SPECTRAL VARIATION OF SOUND TRANSMISSION LOSS ACROSS PLENUM WINDOWS WITH NON-PARALLEL GLASS PANES

S K Tang

The Hong Kong Polytechnic University, Hong Kong, China
email: shiu-keung.tang@polyu.edu.hk

It has been reported in a previous scale model study that the overall traffic noise transmission loss across a plenum window can be enhanced by making the two glass panes of the window inclined relative to each other. The improvement, by tilting the internal glass pane varies with the elevation angle of the window outer opening relative to the source, and ranges between 0 to 4 dBA. There are two elevation angles, 8 and 19 deg, where no improvement is found. This study is made in an attempt to explain the observations. It is found that these elevation angles are those at which the sound transmission loss in the 800 Hz 1/3 octave band of the parallel pane cases are relatively high. The opposite is observed for the case of the largest improvement, which occurs at an elevation angle of 13 deg. The separation between the two glass panes in the parallel case is 400 mm, which is approximately the wavelength of a 857 Hz sound. There are many resonance cases but the excitation of this transverse gap mode (the second cut-off) appears dominating in the overall A-weighted traffic noise reduction.
Keywords: sound transmission, building acoustics, noise control, plenum window

1. Introduction

Traffic noise control has long been a challenging task for acousticians and government offices of a congested high-rise city, which many residential buildings have to be build next to noisy trunk road because of the shortage of inhabitable land area. Conventional measures, such as noise barriers and enclosures [1], are proven not so effective again due to the shortage of land and the expensive construction cost. Safety is also an issue. Double glazing windows can offer good sound insulation [2] but do not allow for natural ventilation. They are not preferred nowadays because of sustainability concern. Balconies are welcome by many people. While a standalone balcony can provide good sound insulation to the areas behind it [3], the multiple reflection from the ceiling of a balcony on a high-rise building largely erases its noise screening effect [4]. Sound absorption has to be acted into the balcony void to improve the sound insulation performance [5]. There are also relative complicated proposals to improve balcony noise screening performance in recent years (for instance, Refs 6 and 7).

Under the concept of sustainability, it is desirable to find a noise control device which can offer good sound insulation and at the same time allow for an acceptable level of natural ventilation of the residential unit to which it is attached. Tang [8] has carried out a review on these devices and discussed their pros and cons. Among these devices, the plenum window or similar structures appear to be of great potential for practical applications. Their ability to reduce sound transmission has been studied both in the laboratory [9,10] and at real site [11,12]. In order to improve the sound insulation performance of a plenum window, sound absorption (porous rockwool as well as micro-perforated absorbers) has been added into the window cavity [13]. However, the improvement is not so impressive as the transparency of the window has to be maintained for daylighting issue.

Tang [14] investigated the effect of tilting the internal glass pane of a plenum window on the sound insulation capacity of the window. It is found that there is a 2dB sound insulation increase when the window panes are non-parallel and the source is relatively close to the window. There are source distances where no improvement can be achieved. In this study, further analysis to understand the spectral contents of the sound transmission is carried out.

2. Experimental Setup

The experimental setup has been presented in Tang [14], but it is worthwhile to describe it here again for the sake of completeness. The experiment was carried out in the anechoic chamber of HKPolyU using a 1:4 scale down model as shown in Fig. 1. The configuration of the plenum window is approximately a 1:4 scale down model of the actual window adopted in the student hostel of HKPolyU (Fig. 2). This window type was chosen for the hostel project solely because of the predicted extremely high traffic noise levels at the hostel façade due to the very busy trunk roads in the proximity of the hostel.

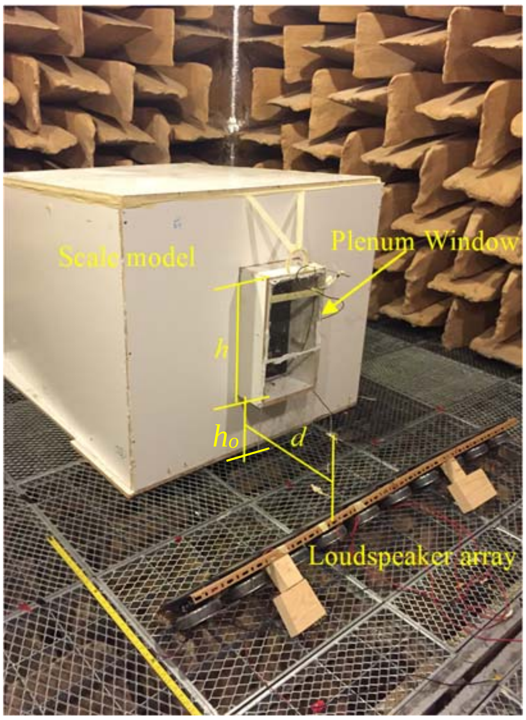


Figure 1: Experimental setup


Figure 2: Plenum windows

The receiver room of the model was used in the study of Tong and Tang [10], which was also the 1:4 scale down version of the one of the author's reverberation chambers. The model was made of 18mm varnished plywood panels. The source was an array consisted of ten 6-inch aperture loudspeakers. The loudspeakers were so tilted such that their normal axes pointed directly to the height level of the outer window pane edge.

