Investigations of the Cnossos sound propagation model

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Summary

An important element of the new EU model for environmental noise, Cnossos-EU, is the sound propagation model. The effect of meteorology on sound propagation is taken into account with Cnossos through a distinction between two meteorological states: favourable and homogeneous. Long-term average sound levels are calculated by weighted summation of sound levels for the two states, using the statistical fraction of the state favourable as a model parameter. We have calculated values of this parameter for the Netherlands. The effect of the asymmetric wind rose is taken into account, as well as the difference between day and night. We have also performed various test calculations with the Cnossos model and compared the results with results of the current Dutch calculation methods for traffic noise and industry noise. From these test calculations, a number of issues with the Cnossos propagation model have emerged. The issues include both real problems of the model and unclarities in the textual description of the model. Recommendations are given for solving the issues and thereby improving the Cnossos model.

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1. Introduction

The new EU model Cnossos for noise mapping was published in EU Directive 2015/996 on 1 July 2015 [1]. The model should be used in all EU member states for the next round of EU noise mapping, in 2022. The use of a single model in all member states will improve the comparability of different noise maps.

2. Cnossos and Dutch noise models

In this paper we consider three noise models:

- EU model Cnossos [1],
- Dutch model RMG2012 for road and rail traffic noise [2],
- Dutch model HMRI for industry noise [3].

While two different Dutch models are used for traffic noise and industry noise, Cnossos is applicable to both road and rail traffic noise and industry noise. Cnossos employs a single propagation model for all noise sources.

All three models are based on point-to-point propagation. Line sources of traffic noise are divided into short segments, which are represented by point sources.

All three models are based on the common engineering approach, which yields the sound level at a receiver by subtracting attenuation terms from a sound emission level of the source. The attenuation terms represent geometrical attenuation, air absorption, ground attenuation, and screening attenuation. Reflections against vertical surfaces are taken into account as separate sound paths.

Major differences between Cnossos and the two Dutch models occur for:

- screening
- meteorology.

Screening with Cnossos is calculated by means of the convex hull, which takes into account all screening objects between the source and the receiver. The Dutch models take into account only the screening object that causes the largest attenuation.

For meteorology Cnossos distinguishes two atmospheric states:

- favourable (F)
- homogeneous (H).

Long-term average sound levels L_{LT} are calculated by averaging the sound levels for the two states:

$$L_{LT} = 10lg\left(p10^{L_F/10} + (1-p)10^{L_H/10}\right), \quad (1)$$

where parameter p is the fraction of time of the year that atmospheric state 'favourable' occurs. Sound levels L_F and L_H are the levels for favourable and homogeneous, respectively.
The Dutch models calculate long-term average sound levels by subtracting a meteorological correction term from a sound level for downward refracting conditions (as with the ISO 9613-2 model).

3. Meteorology

We have calculated values of meteo parameter p for the Netherlands with a statistical meteorological model described in Ref. [4]. The calculation is based on the vertical gradient of the effective sound speed, with contributions from wind and temperature [5]. Parameter p is the statistical probability of occurrence of atmospheric states with a positive gradient.
Figure 1 shows the value of p as a function of the direction of sound propagation (0^o is propagation from north to south, 90^o from east to west, etc.). The values were calculated for a central location in the Netherlands (De Bilt), with a ground roughness length of 0.1 m. Day and night are distinguished in the figure, as well as the four seasons; for the night the seasonal variation is negligible. The figure shows that values of p are in the range between 0.2 and 0.5. The highest value of p occurs for propagation from south-west to north-east, as expected from the wind rose for the Netherlands.
This approach makes it possible to take into account the effect of the asymmetric wind rose on sound propagation. To illustrate this we have converted the values of p in Figure 1 to decibels, for a situation with a point source at height 0.5 m and a receiver at height 5 m and distance 400 m, with a typical absorbing ground surface (flow resistivity 200 kPa s m^{-2}). Figure 2 shows calculated sound transfer spectra, i.e. spectra of the sound level minus the free-field level. Cnossos results are shown for $p = 1$ (fav) and $p = 0$ (hom). Results of RMG2012 and HMRI are also shown.
The Cnossos spectrum for $p = 1$ is rather flat. For comparison, also theoretical sound transfer spectra are included in the graph, for a non-turbulent atmosphere and for a typical turbulent atmosphere [5]. Turbulence reduces the depth of the ground interference minimum.
Figure 3 shows the variation of the sound level with the direction of sound propagation. This graph is based on Figure 1 for the values of p and the sound transfer spectra from Figure 2, assuming a source with a sound emission level L_W of 120 dB (unweighted) for all octave bands.
Figure 4 shows the variation of the long-term average sound level with the value of p, for various values of ground parameter G of Cnossos. For hard ground we have $G = 0$ and for absorbing ground we have $G = 1$. Intermediate values 0.3 and 0.7 are also used with Cnossos. For comparison we have included the long-term average sound level calculated with the Dutch model HMRI for hard ground ($B = 0$) and absorbing ground ($B = 1$). Differences between Cnossos and HMRI are small in this case, since the variation of p is restricted to the range 0.2 – 0.5.

