Acoustic Solution for a Car Cab Interior

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Abstract The paper describes a process focused on sound acoustic issues inside a car cab ("enclosed space"). The problem is solved experimentally with the use of noise measurements and interior-panel-vibration measurements with the aim to reduce noise at such a level that would allow a comprehensive communication among passengers.

Keywords Car interior · Noise · Language comprehension · Verbal communication among passengers

1 Introduction

Noise solutions in "enclosed space" represent a wide topic—covered mainly by so called "Building acoustics" and are defined by specific quantities and solutions, which are based on insulating materials. In the view of Acoustics, the car interior is quite specific space. Its "particularity" is defined by relatively small dimensions and space volume, space design based on structural principles, defined "acoustic" surfaces (e.g. glass panels), objects (e.g. seats), people and noise-sources location (e.g. engine, wheels etc.), commercially lead "interior" design (an esthetic issue), a certain similarity of car interior designs and quite contradictory requirements of a structural interior design [1, 2].

1.1 Physical Ground

Technical acoustic is based on measurements and data processing mainly. Exact and quality measurements are a ground for modelling and value(s) definitions used

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further on for data evaluations. Most of such models are based on equations mentioned below (1) and (2). Acoustic pressure at any point within certain space must meet the wave equation:

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2} = \frac{1}{c^2} \cdot \frac{\partial^2 p}{\partial t^2}. \tag{1}$$

The relation between acoustic velocity and acoustic pressure in the direction of r "carrier" within certain space is described by the motion equation:

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho} \cdot \frac{\partial p}{\partial r} \tag{2}$$

Equations (1) and (2) arise from the acoustic energy spread theory and put together acoustic pressure and acoustic velocity depending on environmental constants and on time. Equations (1) and (2) are usable for theoretical solutions but in real applications they cope with unavailability of an acoustic pressure description (a concrete one) and its dependency on "the" location and "the" time. Nevertheless, these equations are valid in a universal point of view—thus for the car interior, as well.

Than it is necessary to define two theoretical forms of a sound field. A sound field is space through which sound waves are spread out.

1. Free Sound Field—a sound is spread out from a sound-source in the form of waves, where levels of acoustic pressure, acoustic velocity and sound intensity are equilibrated in relation to the "size" of relative values):

$$L_P = L_{\mathrm{M}} = L_I \tag{3}$$

2. Diffusion Field—represents an omnidirectional sound-wave incidence. Levels of acoustic quantities are not equilibrated:

$$L_P \neq L_{\mathrm{a}} \neq L_I \tag{4}$$

2 An Acoustic Situation Inside a Car-Cab

It should be noted that the self-supporting coachwork is composed of flexible components, which have significant resonance frequencies, components of 2D or 3D symmetry (bonnets, roofs)—so that modal characteristics (locations of nodes and antinodes) are exacerbated—and of cavities through which acoustic energy spreads out easily. So, we can observe that supporting parts without acoustic (anti-noise) modifications exacerbate noise conditions. A vehicle can be divided into 3 sections as regards acoustic (anti-noise) modifications. We consider a car with an engine in the front, with a front-wheel drive and a separate trunk in the rear, so the mentioned sections are:

(1) Engine Space
(2) Car-cab (the interior space)
(3) Trunk (the luggage space)

There are sound-absorbing materials "used" with a car. They are applied (practically) inside the whole car and are thought for inner-and-outer noise reduction. Generally speaking, sound-absorbing materials represent a compromise for contradictory requirements as regards their applications (e.g. a vehicle weight/a vehicle price/further processing/ecological issues—like disposal, design features etc.).

3 Interior Measurement Possibilities

3.1 RASTI Method

The car interior is designed for passenger transport (primarily) aiming at comfort and safety issues. An easy-communication requirement is in fact a minimal language-signal disturbance requirement. The RASTI **(RA**pid **S**peech **T**ransmission **I**ndex) method represents a universal method that is used to evaluate a concrete (artificial) language-signal in a noisy background in relation to the speaker location. The RASTI Index (in the range of 0–1) "classifies" an interior according to its sound quality—and places the interior into one of 5 groups (1 is for excellent comprehension, 0 is for bad comprehension).

