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ACTIVE AND PASSIVE FACADE INSULATION AGAINST AIRCRAFT NOISE

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Abstract

Practical sound insulation in buildings around airports is generally obtained by implementing airtight double glazing windows. Acoustic air inlets are available for hygienic air circulation, namely 30 m^3/h. When higher flow rates are necessary during summer time for refreshing purposes, only force ventilation systems equipped with mufflers are available. An alternative is to use air-conditioning system. Both of these choices are not satisfactory for comfort or energy saving reasons. The present paper presents an active and passive insulated window combining a good sound insulation index while insuring proper ventilation for buildings near airports. The system, developed for the EU founded project TERIA (Territorial Inserts of Airports), is designed to provide ventilation levels close to those of an half opened window. It uses active noise control combined with passive absorbing material to provide short duct-type openings, positioned in the lower part of the window, with a high sound insulation index. Prototypes have been installed in two experimental sites near Lyon-Saint-Exupery and Milan-Malpensa airports. This paper presents the system in details and reports on its measured performances under real aircraft sources.

INTRODUCTION

Classical solutions for façade insulation against aircraft or traffic noise include high sound reduction index windows associated with acoustic air inlets. This is generally enough to comply with sound insulation and hygienic air circulation. In quiet areas, refreshing in summer is obtained by opening or partially opening the windows to obtain a larger air circulation or cooling when the outside air is cooler than the inside temperature. In noisy areas, this leads to an impossible choice between temperature or noise comfort. Alternatives such as high flow rate forced ventilation or air conditioning are not appreciated by communities for comfort or energy saving purposes. This paper presents a solution allowing natural ventilation while maintaining sufficient insulation levels for buildings in the vicinity of airports.

The proposed approach, developed under the EU funded project TERIA (Territorial Inserts of Airports), is a hybrid active window featuring separate ventilation openings. The main objective is to combine efficient natural ventilation with proper sound insulation. Under normal operation, the window remains close. The openings then provide ventilation levels similar to those obtained with the window slightly opened (roughly 300 m^3/h under a 10 Pa depression). The proposed openings consist in three rectangular short ducts equipped with passive and active noise control technologies. This approach studied in previous work at CSTB [1] uses the specific properties of sound propagation through ducts. In this case, the duct plays the role of a wave guide which greatly simplifies the acoustic field transmitting sound from the outside to the inside. As a result, significant levels of sound attenuation are expected through the opening of the proposed hybrid window.

The passive treatment of the openings with porous material improves sound insulation in the mid-high frequency region. In the low frequency region, passive control becomes inefficient and Active Noise Control (ANC) is implemented instead. ANC has been applied successfully in the past to one-dimensional systems such as ventilation ducts [2] and industrial chimneys [3]. Compared to these applications where the controller is often designed to attenuate single tones and the length of the duct offer proper positioning of the transducer, the incoming noise in this work is broadband transient (aircraft noise) and the opening duct shall have a limited length for practical and aesthetic reasons.

After developing and testing the appropriate control strategies on a prototype under laboratory conditions, two hybrid active windows were designed and installed in separate experimental sites near Lyon Saint-Exupery and Milan Malpensa airports. This paper presents the system and its performances measured on the Malpensa site.

WINDOW DESCRIPTION

The prototype window was designed to be easily substituted to an existing window, without any extra work in the masonry part of the façade. This motivated the integration of the ventilation openings within the window frame. The three openings are located in the lower part of the window, but they could have been implemented as well on the side or at the top. Comfort regarding air draughts has to be considered more carefully in future applications to find the best situation. Figure 1 shows a drawing of the window and the prototype installed near Milan-Malpensa airport.

As shown in Figure 1, the ventilation openings consist of three short ducts with a 13 x 20 cm^2 rectangular section. Such geometry ensures that plane waves only will transmit noise below the duct cut-off frequency around 600 Hz. In this frequency range, and provided a number of other conditions are met, a single channel active noise control system is able to attenuate efficiently sound transmission. Above the cut-off frequency of the duct, the active system does not attenuate sound transmission efficiently and absorbing material provides passive attenuation of acoustic waves at higher frequencies. Three small doors can be open or shut to control the air flow rate according to the needs.

Figure 1: Hybrid active window on site (Milan-Malpensa) Manufactured by HUET (JH Industries).

Each ventilation duct is equipped with a reference and error microphone and a loudspeaker positioned on the inside wall of the duct. A normalized feed-forward control algorithm (normalized filtered-X LMS) implemented on a DSP board has been chosen for this application where stability and robustness are critical.