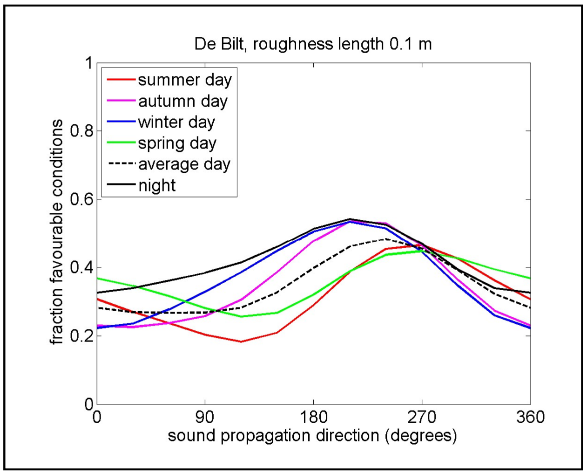

Figure 1. Values of meteo parameter p as a function of the direction of sound propagation.

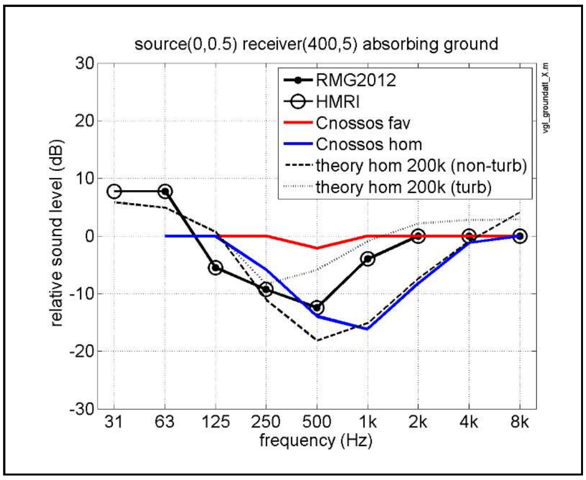

Figure 2. Sound transfer spectra for propagation over 400 m of absorbing ground.

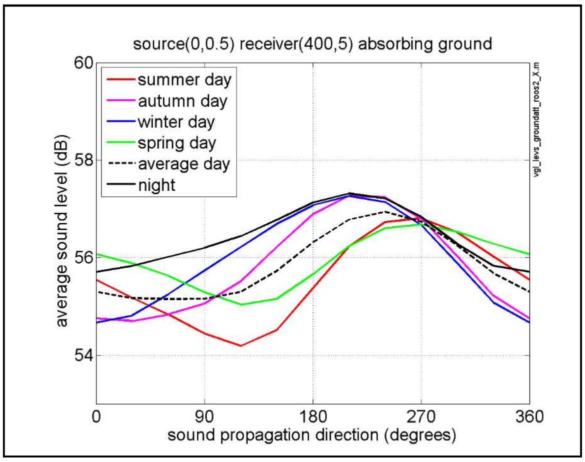

Figure 3. Sound level as a function of the direction of sound propagation.

