is to lower a level of noise on 3 dB on high frequencies. Certainly, the porous materials absorb the sound and as they partly reduce the energy of the sound, they reduce also the energy of the wave which passing through them. But to receive in the slightest degree the worth attenuation, the thickness of the absorbing material layer should be comparable to the length of a sound wave. As in practice it is frequently necessary to deal with the sound waves several meters long, it’s clear, that it is out of the question to use the absorbing materials directly as a sound insulator». Other experts also adhere to this point of view. However, our investigations have shown, that it is possible to achieve an extraordinary reduction of noise level for thin-walled porous, cellular and fibrous materials. In particular, for a technical foam panel of 30 mm thickness and with a specific area weight of less than 1 kg/m^2 the average reduction of the noise level can be up to 12 dB. That approximately corresponds to the characteristics of a 30 mm pine board with a specific weight of 20 kg/m^2 featuring a soundproofing capability of 12 dB [2].

That effect has been achieved by the new so-called 4S-technology (Steerable Sound Suppression System). The creation of deformation zones on a surface and along the thickness of an insulating material, and also the interaction of that material with elastic membranes covering that material, are the underlying principles of the effect (fig.1). Varying the degree of deformations and, hence, the density of a sound insulation material, enables a variation of the degree of sound suppression, and also the frequency band, which allows to create active and adaptive systems for sound insulation, alongside with passive ones.

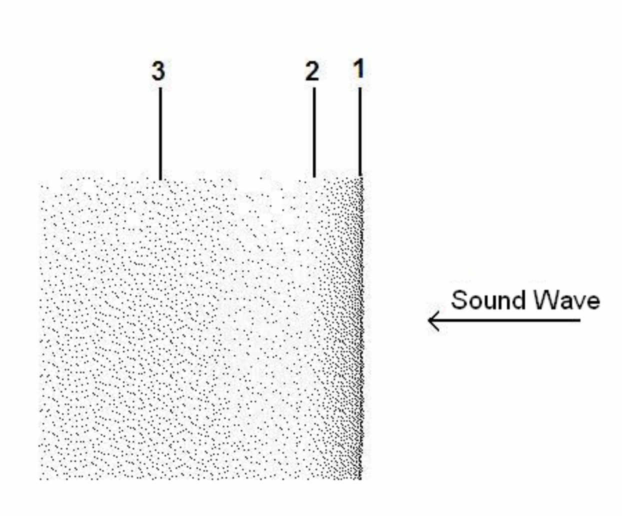

FIG 1. Stress distribution inside an enclosed damping material (cross section), 1 – film, 2 – high deformation zone, 3 – low deformation zone

The 4S-Effect is predominantly achieved by

- an interaction of a noise damping material with a film,
- a non-uniform deformation of the noise damping material due to pressure or external force and
- an effective process of controlling sound absorption by means of controlled stress variation.

2. DESCRIPTION OF EXPERIMENT

The sound-proofing property has been investigated at different mechanical stresses. The stress in the test specimen was produced pneumatically (fig. 2), using differential pressure. The tests have been carried out in a frequency band from 63 up to 10000 Hz. A pink noise generator was used as acoustic source. The sound pressure level was measured using a PC-based noise level analyzer.

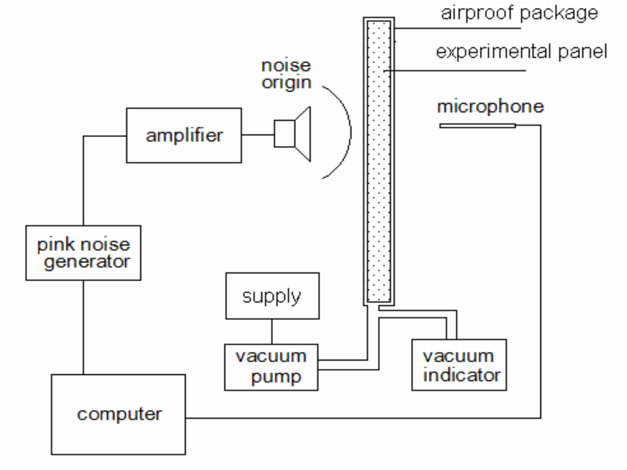

FIG 2. Experimental set-up

During the experiments the type of damping material, the degree of deformations, porosity, rigidity etc. have been varied. The experiments were conducted with specimen of size 400 x 400 mm and 2000 x 1000 mm with different thickness (fig. 3, 4).