3.2 Articulation Index

The index arises from a mathematically processed noise-spectra measurement at a given point of an interior. It evaluates only the "state" at the given point (not the transmission or the source). The space is not "aroused" by a special signal (as with the RASTI Method), but its features are evaluated through masking a frequency spectrum of a speech-signal by a background noise.

4 Solution Steps

4.1 Problem Definition

The anti-noise applications in the car cab are based on a combination of sound-absorbing materials and objects according to given requirements—criteria as

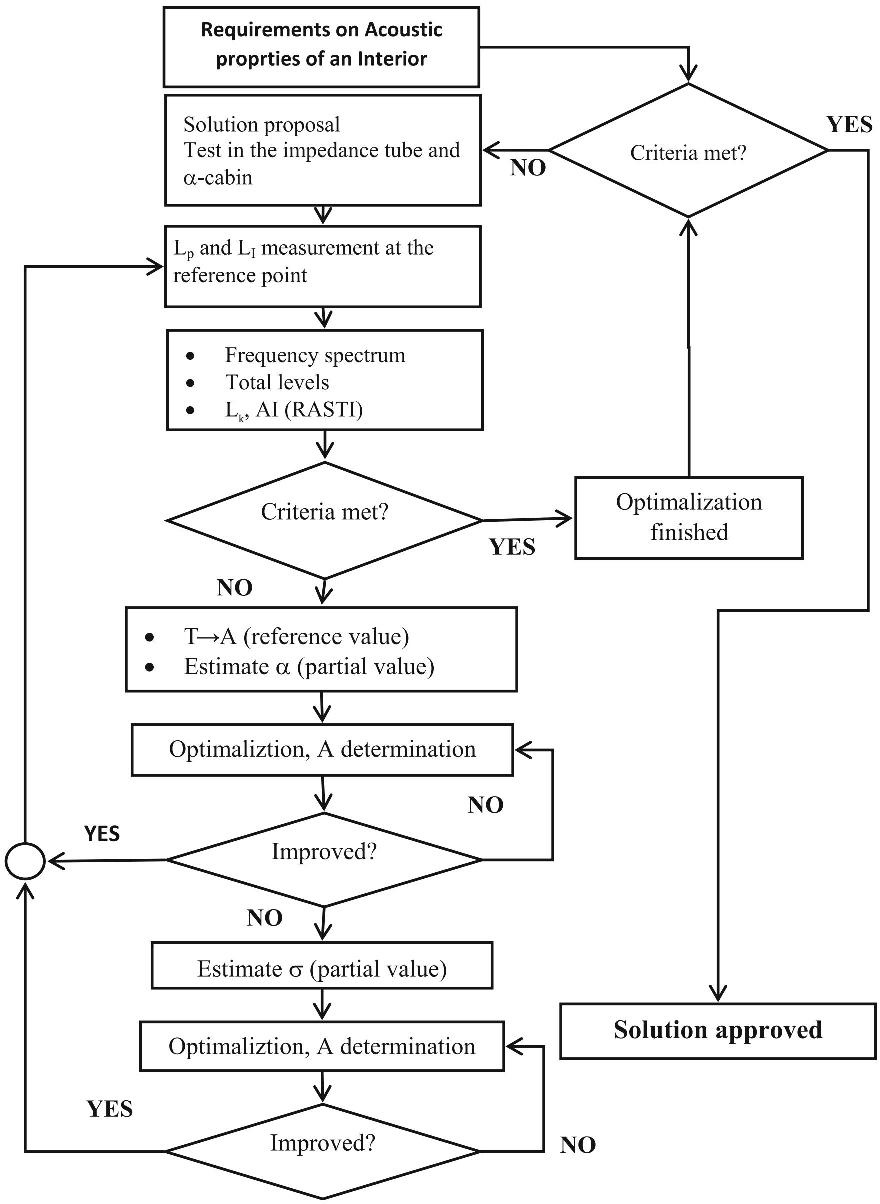

Fig. 1 Flow chart of an acoustic solution made for a car cab interior

regards functions, a safety and an operation of a vehicle. The noise evaluation is made after the a.m. criteria are met. A problem of such noise is its “changeability” in source acoustic performance as regards sound-level and frequency (an engine, wheels, air-conditioning etc.). (Fig. 1).