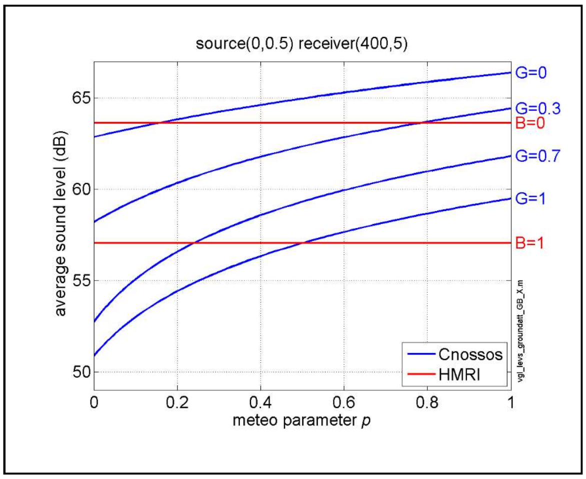

Figure 4. Long-term average sound level as a function of meteo parameter p.

4. Propagation model

4.1 Calculations for a highway

In this section we illustrate differences between Cnossos and RMG2012 for sound levels near a highway.
For the calculations we have assumed the following values for the traffic flow (in h^{-1}) of the three vehicle types (light, medium, heavy): (6800,360,440) for the day, (4200,100,300) for the evening, and (1400,140,26) for the night. For the vehicle speeds we have used (115, 90, 90) km/h.
For the road we have assumed a surface of porous asphalt, with a width of 36 m, and a single source line at the center of the road. For the road length we used an aperture angle of 140 degrees. The receiver height is 5 m.
Figure 5 shows calculated values of the day-evening-night level (L_{den}), as a function of the distance from the center of the road, both for absorbing ground (G = 1, B = 1) and for hard ground (G = 0, B = 0). Cnossos results are given for four values of p: 0, 0.2, 0.5, and 1. We recall that in practice values of p in the Netherlands are in the range 0.2-0.5. The RMG2012 result agrees within about 5 dB with the Cnossos results for p = 0.2 and p = 0.5. It should be noted that differences between Cnossos and RMG2012 are due to differences in both the road emission model and the propagation model. It should also be noted that we have corrected an error in the Cnossos formulas for ground attenuation (see next section).
Figure 6 is similar to Figure 5 with absorbing ground, but now we have included a noise barrier

at 35 m from the road center, both for a barrier height of 4 m and for a barrier height of 10 m. Again the differences between Cnossos and RMG2012 are within about 5 dB.
Figure 7 is also similar to Figure 5 with absorbing ground, but now we have included noise barriers on both sides of the road (at 35 m from the road center), so both reflection and screening of sound plays a role here. For 10 m barriers, Cnossos results are about 5 dB higher that RMG2012 results for distances around 400 m. It should be noted that we did not include the Cnossos retrodiffraction attenuation (see next section).
Figure 8 is similar to Figure 7, but now we have used tilted barrier, with an angle of 14° from the vertical. In this case Cnossos results are up to 10 dB higher than RMG2012 results. This is due to the fact that Cnossos assumes vertical barriers if the angle from the vertical is less than the maximum angle of 15 degrees, while with RMG2012 the maximum angle is 5 degrees. For simplicity we ignored the reflection contribution with RMG2012, neglecting a minor diffraction contribution from the tilted barrier (which may be calculated with an appropriate numerical model).

