Designing canopies to improve downwind shielding at various barrier configurations at short and long distance

Timothy Van Renterghem* and Dick Botteldooren

*Corresponding author's address: INTEC-acoustics, University Ghent, Gent, 9000, W-Vlaanderen, Belgium, tvrenter@intec.ugent.be

The positive effect of a row of trees to improve downwind shielding in the acoustic shadow zone behind a noise wall has been shown before by means of a wind tunnel experiment, a field study and by numerical simulations. This research focused at a rather short distance in downwind direction, where important recovery of the shielding lost by screen-induced wind refraction was observed. However, opposite effects are possible at longer distance. This can be explained by shifts in the zones with strong (positive) gradients in the horizontal component of the wind speed. Leaving a gap between the barrier top and canopy bottom helps reducing these negative effects at longer distance, and results in a generally optimized performance downwind. Trees behind noise walls at either side of the source lead to a full cancelling of wind effects at short distance, but to strong negative effects at longer distances downwind. Trees as windbreaks seem to be especially useful near single, vertically erected noise walls. Near steep berms, no net effect of trees is predicted. The design rules presented in this paper are derived based on numerical calculations with a previously validated CFD-FDTD-PE model.
INTRODUCTION

In acoustic shadow zones formed by non-streamlined obstacles, downward refraction can be pronounced under conditions of downwind sound propagation. A clear case is the so-called screen-induced refraction of sound (SIROS, also called RESWING as in Salomons, 1999) by wind near vertically erected sound walls (De Jong and Stusnick, 1976; Rasmussen and Ar ranz, 1998; Salomons, 1999). This is caused by the additional and strong gradients in the horizontal component of the wind field appearing near the top of the obstacle, leading to downward propagation into the shielded zone. The fact that levels are limited there makes these zones sensitive to small increases in the acoustic energy received.

A possible strategy to deal with this problem is placing a row of trees behind a noise wall, acting as a windbreak. A wind tunnel scale-model experiment using synthetic windbreaks (Van Renterghem et al., 2002), and a field experiment along a highway (Van Renterghem and Botteldooren, 2002) clearly showed the positive effect at close distance. In Van Renterghem and Botteldooren (2007), this research was linked to documented physical properties of the canopies of trees.

As the positive effect of trees arises primarily from a shift in the zone containing downwardly refracting gradients, the effect needs to be assessed at larger distances as well as negative effects could appear. The effect at both short and longer distances will be studied in this paper.

In addition, different canopy strategies are numerically assessed with the purpose of improving barrier shielding in (down)wind conditions. A single noise screen, noise screens at either side of the source, and steep berms are considered. Calculations are performed for realistic highway noise situations.

STUDIED CASES

Geometry and numerical parameters

The geometrical setups of the highway cases considered are shown in Fig. 1. Each of the 4 traffic lanes is assumed to have the same traffic intensity. The total source power (sum of rolling and engine noise) has been assigned to the “engine noise source height” at a height of 0.3 m relative to the street surface. This approach was shown to lead to only minor differences when compared to explicitly modeling the different source heights as demanded by the Harmonoise/Imagine road traffic source power model (Jonason, 2007).

For each case, a “moderate” ($u^*=0.4$ m/s) and “strong” ($u^*=0.8$ m/s) wind is modeled, assuming a purely logarithmical wind speed profile (neutral atmosphere) with an aerodynamic roughness length of 0.01 m as inflow boundary condition. The flow fields are calculated with the CFD software Fluent using the k-ε turbulence closure model. An important aspect of this study is the prediction of the influence of the canopy of trees on the flow field near the berms and screens. This interaction has been simplified to fit basic functionalities of CFD software. The effect of the crown of the tree is modeled as a pressure drop over it, characterized by the pressure resistance coefficient $k_r$. This parameter can be related to physical characteristics of the canopy of trees as the product of the width of the canopy layer in horizontal direction, the drag coefficient of the elements of the canopy, and the leaf area density (Wilson, 1985). Details on the use of this model and the typical range of values for both deciduous, coniferous and so-called “windbreak” species can be found in Van Renterghem and Botteldooren (2008).

Sound propagation between sources and receivers is calculated with the Finite-Difference Time-Domain (FDTD) model, solving the moving medium sound propagation equations, coupled to the Green’s Function Parabolic Equation (GFPE) method (see Van Renterghem et al., 2005 for more details).

