Relationships Between Quantitative And Qualitative Aspects Of Sounds: Case Of Acoustic Radiation From A Plate

C. Marquis-Favre and J. Faure
LASH/DGCB URA CNRS 1652 ,ENTPE, Rue M. Audin, 69518 Vaulx-en-Velin, France, E-mail : Cathy.Marquis@entpe.fr

1. Introduction

Recent studies undertaken in car and household appliances industries [1] have underlined the importance of taking into account sound perception in the acoustic behaviour analysis of vibrating objects. These important results have led one to undertake a sound quality study applied to building structures. The starting point of this study is one particular component of a building wall: a single panel. The purpose of this work is to determine the influence of the mechanical parameters of a rectangular steel plate according to the relationships between a qualitative analysis and a quantitative analysis. This paper accounts for methods used to achieve the results obtained in the case of a radiating steel plate. The obtained results can also be applied to other industry trade such as car industry.

2. Method and experimentation

The general approach (fig.1) consists of two steps. First, the response of the structure is studied on the physical standpoint by varying various mechanical parameters. Then, the effect of these variations on sound perception is analyzed. This study makes it possible to evaluate the importance of the different parameters.

The studied structure is a homogeneous steel baffled and simply supported plate radiating in a semi-infinite field. The variation of three mechanical parameters is considered: the density, the Young's modulus and the plate thickness. The variation range of these parameters corresponds to the current values encountered for steel plate (fig.2). The vibroacoustic response of the plate, excited by a normal incidence plane wave, has been simulated for each value of parameter.

This computation has been undertaken from 0.5Hz up to 5kHz by 0.5Hz interval in two steps: first, the plate displacement has been analytically calculated by decomposition on the plate *in vacuo* eigenmodes basis [2]; secondly, the acoustic response of the baffled plate has been calculated at two receiver points corresponding to ears positions of a human who would have been placed in front of the plate. The influence of these different mechanical parameters on the vibroacoustic behaviour of the plate is succinctly presented in part 3.

At the same time, sounds have been synthesized from the calculated spectra by using inverse Fourier transform. For each parameter, the various sounds have been submitted to a jury of 15 persons (between 21 and 45 years old) using the pair comparison method [4]. For each pair of sounds, it was required of them to judge the similarity between sounds on a seven-point response scale with verbal end points, starting from 1 for "very different" up to 7 for "very similar". The subjects were also asked to choose which of the two sounds they preferred. The test was 20 minutes long and was carried out in a semi-anechoic room. The sounds listening and subjects responses were done with the help of a graphic interface. For sounds restitution, a sound card Sound Blaster (Sr. 44KHz) and an open headphone (SENNHEISER HD580) have been used. According to test results and data processing, an evaluation of the perceived distance between sounds as well as a note of preference have been obtained for each sound. These notes allow the preference to be represented versus different values of the considered parameter. Distances between stimuli have been evaluated using the Torgerson matrix and his factorial analysis [5]. This latter gives a graphical representation of sounds distances for each parameter.

Density	Young modulus	Thickness
7700 Kg/m^3	1.700 10^{11} Pa	1.00 10^{-3} m
7800 Kg/m^3	1.900 10^{11} Pa	1.30 10^{-3} m
7870 Kg/m^3	2.000 10^{11} Pa	1.50 10^{-3} m
7900 Kg/m^3	2.050 10^{11} Pa	1.55 10^{-3} m
7950 Kg/m^3	2.075 10^{11} Pa	2.00 10^{-3} m
	2.100 10^{11} Pa	3.00 10^{-3} m
	2.150 10^{11} Pa	

Fig. 2. Variation of parameters

3. Results and discussions

From a physical point of view, the density increase shifts down natural frequencies to low frequencies and leads to a decrease in the radiation efficiency [3]. When various sounds have been submitted to the jury, the subjects have found them all similar. This feeling is due mainly to the small percentage of the density variation (3.3 % of the minimum value). The range of this variation is however significant for a material such as steel. The sound radiation modification does not affect the perception of the distances in the present case. The density is thus not a very influential parameter on sound

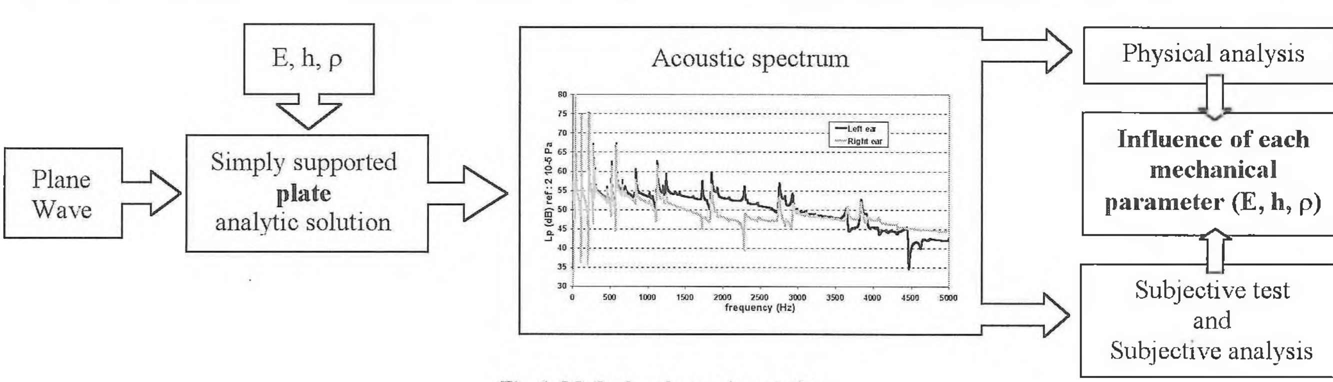

Fig. 1. Method and experimentation

perception in the case of a steel plate. The accurate knowledge (±100 kg/m^3) of this parameter as input of predictive computational tools or for the choice of a specific steel is thus not necessary.

