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Technical Note

Active control of aircraft fly-over sound transmission through an open window

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This paper presents an experimental work on active control of sound transmission through a restricted opening bottom hinged window. The main goal of the work is to demonstrate the feasibility of the active technique to limit the loss of attenuation due to the aperture of windows, and its application to aircraft fly-over incident noise. The experimental window is placed in an exposed façade of a dwelling close to an airport and subject to fly-by aircraft noise. The active control is configured to cancel the pressure at the aperture using a single-input single-output feedforward adaptive system. As a result, a reduction of sound transmission is achieved with low power consumption. In global terms, an increase of almost 3 dB of transmission loss (with respect to the partially opened window insulation values) in the low frequency range (below 160 Hz and according to the National Danish Method for evaluating low frequency noise) is demonstrated, which is equivalent to a reduction of 50% in the loss of insulation caused by opening the window.

1. Introduction

As a result of the effect of aircraft noise on population, one of the usual procedures to reduce the noise impact of an airport on its surroundings is to increase the sound insulation of the affected dwellings to improve, for example, students' academic achievements [1] or to solve noise-induced sleep interference problems [2]. The most common solution to achieve the required insulation levels is to replace the windows. The weakness of this solution is that it only works when the windows are closed, which is incompatible with the need in many areas for natural ventilation of rooms [3]. This problem might be solved with an air conditioning system, but that introduces an additional on-going power consumption which raises the overall power consumption of the dwelling. As an alternative, the necessary ventilation can be achieved through openings in the walls, but this further weakens the sound insulation of the walls. To solve this further problem, noise transmission through these openings might be reduced by passive means, except that poor acoustical performance can be expected due to the inherently poor attenuation of passive devices in the low frequency range [4] characteristic of aircraft fly-over or fly-by noise.

Given all of the foregoing, active control should be considered as a viable option since it requires little space to be installed and is efficient in the low frequency range under consideration. There are several examples of numerical studies of active control of airport run-up noise in the vicinity of airports [5] and even an experimental control of a jet engine test facility [6], suggesting the suitability of active control to effectively attenuate aircraft noise. In these studies, the secondary sound source(s) was located in the proximity of the aircraft and was expected to achieve cancellation in the far field, where the neighborhood is expected to be, but atmospheric refraction can cause fluctuations that decrease the performance of the control system, making it ineffective in some cases [7]. As a result, active control seems to be more suitable if it is applied to apertures rather than to attenuate the incident sound and, taking this into consideration, a collaborative project TERIA was proposed in order to develop different approaches for active control of sound transmission through apertures. One of the approaches [8] considered the aperture as a duct, reducing the problem to a plane wave cancellation [9]. Other recent experiments, although not applied to aircraft noise, consider also the application of active noise control to duct installed at the window [10]. Some experiments based on this principle have yielded successful attenuation, but the active devices required are relatively bulky [8,11]. Another approach [12] was to create an acoustic shadow in front of the façade by means of an active acoustic barrier, comprising an array of 64 secondary loudspeakers, giving

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promising results further developed by Tarabini et al. [13,14], increasing the acoustic insulation of a wall even in a reverberant incident acoustic field.

This paper presents the results of an experimental application of the active control technique to a commercial restricted opening bottom hinged window installed in a dwelling affected by aircraft noise. The aim is to reduce the sound transmission through a relatively small vent area. The objective is sound pressure cancellation at the aperture surface, since it has previously been proven to efficiently attenuate sound transmission [15–18].

2. Methodology

2.1. Description of the experimental site

The experimental site is located in the vicinity of Malpensa airport (Milan), in a dwelling located 550 m from the centerline of the main runway. This is an inhabited dwelling placed in an otherwise quiet zone, disregarding the existence of the airport, and therefore the background noise is clearly dominated by aircraft fly-over noise. In this experimental case the aircraft noise is, strictly speaking, fly-by noise, but for the purposes of this investigation, the term fly-over is assumed to be equivalent. The noise level at the subject dwelling during the fly-over event usually reaches a maximum value of L_{max} of 70 dB (A) and the mean time of the sound event is about 30 seconds. The tested window is in the dwelling's façade that faces the runway and is shown in Fig. 1. The test was performed only for aircraft take off conditions, thus the average angle of elevation of the noise source (aircraft) on the test plant was approximately 14.