The size of the plenum window was 500 mm (Height, h) by 300mm (Width) by 150mm (Depth). The window panes were made of 3 mm thick acrylic sheet and its frame 18 mm varnished plywood panels. The outer window pane was kept vertical, while the inner window pane could be tilted at three different inclination angles (θ) with the vertical plane : –5º, 0º and +5º as shown in Figure 3. As the gap size, g, was limited at 100mm, the inclination angle θ of the inner window pane was also limited to within ±5º. The inner window opening was fixed at 200mm. The window sill was at a height of 200 mm above the chamber floor, thus h_o = 200 mm. However, the centres of the loudspeakers were ~100 mm above the floor. The elevation angle, ϕ, in this study was defined as $\phi = \tan^{-}[(h + h_o - 100 - w)/d]$, where w was the width of the outdoor window opening. It was fixed at w

= 0.5*h* in this experiment, such that $\phi = \tan^{-1}[(0.5h + 100)/d]$. In this study, the acoustical performance of the plenum window was described in term of noise reduction, *NR*. *NR* was defined as the reduction in noise level inside the model receiver room compared to the reference case where the window was fully opened (no window panes). The noise level inside the model receiver room was the average of 13 microphone measurements made inside that room. These microphones spanned the entire internal volume of the receiver room basically uniformly in the present study. The powers and their spectral contents fed to the loudspeakers were kept unchanged throughout the study. The data acquisition system used was the Brüel & Kjær 3560D PULSE system with a sampling rate of 65536 samples per second per channel

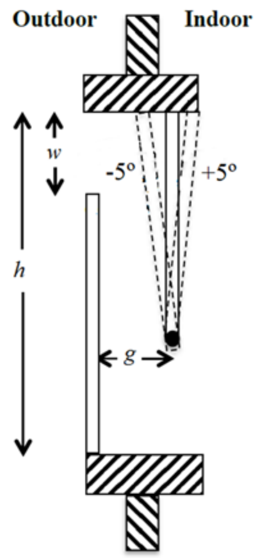


Figure 3: Definition of internal pane inclinations θ.

3. Results and Discussions

In the experiment, the source distance was varied from 0.5 m to 3 m and thus the elevation angle ϕ was varied from 7º to 35º. In the foregoing discussions, unless otherwise stated, the frequencies and *d*s are scaled back to the full-scale window condition. Figure 4 illustrates the one-third octave band spectra of *NR* with $\theta = 0$º at various ϕ. It should be noted that there was no traffic noise insulation improvement by tilting the inner pane when $\phi = 8$º and 19º as shown in Tang [14].

