Validation of a geometric diffraction model with respect to level-time history prediction

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Introduction

Noise induced wake-up reactions strongly depend on single noise events, which are characterized by the maximum sound pressure level and the steepest slope of rise in level time-history [1], [2]. To identify urban areas where traffic based wake-up reactions can be of significance, efficient ways to predict the level-time history of single noise events need to be applied.

In this paper the applicability of the CNOSSOS-EU guidelines in terms of assessing the level-time history of moving sound sources is investigated. Generally, major changes in noise level occur due to shadowing effects. Therefore, the focus of this investigation lies on the diffraction model. The CNOSSOS-EU model distinguishes between three different diffraction cases: the partial diffraction, when the direct ray comes close to an edge, the single and the multi diffraction. The three cases are investigated in a scenario of a sound source passing-by a square box.

The CNOSSOS-EU guidelines require a ray-based description of the sound propagation which neglects wave phenomena like interference. However, in case of low frequencies the constructive and destructive interference of waves can play an important role for the sound propagation in urban topology. Therefore, the low frequency results of the chosen acoustic scenario are further compared to numerical solutions of the linearized Euler equations using a fourth order Discontinuous-Galerkin method. Finally possible improvements of the level-time prediction are discussed.

Methodology

In the following section the CNOSSOS-EU diffraction ray tracer (RT) and the numerical method for solving the linearized Euler equation (LEE) are briefly described.

CNOSSOS-EU Guidelines

The main approach of the CNOSSOS-EU guidelines is a 2.5D acoustic ray tracing procedure. It is assumed, that the major amount of sound energy travels within a horizontal and a vertical cutting plane between source (S) and observer (O). The planes are defined by the three vectors u, v and z, where u is the normalized vector between the observer and the source. The vector v is orthogonal to u in the horizontal plane and calculated as stated in equation (1), while z is the orthogonal vector in vertical direction.

$$\begin{pmatrix} u \\ v \\ z \end{pmatrix} = \begin{pmatrix} u_x & u_y & u_z \\ -u_y & u_x & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad with \quad u = \frac{1}{|\overrightarrow{SO}|}\overrightarrow{SO} \qquad (1)$$

Within the two cutting planes (u,v) and (u,z) possible acoustic propagation paths are investigated, including reflection and diffraction paths. In this paper the RT implementation has been performed with the open source high performance graphics toolkit OpenSceneGraph (OSG) [5]. The implementation enables to find valid ray paths in two or three dimensions around rectangular objects. In the current study it is bound to 2D.

The sound pressure level of the observer L_O is calculated for each detected path from source to observer $\overrightarrow{SO}$ by the following procedure:

$$L_O = L_{S,W} - \Delta L_{geom} - \Delta L_{atm} - \Delta L_{ground} - \Delta L_{diff} \qquad (2)$$

where

- $L_{S,W}$ represents the sound power level of the source
- ΔL_{geom} represents the attenuation due to geometric spreading of a spherical sound source
- ΔL_{atm} represents the attenuation due to atmospheric Absorption
- ΔL_{ground} represents the attenuation due to ground absorption
- ΔL_{diff} represents the attenuation due to diffraction

In this paper ΔL_{atm} and ΔL_{ground} are neglected whereas ΔL_{geom} and ΔL_{diff} are adopted for the 2D case. The calculation of ΔL_{diff} subdivides into two cases:

$$\Delta L_{diff} = \\ = \begin{cases} 10 \cdot C_h \cdot \log_{10}\left(2 + \frac{40}{\lambda} \cdot C'' \cdot \delta\right), & \text{if } \frac{40}{\lambda} \cdot C'' \cdot \delta \geq \\ 0 & otherwise \end{cases} \qquad (3)$$

The coefficient C_h is calculated via

$$C_h = \min\left(\frac{f_m \cdot h_0}{250}, 1\right) \qquad (4)$$

with f_m as nominal center frequency of one frequency band and h_0 as height parameter of the diffracting obstacle. λ represents the wavelength at the nominal center frequency, δ is the path difference between the considered diffraction path and the (virtual) direct path through the obstacle. If, in case of partial diffraction, δ is less than $\lambda/20$, free-field propagation is assumed. The coefficient C'' is used to differentiate between single and multiple diffractions. It is calculated as follows:

$$C'' = \frac{1 + \left(\frac{5 \cdot \lambda}{e}\right)^2}{\frac{1}{3} + \left(\frac{5 \cdot \lambda}{e}\right)^2} \quad (5)$$

Here e indicates the total distance between the diffraction point closest to the source and the diffraction point closest to the observer. If single diffraction occurs $C'' = 1$. The overall procedure of the attenuation model is described in the CNOSSOS-EU guidelines [3] or the corresponding French NMPB model [4].