The reference microphone is located at the entrance of the duct for different reasons: an exterior microphone would have been impractical to install and not consistent with the concept of a "plug and play" window. Moreover, an exterior microphone would have been affected by the direct and reflected waves from the aircraft sources, e.g., ground reflection or façade reflection, combined with varying delays as the source moves, which prevents the controller from converging to a stable minimum (a single channel controller cannot efficiently control more than one wave). Once inside the duct, the reference microphone measures the single plane wave propagating through the duct below the cut-off frequency which then enables better control.

A critical parameter influencing the performances of an active control system dealing with broadband noise is causality. Control is optimum and stable if the system is causal. For this application, causality introduces a constraint on the length of the duct. The length of the duct ahead of the control loudspeaker needs to be sufficient in order to ensure that the reference microphone captures the incoming wave early enough in order for the control response to remain causal. The system uses a number of techniques to reduce as much as possible these delays thereby allowing a more compact system.

CONDITIONS OF INSTALLATION

The prototype of the three ducts, without the window has been tested in laboratory conditions on the wall of a reverberant room. The sound source was a loudspeaker outside the room, the incident pressure was measured 2 m away from the façade and the transmitted power was measured according to ISO 140 series.

The index Dn,T,w was measured in three situations:

- The 3 doors closed — Dn,T,w = 54 dB — Dn,T,w+Ctr = 53dB
- The 3 doors open — Dn,T,w = 35 dB — Dn,T,w+Ctr = 31dB
- The 3 doors open, ANC on — Dn,T,w = 49 dB — Dn,T,w+Ctr = 43dB

The conclusion is that with a fixed sound source and a steady state broad band noise, in laboratory conditions, the ANC provides an excess attenuation of 14 dB for pink noise and 12 dB for traffic noise.

The window associated to the duct system should be of the same category of insulation, i.e. Rw+Ctr larger than 36 dB for a 1.8 m^2 window. Moreover, the insulation of the room where the window is installed against exterior noise should be high enough.

The proposed system is installed in two experimental sites near Lyon Saint-Exupery (Jons) and Milan-Malpensa airports. Only the case of Milan will be reported since the other one did not fulfilled totally the above conditions.

The house in Milan is situated 550 m from the landing track, and the room where the window is mounted is facing the track – See figure 2.

Figure 2- Situation of the experimental house in Milan airport

The walls and other apertures of the room have been covered with a lining, to be sure that the window is the real acoustic weak component.

The window has a wood frame, and the glass is a double glass, one being a laminated glass (4.2.4-10-10) in mm.

PERFORMANCE OF THE WINDOW

The window is characterized in two different configurations: (1) opened ducts without active control, (2) opened ducts with active control. To evaluate the influence of duct length on control performances, the ducts were also equipped with extensions increasing their length by 30 cm. In this “long duct” configuration, the reference microphone is further away from the control loudspeaker which gives more time to the controller to cancel the incoming sound field.

The normalized insulation index, DnT, is evaluated according to Standard ISO 140-5 [4] using both fixed loudspeaker sources and real airplanes. This index represents the overall sound insulation performance of the facade. Table 1 presents the measured sound insulation index for the “short ducts” and “long ducts” configurations using a fixed loudspeaker source. Overall, the active noise control system increases the insulation index by 10 dB for the long duct and 8 dB for the short duct. As expected, the increased distance between the reference and control plane provided by the long duct yields better control performances by making the system more causal.

Table 1: DnT control performance – Fixed source

DnTw+Ctr (100-5000 Hz)	Control Off	Control On
Short ducts	29	37
Long ducts	28	38

Figure 3 presents the window performance measured with airplane sources. The values for the uncontrolled (red curve) and controlled (blue curve) cases were obtained by averaging the insulation values measured over several airplane passages. The curves clearly show the frequency range of efficiency for the active control system. Starting around 800 Hz, non-plane waves propagate through the ducts. The single channel controller is unable to control this type of waves and the uncontrolled and controlled curves present similar levels above 800 Hz. The overall insulation index is increased by 7 dB by the active system. As expected, the active system performances slightly decrease in presence of real airplane sources due to their non-stationary time and spatial properties which require constant adaptation of the control filter.

