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Perceptual representation of aircraft sounds

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Abstract

This study is part of a research program supported by the European Commission through the Sixth framework program: "Sound Engineering For Aircraft". This program is devoted to the acoustic features of aircraft noise which could be improved by aircraft manufacturers from a sound design point of view. The present study focuses on aircraft sound perception. Fourteen different aircraft sounds are studied and correspond to seven take offs and seven landings. Preference tests are carried out in order to assess the sound agreement using a seven-point scale, each stimulus being compared to a reference sound. For each pair, subjects have to justify their answer in their own words. Their descriptions are analysed in a linguistic way. Dissimilarity tests are also carried out using the same stimuli. Four perceptual factors, which explain the distance between aircrafts sounds, are extracted thanks to INDividual multidimensional SCALing (INDSCAL) analysis. They correspond to the temporal evolution of the sound level (one factor for the slope of the increase and another factor for the regularity of the increase) and to the timbre aspect (one factor for tonality and one factor for the texture of noise). The verbalisation helps to understand and interpret these dimensions. Objective classical criteria are tested to characterize these perceptual effects using correlations between objective and subjective measurements.

Keywords: Aircraft sounds; Sound environment; Sound quality

1. Introduction

People are very concerned about the quality of their environment. It is not then surprising that noise is quoted as the first reason of annoyance in most surveys. More than 30% of Europeans complain about their sound environment [1]. In 2002, a large survey relative to the quality of life showed similar results for half of French citizens [2]. Among all noise sources, aircraft noise is considered as the most annoying. During the last 10 years with the development of the transport industry, noise became a society problem.

The World Health Organization defined noise as, an unwanted sound [3] which creates negative sensations. These sensations could cause social and behavioural troubles, generally grouped in the term "annoyance" [3]. Annoyance, revealed by field surveys, is the long term effect of this noise on human beings. It actually depends not only on acoustic factors but also on non-acoustic factors called mediators and moderators. Moderators are completely independent from the source, such as age or gender. Guski [4] presented some mediators which are linked with the sound source, but not with sound properties (for instance fear of crash, trust in authorities in charge of airport regulation, noise sensitivity of residents., etc). Vallet's study [5] showed that a small proportion (about 33%) of annoyance variance is due to the properties of the sound environment.

In the frame of a sustainable development, the responsibility of all aeronautical industry actors is to reduce population annoyance around airports. Politics can take into account the noise problem, proposing tax, subvention or urban development regulations, and then increase their role as mediators. Noise reduction can be obtained by changing the flight trajectories to reduce the noise footprint, i.e. the noise perceived on the ground. It was experimented around Schipol airport by NLR [6] and developed on SOURDINE

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projects [7]. The other way is to limit the number of events, as is already done for night flights in some airports such as Orly Airport in France or Geneva in Switzerland. For economical reasons, this limitation is not a realistic solution for the day time period. It is actually planned that the day traffic will increase (it has already doubled during the last 10 years).

The airplane noise is linked anyway to the sound source. A huge work has been already done on sound level reduction using new technologies (around 20 dB during the last 30 years). Standards of certification defined by ICAO [8] are now quite severe, and companies had to renew their fleet: chapter 2 planes and most annoying chapter 3 ones are banned in European and US airports. These chapters are used for old planes, but a new and more restrictive chapter (chapter 4) was defined in 2002 to limit new aircrafts noise emissions. Sound level reduction will be more and more difficult and expensive, so manufacturers decided to have a look at other sound features of aircrafts, from a sound design point of view. They assume that every effort to reduce the unpleasantness of an aircraft sound is worth making, even if the effect on sound annoyance is perhaps limited.

Two manufacturers SNECMA and EADS proposed with 20 other partners to the European Commission, a program named "Sound Engineering For Aircraft" through the Sixth Framework Program. The study presented in this paper is part of this program. Its aim is to help manufacturers concentrating their efforts in reducing the sound components which are very unpleasant for people, not only in terms of level but also in terms of sound quality. This paper focuses on the sound properties to which people are sensitive. Current sounds are tested in order to find attributes which differentiate aircraft sounds. A semantic differential questionnaire is often used to characterize environmental sounds [9], urban environments [10], and others specific sounds as interior car sound system [11], refrigerator noises [12], etc. but the meaning of adjectives can be difficult to interpret by subjects and can even be different between subjects. Moreover, if a pair of adjectives is forgotten in the list of the semantic differential questionnaire, this feature will not appear in the analysis of the subjects' answers. Guski [13] pointed out that for each kind of sound, specific adjectives have to be selected: there is not only one common list for all studies. As there is no literature on semantic differential for aircraft sounds, a method based on dissimilarity tests has been preferred to extract factors which can discriminate two aircraft sounds. Subjects are asked to estimate differences (dissimilarities) between two sounds presented in pairs. This full pair comparison method has already been used in different acoustic domains of industry such as perception of car ventilation noise [14], air conditioning systems [15] or road traffic noise [16]. One disadvantage of this method is that the interpretation of experimental results is not easy due to the lack of linguistic explanation. This problem can be solved by collecting free verbalizations, as has been done, for instance, for low frequency perception in urban areas [17], using another pair comparison test with open questions. During our test, subjects had to describe sounds from different airplanes comparing them to a reference one. They are also asked to choose the sound they prefer, in order to help manufacturers to design new and more acceptable aircraft sounds.

Classical psychoacoustic and acoustic indicators (Loudness, Sharpness, L_{Aeq}, L_{max}, etc.) are calculated for each sound using *dBenv32*® software from 01 dB, in order to find physical measurements linked with perceptual factors.

2. Methodology

2.1. Sounds

Aircraft recordings were made around Munich airport. These recordings were made in an environment far from industrial or urban areas in order to avoid any other noise sources. A large number of existing aircrafts were recorded in approach and take off configurations. Recordings were made at a small distance from the end of the runway (3 km) as defined by the aircraft noise measurement certification. The recordings were made by SASS Acoustics and DLR researchers early in the morning on a very hot and sunny summer day (July 2004), applying a binaural head set microphone technique having a linear free-field response (*SASS® – KMB2 measurement system*). Seven recordings of landings and seven of take offs were selected in regard to their different sound quality.

The aim of this work is to investigate dimensions of sound perceptual representation. Aircraft sounds have generally been studied only in term of sound level and Zwicker's loudness seems to be the best way to characterize the perceived sound level [18]. This study aims at revealing other factors, even if they are less salient than loudness. Manufacturers need to know how to make the passage of a plane less noticeable.

To avoid the prominence of loudness, stimuli are equalized towards the A weighted maximum level using an integration time of one second and a slow time weighting function, as it is used for aircraft noise certification [19]. As the duration of a stimulus has an influence on loudness [20], all the stimuli last 40s. The measurements (Table 1) correspond to the mean value of the left and right channels as recommended by Preis [21]. They are calculated over 40s.

As these sounds are non-stationary, characteristics change during time evolution (level, tonality due to Doppler shift). Timbre parameters such as Sharpness or Fluctuation Strength have then to be interpreted very carefully.

2.2. Subjects

Subjects' hearing was measured by an audiogram before the test. The only criterion for excluding a subject was a hearing loss. Fourteen subjects have run the preference test