Annoyance and loudness of pure tones in noise : application to active control of fan noise.

S. Meunier, G. Rabau, E. Friot

Laboratoire de Mécanique et d'Acoustique, CNRS, Marseille, France, Email: meunier@lma.cnrs-mrs.fr

Introduction

The aim of the work reported here is to study the perception of hissing or booming sounds in noise. These kinds of noises are known to be very annoying. They are composed of a background noise, to which a pure-tone signal is added. If the frequency of the pure tone is high, a hissing is heard, if it is low, a booming is heard. The signal is partially masked by the noise. We have measured the annoyance of the signal plus noise as a function of signal level.

Many studies have been done on the perception of pure tones in noise, especially by R. Hellman [1] and by C. Huth [2] and M. Bodden [3] for applications. In this paper, we will focus on a particular application which is active noise control of aircraft fan noise and we will examine the links between the annoyance of the signal plus noise and the loudness of the signal in the noise, which can be calculated [4].

Procedure

Three experiments have been run. In the first one, the background noise was a white noise and the signal a pure tone at 100, 500, 1800 or 4000 Hz. In the second experiment the background noise was 20-2500 Hz wide (low pass) and the signal was a 1800-Hz tone. In the third one, the noise and the signal came from a recording of fan noise. The most salient spectral component was extracted from the noise using digital signal processing. Thus, in the third experiment, the background noise was the fan noise without this spectral component, and the signal was the spectral component itself. Its frequency was 1788 Hz.

Each experiment was divided in three parts. In the first part, the threshold of the signal in the noise was measured using the method of constant stimuli [5]. The threshold corresponded to the 50% of the psychometric function.

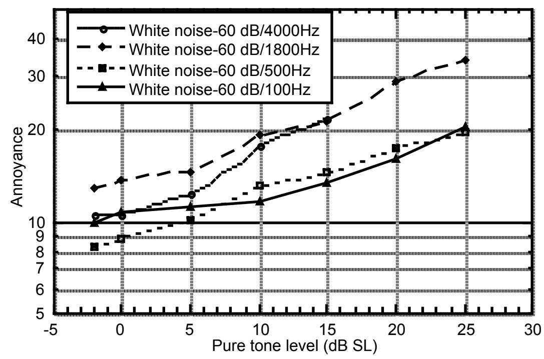
In the second part, the annoyance of the signal plus noise was evaluated using absolute magnitude estimation without reference [6] for two noise levels: 60 and 80 dB SPL. The level of the signal was fixed at a level above masked threshold (dB SL) : -2, 0, 5, 10, 15, 20 and 25 dB SL. In the first experiment, for a noise at 80 dB and a signal at 4 kHz, the 20 and 25 dB SL conditions were removed, because the signal was too loud for the subjects.

In the third part, the loudness of the signal in the noise was estimated using absolute magnitude estimation without reference [1, 6]. Noise and signal levels were the same as in the second part.

Fifteen listeners participated in the experiment.

Results

Fig. 1 shows annoyance as a function of the level of pure tones at different frequencies added to a white noise. Each data point is based on the geometric mean of the jugdments by the group of 15 listeners. Annoyance increases as a function of signal level. Annoyance is greater for high-frequency (1800 and 4000 Hz) than for low-frequency pure tones (100 and 500 Hz). Moreover, the growth of annoyance is faster at high than at low frequencies. The annoyance produced by a 4-kHz pure tone added to the white noise grows more steeply for a 80-dB than for a 60-dB white noise. For a 80-dB white noise, annoyance is greater as frequency increases. It seems that two classes of subjects could be extracted from the group. The results from the first class are the same as those described here. For the second class, annoyance judgments stay constant whatever the signal level. We have to check whether this result comes from an experimental biais. The same results as described in this paragraph are observed for the low-pass noise and the fan noise.