Due to the multiple reflections in between the barriers (double noise screen cases), the screen surfaces play an important role. Here, it is opted to calculate with perfectly reflecting screens. Although in practice (partly) absorbing noise barriers are more appropriate, this situation can be considered as an extreme case. When the screens placed at either side of the traffic lanes are strongly absorbing, the single noise wall case is approached (however, the upwind noise barrier would still influence the flow field). At the surfaces of the berm, grass-covered soil is assumed.

The different canopy configurations for the different barrier cases considered are shown in Fig. 2.
FIGURE 1. Geometrical setup of the configurations considered: (a) a single noise wall, (b) a steep triangular berm (slope angles of 45 degrees), and (c) noise walls at either side of the 4 traffic lanes. The distances are indicated in m. The heights in the receiver zone extended from ground level up to the barrier height ($H=4m$). Rigid ground is assumed in the first part of the simulation domain, and grassland near the receiver zone.

FIGURE 2. Combinations of tree rows and single noise screens (a), noise screens on either side of the sources (b), and steep berms (c). Canopy geometry and their properties assumed in the numerical study are indicated as well (with $H$ the screen or berm height and $k_r$ the pressure resistance coefficient; $k_r=1$ denotes a moderate and $k_r=2$ a dense canopy).
**Definition of acoustical indicators**

The insertion loss $IL$ is defined as the sound pressure level in absence of a noise barrier, minus the sound pressure level in presence of a barrier, for the same source receiver configuration. Wind effects are not considered.

The screen-induced refraction of sound by wind $SIROS$ is the sound pressure level with the noise barrier in the presence of wind, minus the sound pressure level with the noise barrier in absence of wind, for the same source–barrier–receiver configuration.

The tree effect $TE$ is defined as the sound pressure level in the presence of a noise barrier and wind, minus the sound pressure level in the presence of a noise barrier combined with trees and wind, for the same source–barrier–receiver configuration.

Positive values of $IL$ indicate that the noise barrier is effective in reducing sound pressure levels in absence of wind. Positive values of $SIROS$ indicate that the wind reduces the barrier efficiency. Positive values of $TE$ indicate that the presence of trees increases shielding when there is wind, or stated otherwise, part of the $SIROS$ is counteracted.

**Row of trees near single noise wall**

*Acoustical effects*

In Fig. 3, $IL$, $SIROS$ and $TE$ is shown for the single noise screen configurations, at a fixed height ($z=2m$) in function of distance $x$. Total A-weighted road traffic noise (vehicle speed of 110 km/h) is considered. With increasing wind speed, and with increasing vehicle speed, values for $SIROS$ tend to increase. The negative action of the wind for this 4-lane road traffic noise situation increases with distance, and gets a maximum of 10 dBA at a distance of 100 m for the strong wind.

At close distance downwind the single noise wall, the $TE$ is predicted to be positive for all configurations. Only in case of the presence of gaps, effects are close to zero or could be even slightly negative. The positive action of the wind breaking effect of trees can exceed 5 dBA for 4-lane road traffic under strong winds. Up to 60% of the $SIROS$ dBA can be recovered in the zone $3H$ to $13H$ downwind, averaged over receivers heights (from ground level) up to the screen height.

Care is needed since at larger distances downwind, negative effects by placing trees are possible. For the moderate wind speed, the tree configurations including gaps between the top of the barrier and bottom of the canopy give positive effects over all distances considered. For the strong wind, the tree effect is enhanced, and strong positive effects are found at close distance behind the barrier, while important negative effects are predicted at a longer distance. Again, the configurations with gaps seem to be the global optimal solution, although at large distance in strong wind, slightly negative effects are observed as well.
FIGURE 3. Plots of IL, SIROS and TE for \( u^* = 0.4 \) m/s (a) and for \( u^* = 0.8 \) m/s (b), downwind from a single 4-m high noise barrier (located at \( x = 24 \) m), at a fixed receiver height of 2 m. 4-lane total A-weighted traffic noise is considered (light vehicles at 110 km/h). \( (TE \ 2Hkr1 \) means the tree effect of a canopy starting at the barrier top, with a total canopy height of \( 2H \) and a moderately dense canopy, \( TE \ 0.25Hkr2 \) means the tree effect in case of a gap of \( 0.25H \) and a dense canopy – all cases involving gaps have a top canopy height at \( 2H \) above the barrier top).