4.2 Problems with Cnossos

There are some issues with Cnossos, which require correction before the model can be implemented in the Netherlands (and other countries). The issues include both real problems of the model and unclarities in the description of the model.
For the ground attenuation there are several issues. First, the Cnossos description [1] suggests that modified heights from Eq. 2.5.19 should be used in Eq. 2.5.20; this seems to be an error, and we have used unmodified heights here. Secondly, there is a 'mismatch' between the emission and propagation models of Cnossos: the emission model assumes a source in free field while the propagation model assumes a source above a ground surface and therefore in semi-free field. The mismatch amounts to 3 dB at most, and may be solved by a simple correction formula (this has not been done in this study). Finally, a value of ground parameter G for porous asphalt is missing; here we used $G = 0$, but $G = 0.5$ may be more appropriate.
For situations with a source between parallel reflecting surfaces, Cnossos provides a so-called retrodiffraction attenuation. This attenuation accounts for the finite size of a reflecting object in relation to the wavelength. Figure 9 shows values of the retrodiffraction attenuation calculated for four point-source geometries for Figure 7 (with 4 m barriers). The values are small and have a negligible effect on broadband levels in this case. Application of retrodiffraction in more complex situations is not clearly described in the Cnossos text.
For the screening attenuation there is a problem in situations with multiple diffraction. This is illustrated by Figure 10. Shown are sound transfer spectra for three situations with one or two noise screens with a height of 6 m. The propagation geometry is indicated above the graphs. In all cases the receiver is located at 1040 m from the source. Figure 10a shows the result with two noise screens, at 500 m and 1020 m from the source. Figures 10b and 10c show the results with one screen, at 500 m and 1020 m, respectively. Comparison of Figures 10c and 10a shows that adding a second noise screen at 500 m results in a large sound level *increase*, up to 20 dB at high frequency. This is unrealistic. The problem can be traced back to the Cnossos approach to calculating the acoustic path length difference under favourable conditions. This approach does not work well in situations with more than one diffraction point.
We have developed a possible solution for this multiple-diffraction problem under favourable conditions. Our proposed solution first transforms the geometry, using a coordinate transformation that replaces a system with flat ground and a refracting atmosphere by a system with a curved ground and a non-refracting atmosphere [5]. Then the acoustic path length difference is calculated from the straight sound path segments along the convex hull in the transformed system. For the coordinate transformation we assumed a linear sound speed profile with a gradient of 0.05 s^{-1}, but this value should be optimized in further analyses.
Figure 11 shows that the proposed solution gives satisfactory results. In this case the addition of the second screen at 500 m does *not* lead to an increase of the sound level.
It should be noted that for Figures 10 and 11 we did not take into account the so-called Rayleigh criterion with Cnossos. This criterion is intended for a distinction between the 'ground model' and the 'diffraction model' of Cnossos. For situations with a flat ground or a ground with low obstacles, the ground model should be applied. In situations with higher obstacles, the diffraction model should be applied. On page 36 of the Cnossos description [1] a Rayleigh criterion with path length difference $-\lambda/20$ is mentioned for the distinction between the two models. The description is vague,

and suggests that the reader should look up the details of the criterion in the acoustic literature. The source-code of the EU point-to-point software for Cnossos, provided by the EU, contains an implementation of the Rayleigh criterion with two different path length differences. We applied the EU software also to the calculations for Figure 10, and found slightly different Cnossos results, but the multi-diffraction problem still gives unrealistic results. Our proposed solution may be used to eliminate this problem.

5. Conclusions

We have presented values of Cnossos meteo parameter p for the Netherlands, as calculated with a statistical meteorological model. Values of p for the Netherlands are in the range 0.2-0.5. The effect of the asymmetric wind rose may be taken into account, leading to a sound level variation with propagation direction of about 2 dB.

We have also presented numerical comparisons between Cnossos and the Dutch models for traffic noise and industry noise. In many situations, differences are within 5 dB.

A problem has been found with Cnossos for situations with more than one noise barrier under favourable conditions. A possible solution to eliminate this multi-diffraction problem has been described.

In addition, several problems with the Cnossos model and the Cnossos model description have been identified:

- Ground attenuation
  - formula 2.5.20
  - mismatch emission-propagation
- Retrodiffraction
- Rayleigh criterion.

We think that a revision of Cnossos (by the EU) is necessary, so that these problems will be solved. Further, we think that guidance on the choice of some model parameters, such as ground parameter G for porous asphalt, is a good idea. Guidance on tilted screens and the approach to neglect tilt angles up to 15 degrees is also a good idea.