LEE solver

The applied method for solving the linearized Euler equation (LEE) is a Discontinuous Galerkin method (DG). It is using an nth-order discretization scheme, which has been bound to fourth order in the current study. A medium at rest is assumed. The DG method is described by Rao and Morris [6]. The current implementation of the solver has been previously used for aeroacoustic studies as described in [7] and [8].

Description of scenario

The chosen scenario consists of a square box with side length of 10 m, as shown in Figure 1. A sound source is placed at one side of the box in a constant distance of 5 m in y-direction. It is consecutively moved in x-direction with a step size of 0.25 m. The simulated total travel distance is 25 m. On the opposite side of the box an observer at rest is placed in a distance of 5 m.

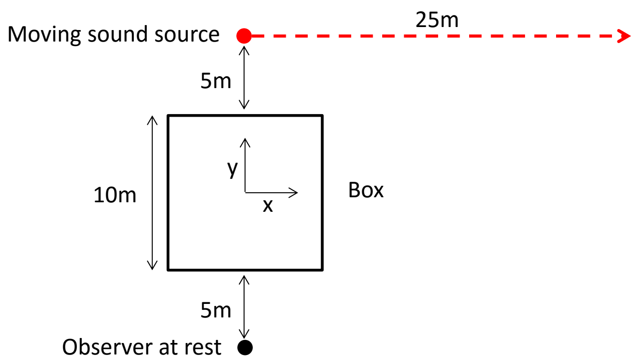

Figure 1 Investigated Scenario of a moving sound source passing by a square box; the source position is varied in x-direction between 0 and 25 m with a spacing of 0.25 m

For each source position a ray tracing and a LEE simulation is performed and the resulting sound pressure level at the observer at rest is calculated for different frequencies. The computational domain has been set to 60x60 m^2.

The RT procedure is illustrated for the box scenario in Figure 2. Two diffraction rays can be seen around the box within the proposed horizontal cutting plane. Note, that the 2D case represents a box with infinite height.

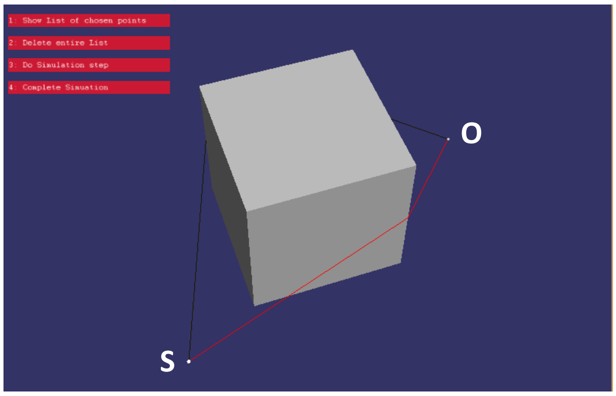

Figure 2 Visualization of the RT implemented with OSG; Detection of diffraction paths around cubic box within a 2D plane proposed by the CNOSSOS-EU guidelines from source S to observer O

The LEE method uses an additional sponge layer with a thickness of 14 m at each side to suppress reflections at the boundary of the computational domain. In Figure 3 the pressure field result of the LEE method for two different source positions is shown. The edge of the sponge layer is indicated by the black line.