Flow field analysis

Near the barrier top, and in an important zone downwind, gradients exceeding 1/s are observed as illustrated in Fig. 4. Placing trees has a clear influence on the flow fields. This typically leads to a displacement of the zone with downward refracting properties. At the height of the barrier top, an improvement is observed, while at larger heights, a worse situation is observed.
For the cases where the bottom of the canopy is present near the barrier top, strong improvements in the flow field occur. Near the tree canopy top, however, additional gradients appear, extending up to larger distances than the improved zone.

The cases with gaps in between barrier top and bottom of the canopy seems to keep the zone with decreased downward refraction limited compared to the connected trees, and at the same time, the increased refraction at larger heights is more moderate as well. The sound propagation calculations show that this gives a general better acoustic shielding over the receiver range considered. At short distances, there is no effect, at intermediate distances an improvement, while at larger distances no or slightly negative effects are present.

The sources further away from the barrier benefit less from the wind-breaking action of the trees. These sources can be influenced by both the zone with increased and decreased downward refracting gradients, depending on the propagation angle. At short distances downwind, a positive effect is observed due the decrease in positive gradients relative to the barrier in absence of trees. At longer distance, sound interacting with the increased refracting zone at larger heights will become important and results in a negative effect on the sound field, thus increasing the levels in wind. Sources closer to the barrier, on the other hand, cannot be sufficiently bent downwards by these zones with increased downward refraction, and benefit more from the presence of the trees.

**FIGURE 4.** Wind field gradient analysis in case of a vertical noise wall in absence of trees (a), in case of a dense rows of trees behind the noise barrier with the bottom of the canopy starting near the screen top (b), and including a gap between canopy and barrier (c). In (a), the vertical gradient in the horizontal component of the wind velocity is shown ([du/dy]no trees, expressed in 1/s, positive values mean downward refraction). In (b) and (c), the change in this gradient is shown, relative to the gradients predicted in absence of a row of trees([du/dy]no trees-[du/dy]trees, expressed in 1/s, positive values here mean improvement, negative values a worse situation).

**Row of trees near steep berm**

Limiting negative wind effects near steep berms appears to be difficult with the tree row configurations as considered in this study. Calculations in moderate wind show a nearly neutral effect (a small positive effect at short distances, and a small negative effect at larger distances downwind). In periods with strong wind, and for some configurations, some decibels can be gained in a very small zone behind the berm. However, at most distances, negative effects by the placement of trees are predicted under strong wind.

Therefore, it can be concluded that placing trees near berms is not advised from the viewpoint of limiting wind effects. Non-steep berms, due to their aerodynamically smooth design, strongly limit wind effects compared to vertically erected noise walls with the same maximum height (Van Renterghem and Botteldooren, 2012). A better design of their shape is therefore a much more interesting action. If steep berms are the only option, trees should not
be placed from the viewpoint of limiting wind refraction. If, for other reasons, trees are required (e.g. visual aspects or as air quality related measure), trees should be best placed at the source-side of the berm.

**Row of trees near noise walls at either side of the source**

In case of noise screens on either side of the source, strong improvements by the presence of trees are predicted at short downwind distance. With increasing wind speed, this effect is even enhanced, but the start of the negative effects by the presence of trees also shifts closer to the screens. Dense canopies are preferred. A large zone with an improvement near 4 dBA has been predicted in case of dense canopies with the canopies starting at the screen top, extending two times the barrier height above it. For less dense canopies, both the positive effects and negative effects are more limited. The presence of gaps seems less interesting here: the positive effect at short distance is reduced, while negative effects at large distance are not limited compared to the tree configurations without gaps.

**CONCLUSIONS**

The negative action of wind on downwind sound propagation over barriers could be strong, and the use of rows of trees can be considered as an efficient measure to recover part of the dBAs that were lost. However, rows of trees near noise barriers to improve downwind shielding should be carefully designed. The optimal choice depends strongly on the location where optimal improvement is desired, the position of the source relative to the barrier, and whether one deals with single noise walls or noise walls at either side of the source. In case of berms, the use of trees is not advised from the viewpoint of reduction of wind refraction.

Some scattering of sound by canopy elements into the acoustic shadow zone can be expected, especially at higher frequencies. This effect was not considered in the current calculations. Based on measurements as reported in Van Renterghem and Botteldooren (2002), this effect was shown to be of limited importance (typically near 0.5-1 dBA for total highway noise).

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**REFERENCES**