Acknowledgement

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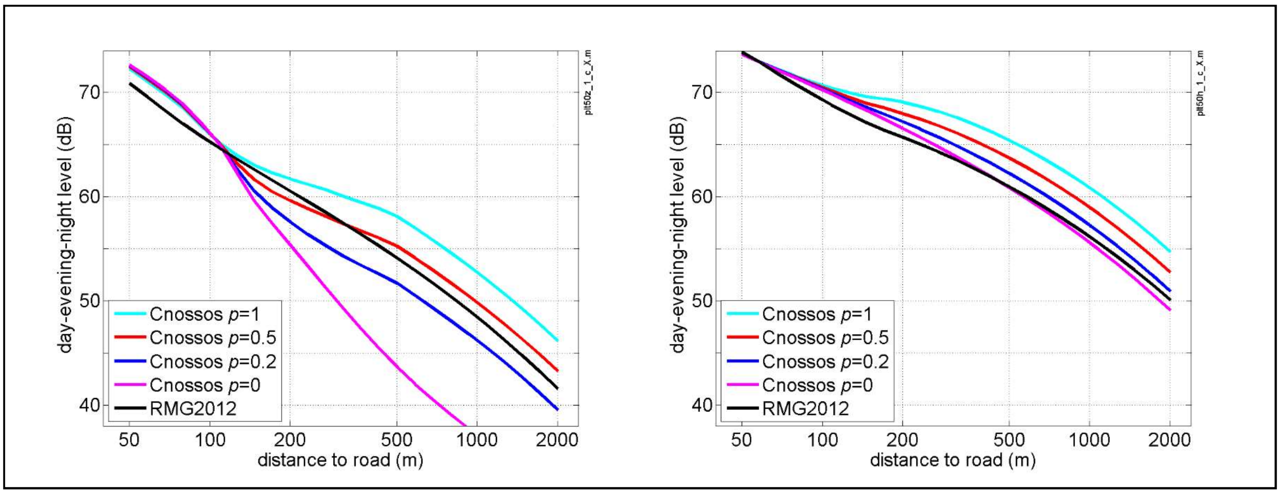

Figure 5. L_{den} as a function of distance from the highway, for absorbing ground (left) and hard ground (right).

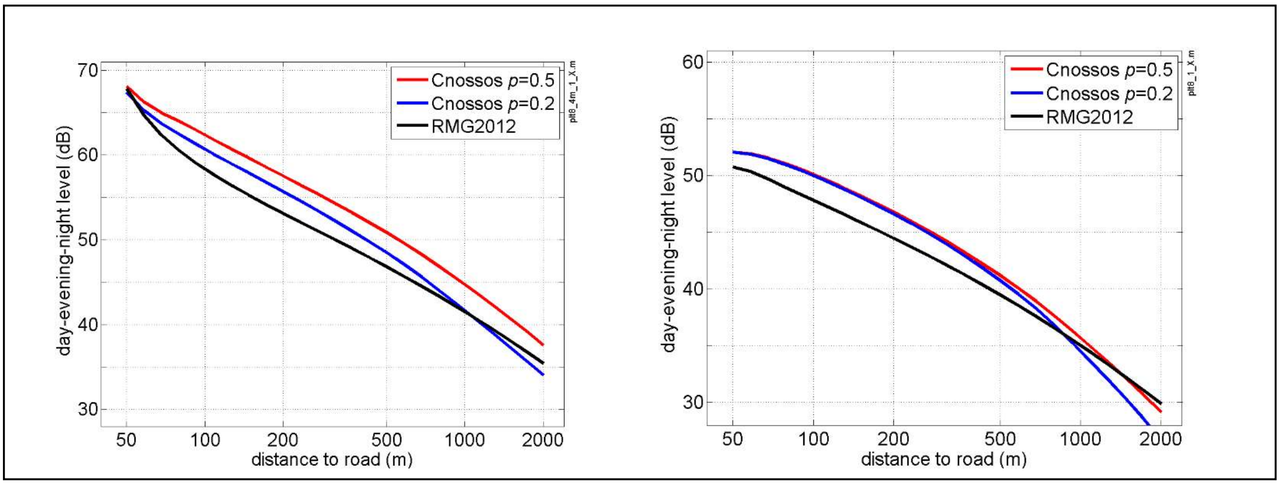

Figure 6. As Figure 5 (absorbing ground), with a noise barrier with a height of 4 m (left) and 10 m (right).