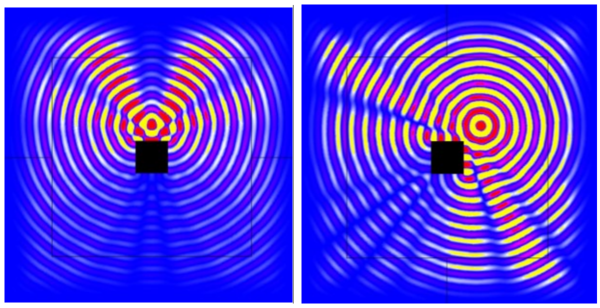

Figure 3 Simulation results of the LEE method for different source positions around a box; black lines indicate the begin of the sponge layer

The LEE method returns the whole pressure field. From that, the root mean square value (RMS) of the sound pressure is calculated at the observer location to compare with the RT solution.

Results

At first the noise level calculated with the RT at the observer location for all simulated source positions is investigated. The acoustic power has been set to 56.78 dBW. The frequency is varied between 100 and 4000 Hz. In Figure 4 the results of the simulation are plotted. The highest blue line indicates a free field solution where no box has been considered. All other lines denote the noise level calculated with the CNOSSOS-EU diffraction model considering different frequencies.

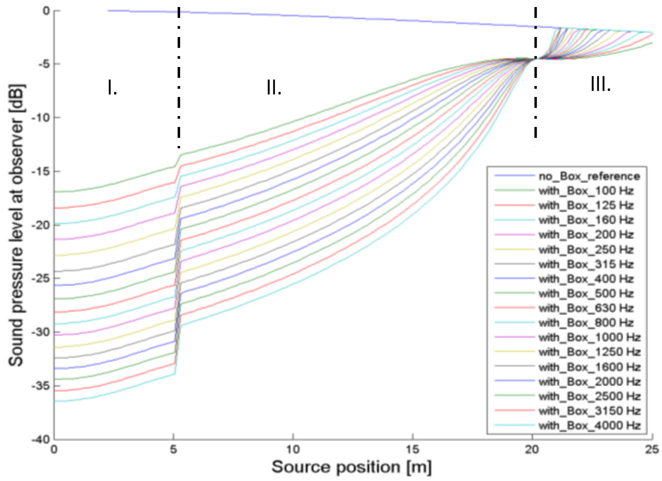

Figure 4 Sound pressure level at observer for varying source positions and different frequencies using the CNOSSOS-EU diffraction model at a sound source power level of 56.781 dBW

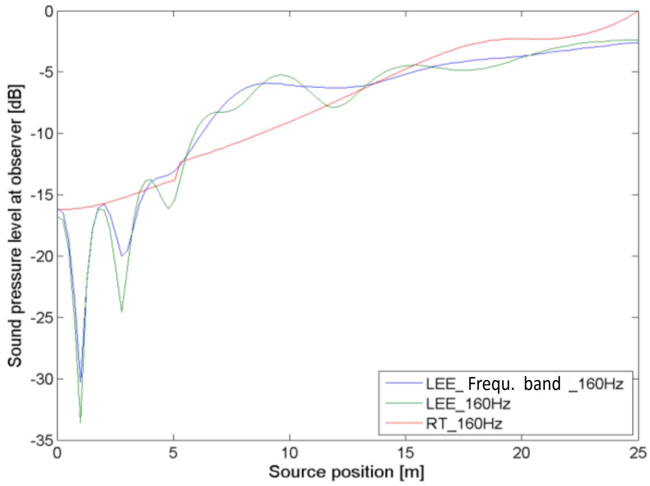

Figure 5 Sound pressure level at observer for varying source positions; Comparison of CNOSSOS-EU RT model and LEE solution for 160 Hz single frequency and 160 Hz frequency band

The graph is subdivided into three geometric regions. Region I reaches from 0 to 5 m of the source position. It corresponds to the double diffraction case. Region II can be observed between 5 and 20 m of the source position. In this region single diffraction dominates the diffraction damping. partial diffraction occurs in the third region (20-25 m). The diffraction damping reaches a maximum value at 0 m and decreases with increasing source potion over all frequencies. At 5 m the source position reaches the edge of the box. Here, a discontinuous jump occurs. It can be explained due to the change from double diffraction to single diffraction. In the single diffraction case the diffraction coefficient C''_{single} equals one. For multiple diffraction C'' is calculated via equation (4). In case of very small wave length and/or large distance e, equation (4) returns $C''_{double} = 3$. Therefore, a jump occurs in the diffraction attenuation term at the transition from double to single diffraction case $\Delta L_{diff}^{transition}$. For high frequencies the jump can reach values of up to 5 dB. It becomes smaller with increasing wavelength / decreasing frequencies.