To further demonstrate the active control system efficiency, the sound pressure level was recorded outside and inside the test room during a single plane passage. The active system is on during the entire passage except for about 4 seconds as shown on Figure 4. The levels are given in dB(A). The red curve clearly shows the times where the controller is switched on and off with around 10 dB(A) of sound pressure level variation inside the room.

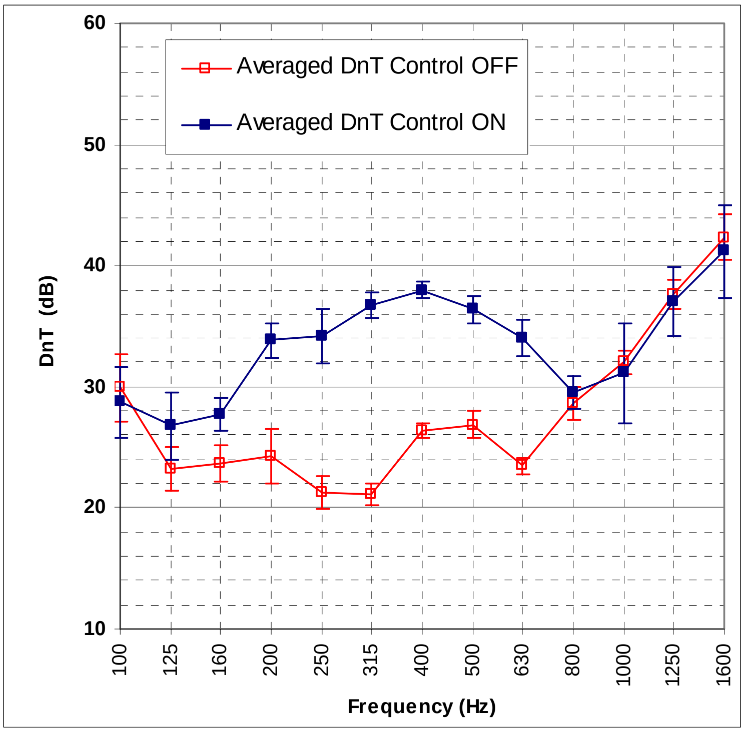

Figure 3: DnT control performance; airplane sources; short ducts; Control Off : Averaged DnT = 26 dB(A); Control On : Averaged DnT = 33 dB(A).

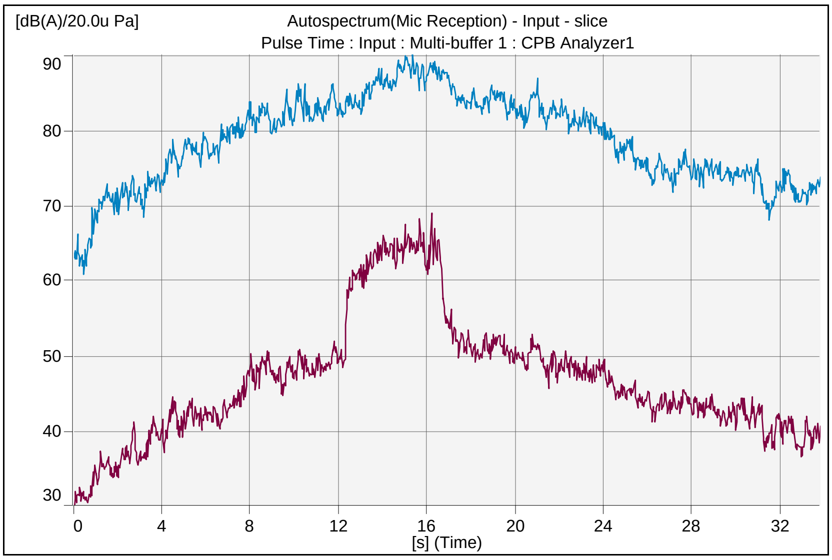

Figure 4: Estimated Leq levels in dB(A) over time measured outside (blue curve) and inside (red curve) during an airplane passage.

CONCLUSION

The feasibility of a window which provides together a good sound insulation and a large opening for natural ventilation has been demonstrated. This has been made possible by using a high performance window equipped with three large air inlets treated by ANC at low frequencies and traditional passive lining at higher frequencies. The performance obtained with the inlets full open and real aircraft noise is $DnTw + Ctr$ =33 dB. The difference with and without ANC is 7 to 10 dB(A) mainly at low-middle frequencies. The system is entirely included in the window and window frame, and do not need any other transducer outside the building. A transition from prototype to industrial product would need to look further at wind effects, aging issues, and cost cutting.

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