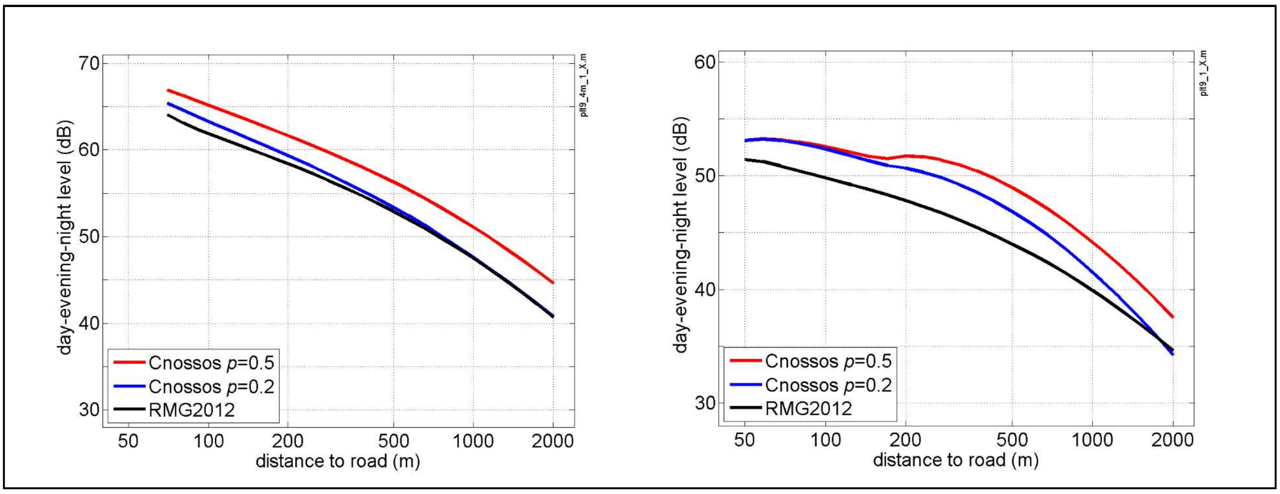

Figure 7. As Figure 5 (absorbing ground), with noise barriers with a height of 4 m (left) and 10 m (right) on both sides of the highway.