In Figure 5 the ray tracing result of the 160 Hz frequency band (red line) is compared to the result of the LEE simulation (green line). In the double diffraction case the LEE solution strongly deviates from RT solution. The explanation lies in the constructive and destructive interference of waves which are simulated with the LEE solver and neglected in the RT method. The negligence of wave phenomena in the RT leads to an overestimation of the noise level of up to 17 dB. The deviation between LEE and RT is significantly smaller in single diffraction and partial diffraction regions. Though, a difference between both methods of more than 5 dB remains.

The CNOSSOS-EU ray tracing theory is based on the assumption that traffic noise consists of broadband noise in a rather high frequency range (tire-road noise, aerodynamic noise), where wave effects are averaged out within a frequency band in the temporal mean. Therefore constructive and destructive interference is neglected.

However, to predict time varying noise levels in urban areas low frequency noise emissions and possibly tonal components need to be taken into account. These can i.e. occur in low speed driving condition of starting busses or trucks. These effects cannot be described with the present ray tracer. To show the effect of averaging the blue line in Figure 5 indicates the averaged result of the lower and upper cutoff frequency and the center frequency in the LEE solution. The averaging within the frequency band reduces the influence of the wave interference. However, a deviation above 10 dB between RT and frequency averaged LEE solution remains.

In the following, the level-path-diagram is transformed into a level-time-diagram by assuming a velocity of the source of 30 km/h. The transformation is described by

$$t = x / v_S \tag{6}$$

where t is the time interval, x represents the source postion and v_S the velocity of the sound source. The transformation into the level-time domain enables to use a temporal averaging period to filter the time series. Here, the 0.125 s period is used, to take the finite response time of the human hearing into account. In Figure 6 the filtered level-time series of RT (red) and LEE solution (blue) is plotted. In addition the unfiltered level-time series of the LEE solution is plotted in green. The blue line represents the level fluctuation as it is perceived by a human.

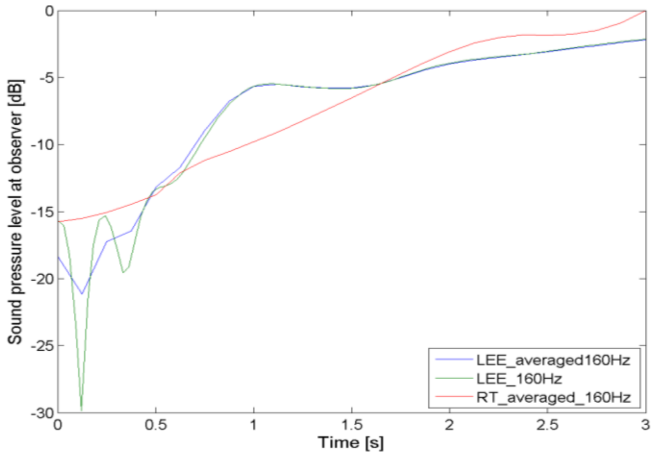

Figure 6 Level-time series of RT and LEE simulation

The filter process reduces the non-physical jump of the RT as well as the wave effects in the LEE solution. The filter therefore can reduce the deviation between both simulation results. The effect becomes even larger if the source travels with a higher velocity. In case of a non-moving source (i.e. truck at red light), the filter process does not have any positive effect any more.

Overall the results show that the CNOSSOS-EU diffraction model is not suitable to predict a level time history of single noise events from vehicle pass-by, if it is characterized by low frequency noise and low pass-by velocity. Assuming high velocities and broadband spectra of the single noise event, the prediction quality increases.

Summary and outlook

In this paper the applicability of the CNOSSOS-EU guidelines in terms of assessing the level-time history of moving sound sources in diffraction case has been investigated. The RT simulation showed discontinuities between the single and multiple diffraction model of one to five dB depending on the chosen frequency band.

The results of the guideline have further been compared to LEE simulation results. A major deviation between both models could be observed in case of double diffraction. This can be explained due to the negligence of wave effects in the RT simulation. Especially for low frequencies the CNOSSOS-EU model leads to large deviations of the sound pressure level.

Literature

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