4.2 Proposed Procedure

(1) To determine targets to be achieved
(2) To use all noise-reducing possibilities primarily (in a vehicle). It means to use components of low-acoustic performance, low vibration levels, flexible mounting etc.
(3) To accept the interior design
(4) To describe the features of an interior with the use of acoustic quantities
(5) To propose measures to improve acoustic parameters
(6) To realize such proposals/applications
(7) To verify impact of the final realization/applications

An important complication for such acoustic improvements and applications is the interior design. Its shape, dimensions and location of glass panels and limitations in use of anti-noise (acoustic) materials. We can recommend a measurement of 5 "crucial" quantities to describe a car interior:

(1) Levels of acoustic pressure dB (A) and third octave sound frequency spectra. Articulation indexes and other needed data can be derived from such measured values. The measuring points are located above passenger heads.
(2) RASTI values for individual couples of communicating passengers. As in the previous case, it is not an "established" value.
(3) Sound termination time (a direct criterion of sound-absorption α) is crucial for next steps
(4) Sound-absorption measurements—A—of individual interior panels
(5) Transmission Coefficient Measurement σ—calculating vibration change of boundary surfaces into acoustic energy

Physical restriction of a technical solution:

- Engine speed revolution frequency and doubled harmonic revolution frequency are both within the range of 50 to 100 Hz. To reduce acoustic features of these frequencies we would need a material of 900 to 1700 mm thickness—which is unthinkable. So, "acceptable" primarily modifications of engine and its mounting are recommended.
- Considering a concrete insulation material thickness to be e.g. 20 mm, we can work with frequencies above 5 kHz. Nevertheless, objects of a higher thickness are applied in the vehicle e.g. passenger seats, sound absorption of which, cannot be determine with α.

4.3 Procedure Application

(1) It is necessary to determine the reference point (the center of front seats at the level of passenger heads).

(2) Noise level and sound intensity at the reference point (in 3 directions) with reference revolutions (mostly 3000 min^{-1}) and RASTI index are measured then.
(3) The Articulation Index and The Reactivity Index are determined from acoustic pressure levels and sound intensity.
(4) An estimate of component acoustic absorption is derived from the Reactivity Index

I would like to point out that the correlation of AI and RASTI is very good in car cab ("enclosed space").

5 Sound Transmission Estimate of Vibrating Panels

Noise coming from individual sources (engine, wheels and their suspensions etc.) gets into the car cab directly through coachwork parts or it is indirectly transmitted by panel(s) vibrations. These panels must be identified and their primary insulating features must be evaluated. It is recommended to cover them with a material that will increase their inner acoustic (it is a material, which will muffle them). We work on the assumption that acoustic power is proportional to acoustic impedance of air, surface, Square of effective vibration velocity and transmission coefficient σ. The coefficient is increasing with increasing frequency and therefore it is necessary to decrease that at higher frequencies. It is possible with the use of shape modifications like ribbing or breaking surface symmetry or applying highly muffling materials on panel surfaces.

6 Conclusion (Solution Summary)

A problem was defined in the given space (a car cab interior) and a procedure of a possible solution was described. Concrete steps represent a combination of objective methods to describe acoustic field in the car cab interior. The targeted outcome is a comprehensive communication of passengers and thus improvement of their safety. A comprehensive communication will be "arranged" with the use of suitable and appropriate insulating materials and by their right application.

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