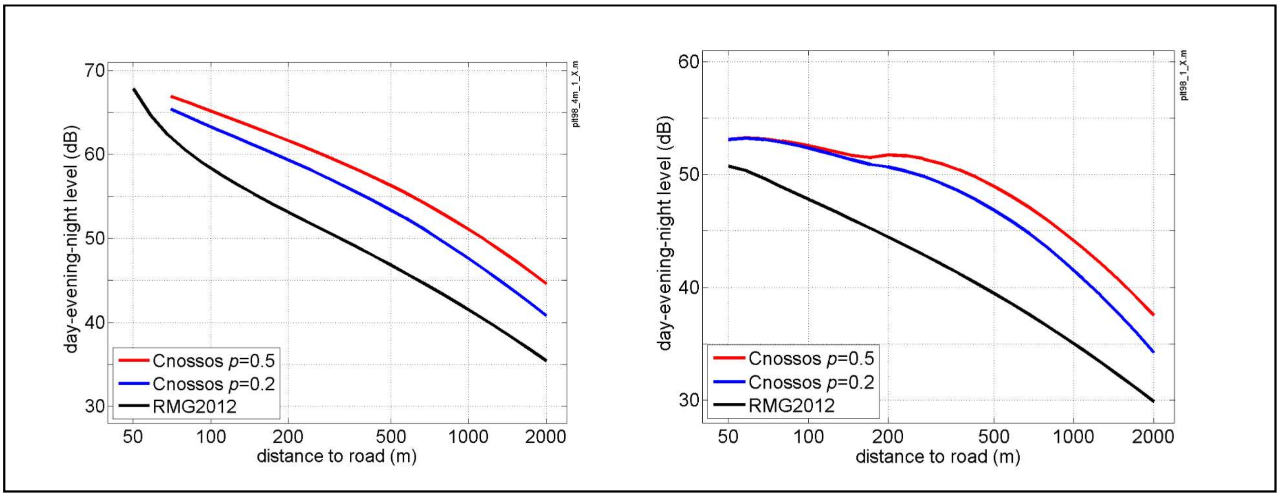

Figure 8. As Figure 7, but now the barriers are tilted.

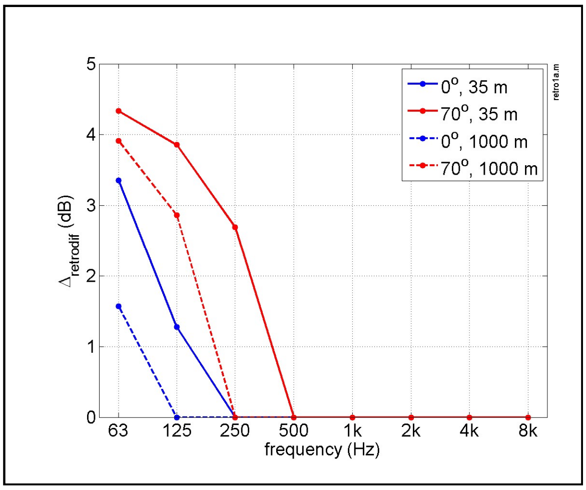

Figure 9. Retrodiffraction attenuation with Cnossos for four point-source geometries for Figure 7 (with 4 m barriers). The legend gives: i) the angle between the line source and the propagation line, and ii) the distance from the line source.

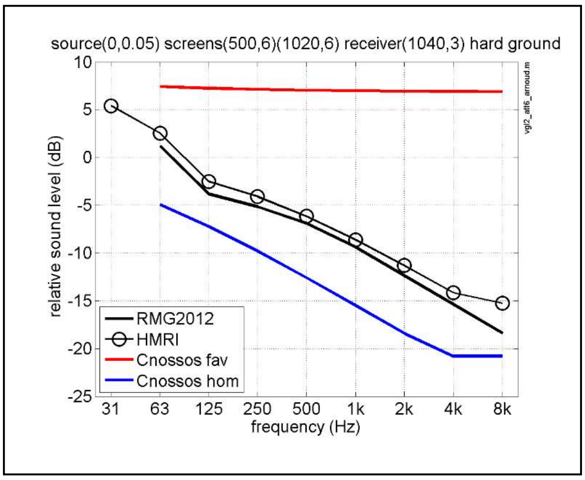

Figure 10a. Sound transfer spectra with screens at 500 m and 1020 m.

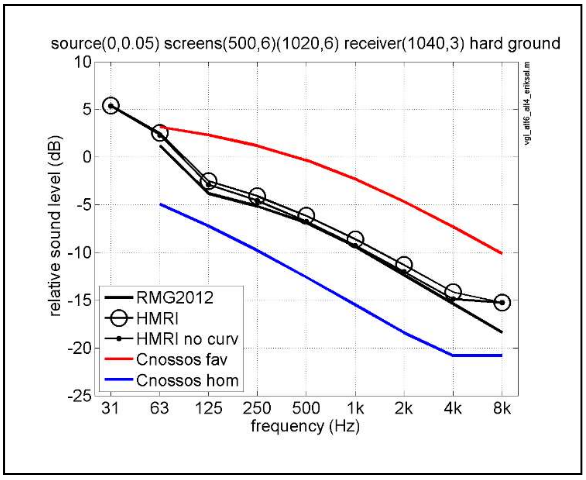

Figure 11a. As Fig. 10a with proposed solution.