A common device to ensure natural interior ventilation is a restricted opening bottom hinged window that allows for a fixed partial opening position for natural ventilation. Such a window is installed in the subject dwelling facing the runway and the objective of the active control system is to control the sound transmitted through the open section. The dimensions of the window itself are 1.42 m high by 0.56 m wide, although the net transmission surface when the window is open is a rather complicated form (see Fig. 2 for dimensions). Moreover, the overall sound insulation of the dwelling has been improved, thus ensuring that the test window is the main noise transmission path from the outside to the inside, effectively minimizing the existence of other transmission paths.

2.2. Active noise control system

A feedforward adaptive control strategy (Fig. 3) is chosen to reduce the noise transmission through the open section of the window and the adaptive algorithm of the control system chosen is the usual filtered-x Least Mean Squared (FXLMS) algorithm. This algorithm can rapidly track changes in the primary signal, is quite robust to errors and is relatively easy to implement. This has been proven effective in the case of moving sound sources [19]. The structure used for the digital filter was a finite impulse response with up to 150 taps with a normalized convergence coefficient up to 0.4 and an update rate of 4. The sample rate was set to 8000 Hz. The identification of the secondary path was made by using random noise as a modeling noise. The active noise control was achieved by means of the digital signal processing board EZ.ANC by casual systems. The reference signal and error signal were picked up by PCB ICP microphones. The power amplifier was an ECLER model MPA 4-80 and the signal filter was a Behringer model UB2442FX-PRO. The secondary loudspeaker was an Audax HTF210FO. The microphones were equipped with foam windscreens to avoid wind-induced noise. The performance of the system was determined by the attenuation achieved inside the dwelling's receiving room and was estimated from the three monitoring microphones within the room. All the signals were recorded by Adlink PXI cards for subsequent processing.

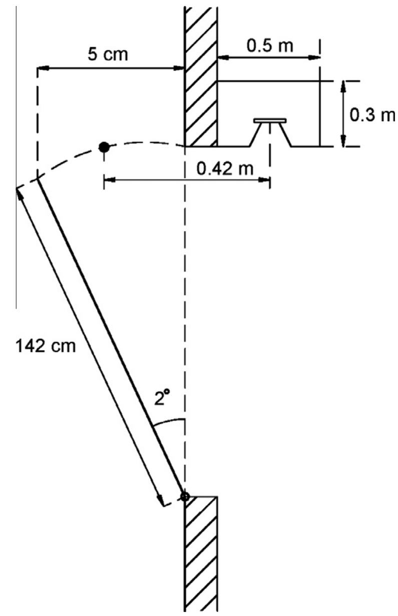

Fig. 2. Scheme of the active window.

The reference microphone was located at a distance of 15 m in front of the dwelling's façade, towards the noise source, and the secondary source and error microphone were placed close to the window. The distance between the reference microphone and the secondary source ensures that the system is causal, by virtue of the propagation time (assuming that the source is almost perpendicular to the façade) of the sound between the reference microphone and the secondary speaker being greater than the time needed by the DSP to process the signal (about 6 ms according to the manufacturer's instructions). This distance is clearly greater than that from the secondary source to the error microphone,

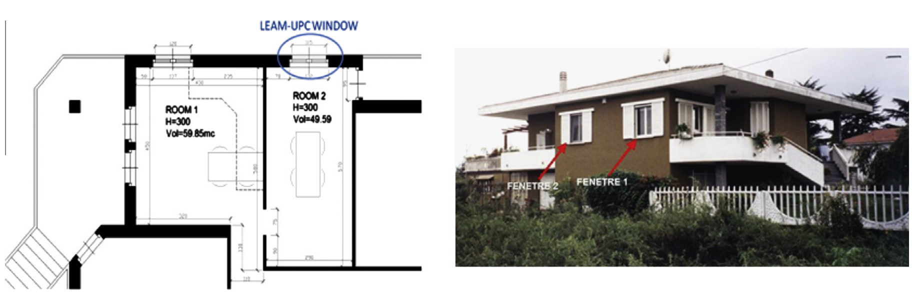

Fig. 1. Location of the test window and room in the dwelling.