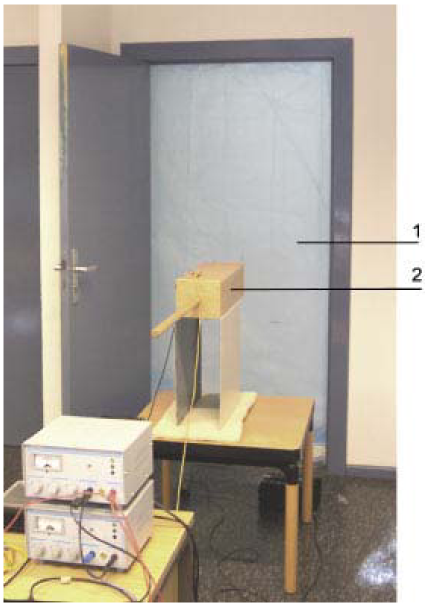

FIG 3. Sound-insulating experimental panel (size: 2000mm x 1000mm x 5mm, 1- experimental panel, 2- noise source).

FIG 4. Sound-insulating experimental panel (size: 400mm x 400mm x 30mm) enclosed in an airproof package. Vacuum pump and indicator in the rear.

3. EXPERIMENTAL RESULTS

Enclosure of sound damping material in a hermetically sealed membrane leads to a significant improvement of the insulation properties over the entire acoustical frequency spectrum. The average sound insulation based on the overall sound pressure level achieved using the 4S-effect was 12 dB (fig. 5), the maximal sound insulation 28 dB at 4000 Hz and the average sound insulation of rock wool 10 dB (fig. 6). The damping efficiency increases dramatically at very small differential pressures (< 200 Pa). At higher pressures the damping marginally is decreasing at a high level.

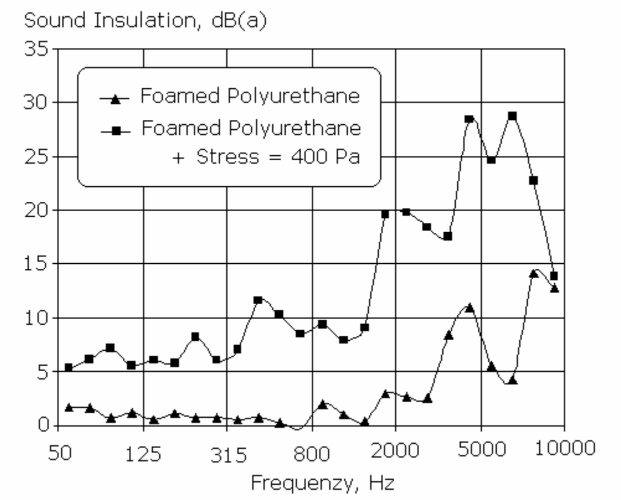

FIG 5. Sound attenuation of rock wool (panel thickness 50 mm)

The degree of sound insulation obviously depends on the mechanical stress in the damping material. By adjustment of the stress it is possible to change the soundproofing ability of the panels. Varying the degree of deformations and, hence, the density of a sound insulation material, enables a variation of the degree of sound suppression as well as the frequency band.

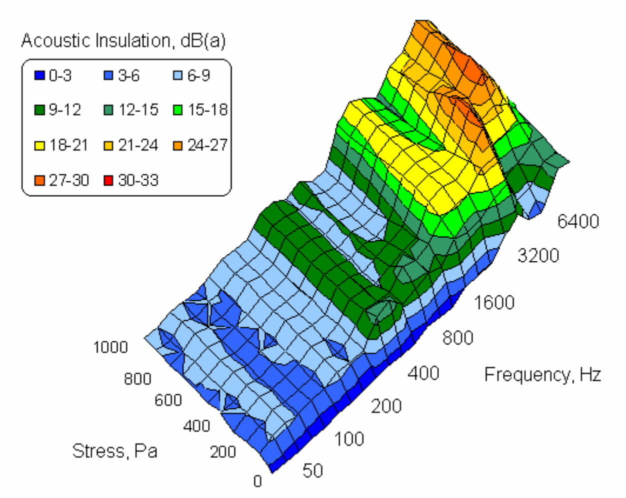

FIG 6. Sound attenuation of foamed polyurethane as function of frequency and stress

A preliminary explanation for the stress effect can be as follows:

- Basically the addition of a relatively dense membrane must lead to a damping increase, even without differential pressure. Secondly a poor structure-borne sound transfer to the core material can be attributed to the dissipation owed to the friction of the free oscillating membrane on the core material. Additionally the smooth surface of the membrane contributes to a superior reflection.
- Increasing the differential pressure leads to an increasing elastic foundation of the membrane, therefore to a shift of its resonance frequency and an increase in damping.
- A further pressure increase leads to a compression of the core material because of its increasing density which in return leads to an increased damping, whereas the damping of a single high density plate is being approached asymptotically.