Increasing Young's modulus shifts up natural frequencies to high frequencies and leads to an increase in the radiation efficiency [3]. Distances between sounds are in this case perceived as a linear function of Young's modulus (fig.3(a)). This linearity is expressed in a significant manner in terms of ratio of distances between sounds for the studied variation range and is given by the following relation:

$$\frac{\delta(i,j)}{\delta(i,k)} = \frac{|E_i - E_j|}{|E_i - E_k|}$$

with δ(i, j) denotes the perceived distance between the ith and jth sounds and E_i is the plate Young's modulus corresponding to the ith sound. The study of the preference has underlined that subjects have a slight tendency to prefer the weakest Young's modulus for the used variation range. This tendency is not very important as the variation percentage is not enough significant (27 % of the minimum value). In this case, the sound radiation modification does not have influence on the preference. It is nevertheless important to pay attention to the accuracy of the Young's modulus values as input to numerical softwares or in the choice of a specific steel since a Young's modulus variation of 0.1 10^{11} Pa is perceived. However it has no influence on sounds preference. The operator will judge the necessity of this parameter accuracy according to the application context.

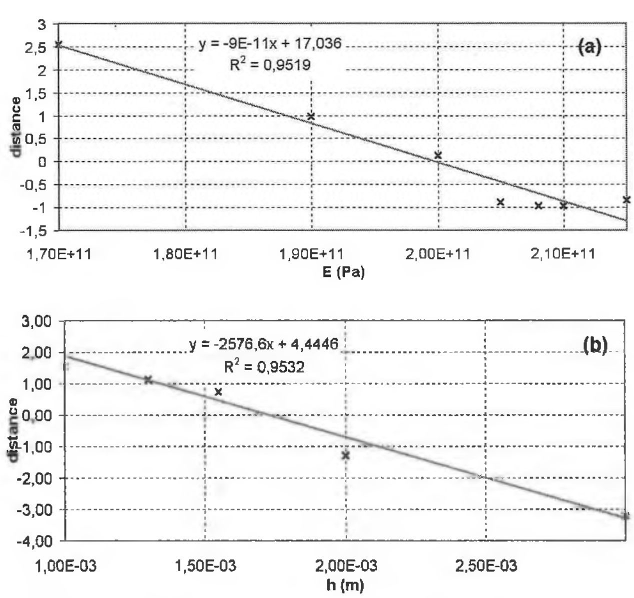

Fig. 3. (a) Perceived distance versus Youngs modulus and (b) Perceived distance versus thickness

The conclusions obtained for the thickness are similar to the Young's modulus ones. Namely, the thickness increase shifts up the natural frequencies to high frequencies and leads to an increase in radiation efficiency [3]. In addition, distances between sounds are perceived as a linear function of thickness (Fig.3(b)). One can establish for the studied variation range the following relation:

$$\frac{\delta(i,j)}{\delta(i,k)} = \frac{|h_i - h_j|}{|h_i - h_k|}$$

where δ(i, j) denotes the perceived distance between the ith and jth sounds, and h_i is the plate thickness corresponding to the ith sound. The preference study shows a more accentuated preference compared to the one observed in the case of Young's modulus variation. In the case of thickness variation, the preference grows as thickness increases (fig.4). The percentage of the thickness variation is more significant (300 % of the minimum value) than for the other studied parameters and thus, the subjects judgements are more accentuated for this parameter.

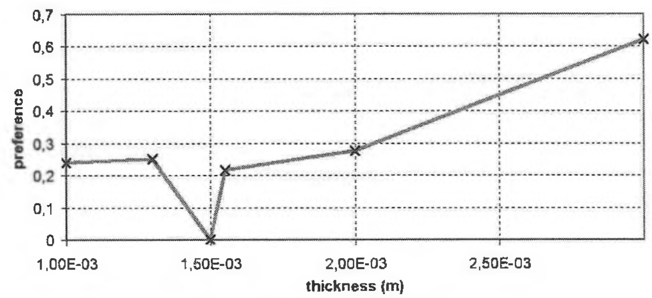

Fig. 4. Preference versus thickness

In the case of plate thickness, it is thus necessary to known with accuracy the thickness values as input of predictive numerical codes and in the design stage of structures since an absolute error of 0.05 10^{-3} m is perceived for the studied thickness variation range and causes a different judgement of subjects preference.
Some investigations are carried out for other structural parameters such as boundaries conditions or structural damping of the plate in order to know whether the tendency given by a qualitative analysis confirms or not the one given by a classical physical study.

4. Acknowledgements

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5. References

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