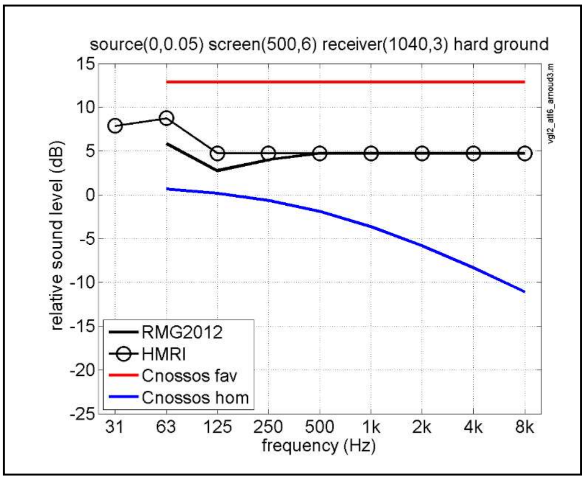

Figure 10b. Idem, with only the screen at 500 m.

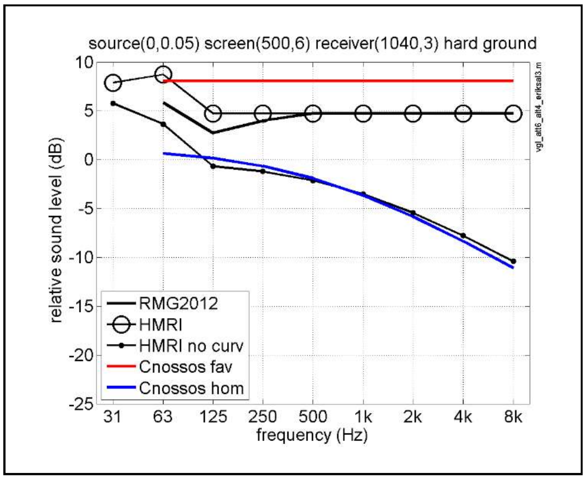

Figure 11b. As Fig. 10b with proposed solution.

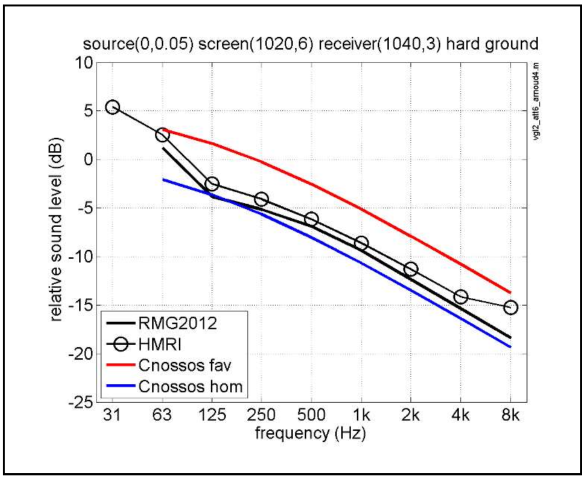

Figure 10c. Idem, with only the screen at 1020 m.

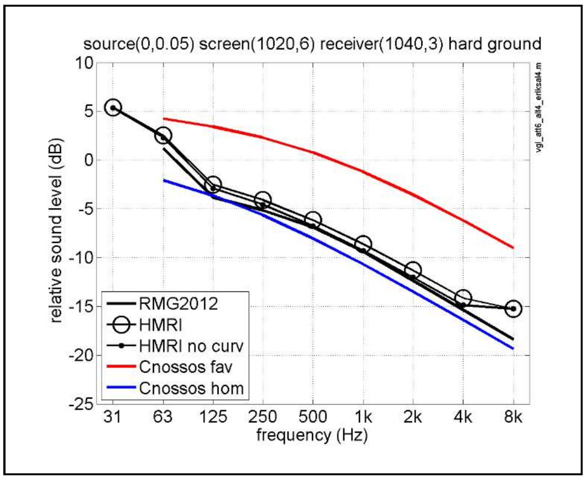

Figure 11c. As Fig. 10c with proposed solution.