4. STRUCTURAL SYNTHESIS OF 4S-ACOUSTIC SYSTEMS

In order to better understand the underlying acoustic principle of the effect, find implementation variants and to prepare for the development of applicable and ultimately optimized 4S-Systems, a systematic structural analysis has been initiated. Possible system set-up's include various methods for introduction of stresses, combinations of insulation panels, control systems, core and membrane materials etc.

For the structural synthesis of complex systems the morphological method can be effectively used. That three step approach consists of the construction of a morphological array which contains the possible solution variants specification criteria (design space), of an analysis of the most important assessment criteria (morphological box) and finally the selection of the best solution. Primarily the method has been created by the Swiss astronomer F. Zwicky [6] and applied and modified by a number of authors (e.g. [7, 8]).

Morphological methods suppose computer realization because of the large magnitude of potential variants to be analyzed which are both, possible and realizable. In order to reduce the dimensionality of the morphological array, efficient methods for the structural synthesis have been developed [8]. The synthesis process for the 4S-System comprises the following stages:

A. Creation of the morphological table. The morphological table (tab. 1) contains in total 1152 potential variants.

No.	Descriptors	option 1	option 2	option 3	option 4
1	Stress variation	pressure increase	pressure reduction	combined	
2	Source of stress	pneumatic	mechanic	electric	hydraulic
3	Membrane	flexible	rigid		
4	Control system	no	controlled	adaptive	
5	Combination of panel units	1	2	3	n
6	Combination of layers	homoge-neous	heteroge-neous		
7	Material morphology	porous	cellular		

TAB 1. Morphological table of possible 4S-acoustic systems

The major problem of choosing viable solutions is determined by two circumstances: complexity of formalization of the problem and the large number of requirements, criteria and restrictions. E.g., the problem describing parameters are not necessarily of consistent nature (quantitative vs. qualitative). The definition of a criterion value for the given alternative is, in essence, the indirect identification of its appropriateness as a means for assessing the purpose achievement.

Henceforth each element of the morphological table is compared with the appropriate value of the criterion on which the estimation will be made. Weighting coefficients are given to criteria depending on the purpose [8, 9].

B. Generation of variants, their estimation, initial selection and forming of an array of rational variants for the subsequent analysis.

C. Clusterization of the variants using the entered measure of similarity. The process of clusterization is considered as the search of a "natural" grouping of objects (see fig. 7).

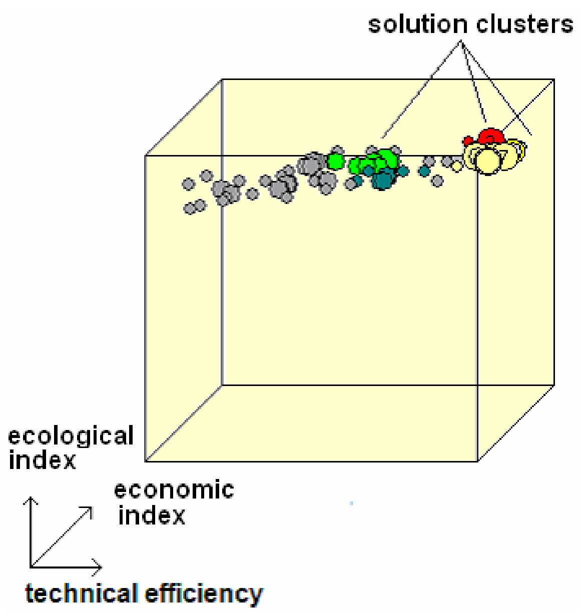

FIG 7. Grouping the variants in clusters.

D. Choosing the most promising variant and conducting a parametrical optimization on that variant.

That exhaustive investigation is currently under way and explicit results are not yet available. However, the expected results will help to identify application opportunities and derivate system solutions.

5. CONCLUSION

Investigations on the presented 4S-technology proved its large potential for noise damping applications. By means of a control loop, which consists of a microphone, a 4S-damping element, a vacuum pump and a controller, the 4S-effect can automatically adopt the sound insulation properties of a noise insulating system to the given noise source in an optimized way, creating an effective, inexpensive and at the same time very flexible sound attenuation system.

Although the effect is not yet fully understood, it seems to be interesting enough for further development and application in a variety of fields, including aeronautics (e.g. cabin noise attenuation, engine inlets), architecture (concert halls, cinemas etc.), automotive and offices tools and furniture (privacy protection, PC ventilation, air conditioning etc.).

Future investigations will focus as well on theoretical modeling as on more generic experiments, which will foster the understanding of the acoustic principle of the effect.

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