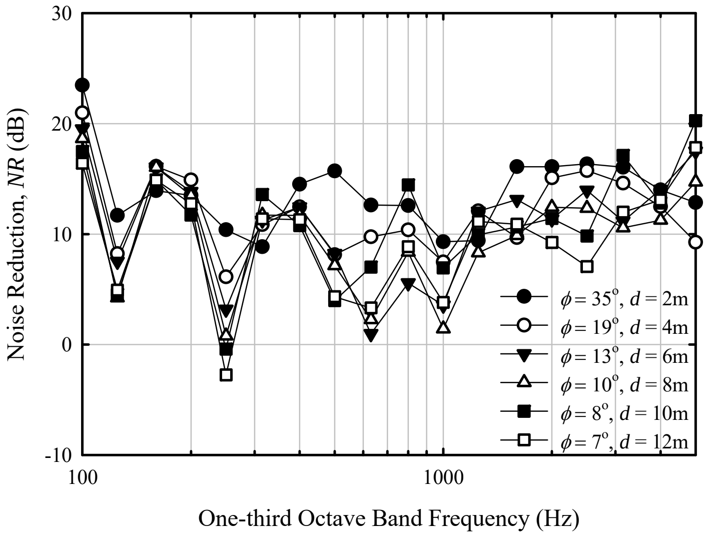
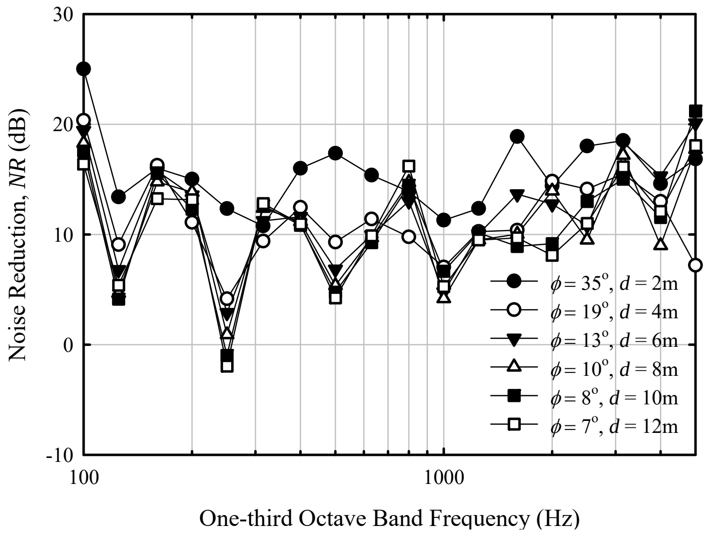
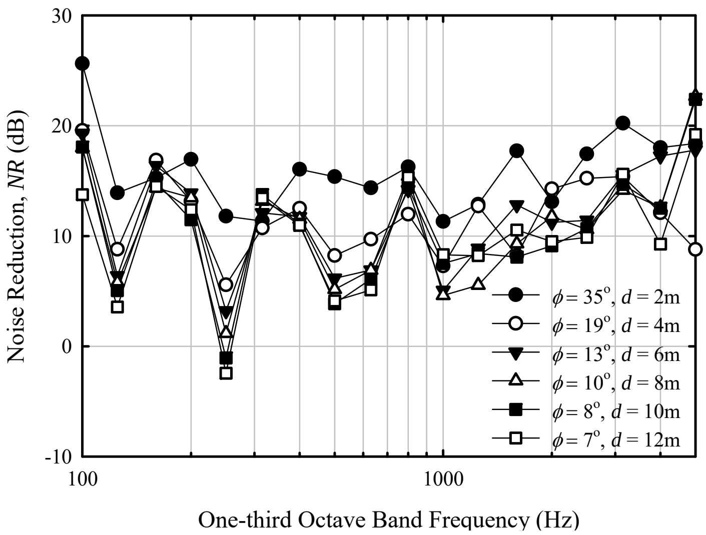


Figure 4 : Noise reduction spectra, $\theta = 0$º.

One can observe from Fig. 4 that there are strong and relatively regular dips at 125 Hz and 250 Hz one-third octave bands nearly for all the elevation angles adopted in the present study. A 125 Hz sound corresponds to a sound of ~500 Hz in the scale model and the corresponding wavelength is 686 mm. This dip is not due to the higher modes in the spanwise and gap-wise directions. A kind of longitudinal resonance between the two openings, which has been observed in the simulation of Tong and Tang [10] should be the main cause of such *NR* dip. The dip at 250 Hz is the first harmonic of this resonance. It is believed that the other two similar dips at frequencies below 1250 Hz are also due to the higher harmonics of this resonance. The "less affected" results for the case of $\phi = 35^o$ tend to suggest that this resonance is not so effectively excited once the elevation angle is large enough to limit the sound energy that can propagate into the cavity.



(a) $\theta = +5^o$



(b) $\theta = -5^o$

Figure 5 : Noise reduction spectra of plenum windows with inclined inner pane

Figures 5a and 5b show the spectral variations of *NR*s for $\theta = +5^o$ and -5^o respectively. However, one can notice that these variations are very similar. For $\theta = +5^o$, the abovementioned longitudinal resonances are more regularly forced out. The small differences in these *NR*s explain the insignificant difference of the traffic noise insertion losses resulted from these inclinations observed in Tang [14].