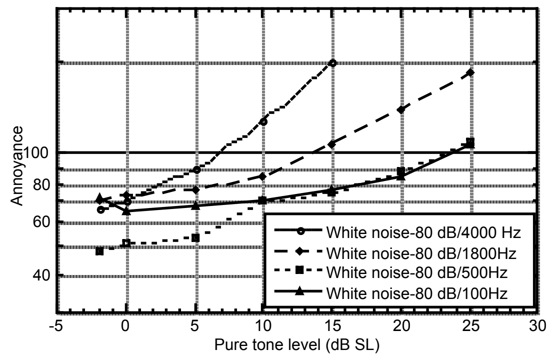


Fig 1: Annoyance as a function of the level of pure tones (in dB SL) added to the noise. The white-noise level is 60 dB (upper graph) and 80 dB (lower graph).

In these experiments, the total loudness of the signal plus noise varies only slightly, much less than annoyance. Thus, annoyance is not correlated with the total loudness. Fig. 2 shows that annoyance is correlated with the partial loudness of the tone. In this figure, the partial loudness of the 1788-Hz tone masked by the fan noise and annoyance of the fan noise (noise + tone) are plotted as a function of signal level.

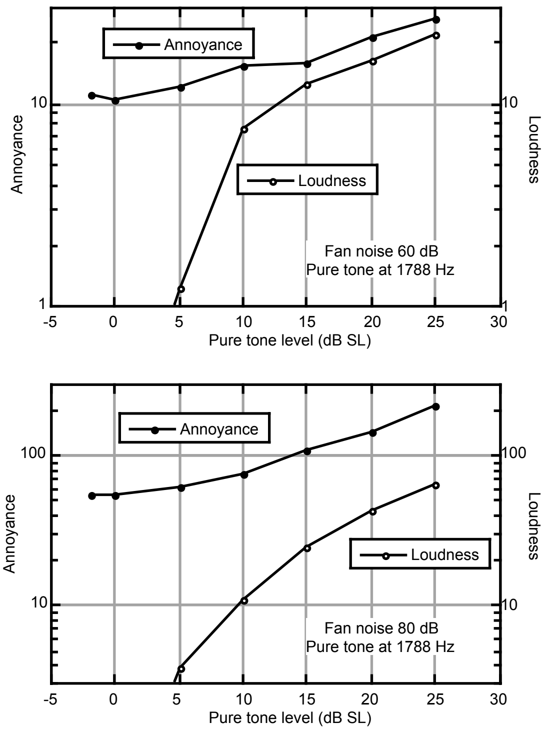


Fig 2: Partial loudness and annoyance as a function of the level of the pure tone (in dB SL) added to the noise. The fan noise level is 60 dB (upper graph) and 80 dB (lower graph).

The usual shape of the masked loudness function [7] is observed and the slope of the function is close to 0.6 for high signal level (>15 dB SL) suggesting that our group of listeners is reliable. Whatever the noise level, the perceived magnitude of annoyance is always higher than the perceived magnitude of loudness. For a pure-tone level higher than 15 dB SL, the growth of perceived magnitude is the same for annoyance and loudness. Below this value, annoyance decreases less rapidly than loudness, because then, the background noise becomes the main component of annoyance. For a fan noise of 80 dB, the ratio between annoyance and loudness is much higher than for a 60-dB fan noise. The same results are observed for the low-pass and the white noise.

Conclusions

A high-frequency pure tone added to a noise is more annoying than a tone at a lower frequency, the more so if the noise is loud. This can be explained by the loudness function of the partially masked signal.

Let us try to give some indications for active noise control. The goal of active noise control is to reduce the level of a noise, and it is particularly efficient in reducing the level of a spectral component in a noise. The question, when a noise or a spectral component has been reduced, is to know what the perceptual effect of the control is. The study reported here has shown that the decrease of annoyance, when the level of a spectral component is reduced, follows the partially masked loudness function, at least for spectral-component levels above 15 dB SL. This partial loudness can be calculated [1]. For spectral components below 15 dB SL, annoyance does not vary much, and it is mainly caused by the background noise. Then, for these levels, the control is less efficient from a perceptual point of view

We have now to figure out whether or not there are two classes of subjects. The other point will be to test the model of partial loudness to study whether it could be used to predict the perceptual effect of active noise control.

Acknowledgments

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