The *NR* differences between the plenum windows with $\theta = +5^o$ and 0^o are presented in Fig. 6. The corresponding results for $\theta = -5^o$ are very similar and thus are not presented here. It can be observed that for a large elevation angle, the increase of *NR* by tilting the inner pane of the plenum window is basically broadband, though a dip is found at the 2 kHz one-third octave band. For ϕ = 19º, the tilting results in poorer acoustical performance at frequency below the 500 Hz band, but both improvement and deterioration can be found at higher frequencies. The case of ϕ = 8º is near the opposite, but the overall effect results in insignificant change of *NR* by the pane tilting. The results of Tang [14] also illustrate the relatively larger improvement at ϕ = 10º and 13º. This is obviously the result of the strong *NR* peaks at the 630 Hz and 800 Hz bands as shown in Fig. 6. The gap width of the window was 100 mm (400 mm in full-scale condition), while the overlapping length of the window was 50 mm (200 mm in full-scale condition) in the experiment. The second higher gap mode frequency should be ~850 Hz [(2,0) mode], while a resonance can take place between the two edges at 767 Hz. There is also a possibility of the excitation of a higher mode, which is formed by a gap-wise mode and a harmonic of the abovementioned longitudinal cavity mode. The frequency is ~659 Hz [(1,2) mode]. Figure 7 shows the narrowband width analysis of the spectral densities inside the plenum windows at ϕ = 13º for θ = +5º and 0º. A group of modes with 650 Hz to 850 Hz appear to have been excited in the parallel case, but are attenuated when the inner window pane is tilted.

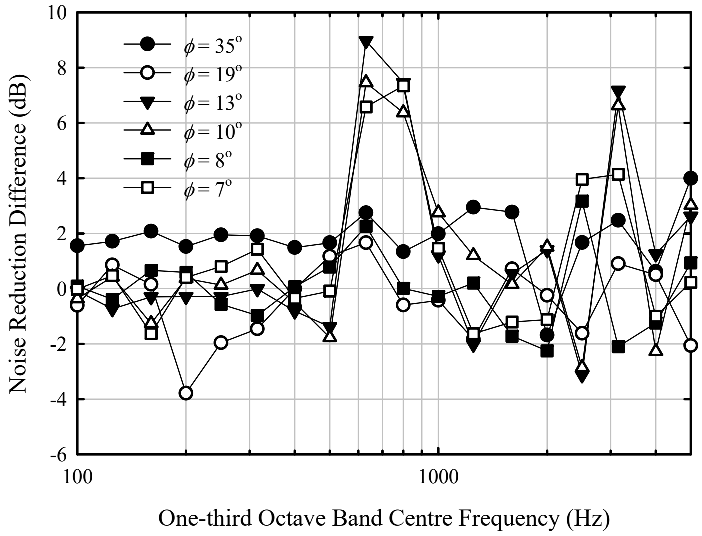


Figure 6 : *NR* differences between plenum windows with θ = +5º and 0º.

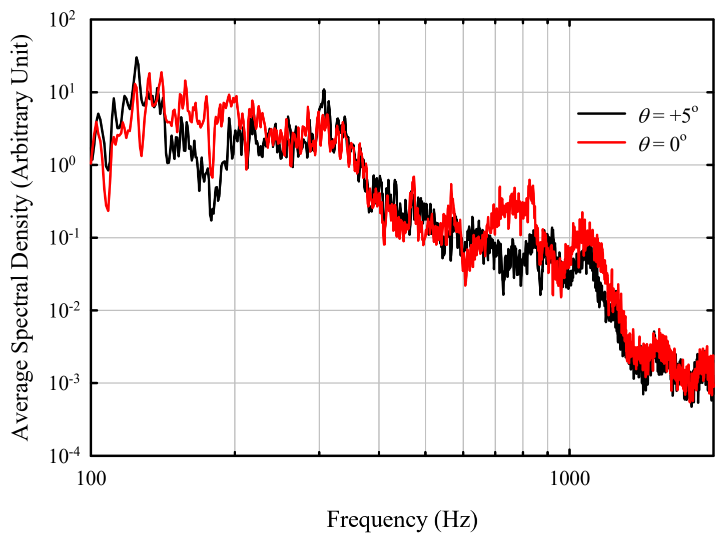


Figure 7 : Average spectral densities inside plenum windows with θ = +5º and 0º at ϕ = 13º.

The results shown in Fig. 6 suggest that the sound insulation improvement by tilting the inner pane is highly sensitive to the elevation angle. In general, the tilting appears to have attenuated the resonance of a group of higher modes which are forced out in the plenum window with parallel window panes. It is conjectured that the cases of “no improvement” at $\phi = 8^o$ and 19^o are due to the reflection of sound rays, either directly back towards the outer window opening or go through the gap without much reflected by the inner window pane.

4. Conclusions

The results of a preliminary study of the author on the improving the sound insulation capacity of plenum window by tilting one of the window panes are further analysed in this study. The present focus is on the spectral content of the improvement and an attempt to understand the mechanisms of such improvement.

The spectral contents of noise reduction show that there are acoustic modes excited within the plenum windows. The tilting of the inner window pane appears to have attenuated such excitation near to the second higher gap-mode. This phenomenon is not observed at a few sound incidence angles. Further experiments are required to explain this phenomenon.

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