From Theory to Practice: Advanced calculation methods applied in OTL – Terrain

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Introduction

Efficiency is a function of time and accuracy. Fast and inaccurate results could be more expensive to the acoustician than longer calculation times which provide more accuracy. So far, our community was relying on simplified and fast calculation methods to predict or simulate acoustical problems. This does not need to be the case anymore, since the advent of technology allows the implementation of complicated mathematical routines to be applied in commercial software. Such software provide accurate and detailed results. Moreover, complicated mathematics do not necessarily imply complicated tools for acoustical analysis. The Olive Tree Lab-Terrain software application implements state of the art and beyond advanced calculation methods in a user friendly environment to provide results at any level of sophistication necessary. In what follows we make reference to the theoretical models the software is based on and then how the effect of sound reflection is handled by simplified and advanced methods.

OTL–Terrain, Theoretical Background

Olive Tree Lab – Terrain [1] is a geometrical acoustics wave based software which simulates sound propagation using advanced calculation methods. It utilizes sound ray modelling which solves Helmholtz's sound wave equation and accounts for recursive sound diffraction and reflection to any order. Furthermore, it accounts for reflection from finite size surfaces of finite impedance using Fresnel zones and spherical wave reflection coefficient concepts, respectively. The latter allows the analysis of the Ground Wave. Furthermore, it takes into account coherent and incoherent source contribution, distance attenuation, atmospheric absorption, and atmospheric turbulence. These embedded features allow the study of wave interference phenomena in resolutions down to 0.001Hz within a range of 0.001 Hz to 100kHz. Furthermore, it provides Impulse Response and Auralisation.

OTL-Terrain is based on the work of Salomons [2] who applies a ray model using analytical solutions. Spherical wave diffraction coefficients are given by Hadden and Pierce [3]. Spherical wave reflection coefficients are based on the work of Chessel and Embleton [4], while ground impedance is based on the Delany and Basley model [5]. Finite size reflectors Fresnel zones contribution is taken into account by applying the work of Clay [6]. The atmospheric turbulence model used is based on Harmonise [7]. The Sound Path Explorer (SPE), a module used by OTL – Terrain, is an in-house developed algorithm to detect valid diffraction and reflection sound paths from source to receiver in a proper 3D environment [1]. Sound path detection is based on the image source method and the Geometrical Theory of Diffraction according to Keller [8].

Sound Reflection at a receiver

Due to limited space and also due to the fact that all of the readers are well acquainted with sound reflection, this topic is presented in detail to demonstrate the weaknesses of using simplified methods.
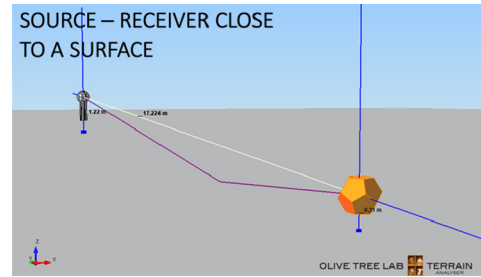

Figure 1: Source-Receiver close to an infinite surface of finite impedance, flow resistivity of 200 kPa s m^{-2}.

Statistical, Plane and Spherical wave, Reflection Coefficients - Equations

The following equations represent the calculation of (1) the statistical reflection coefficient, ρ [9], (2) the plane wave reflection coefficient, R_p [4], (3) the spherical reflection coefficient, Q [4].

$$\rho = 1 - a \tag{1}$$

$$R_p = \frac{Z_m \cos\theta - \rho c}{Z_m \cos\theta + \rho c} \tag{2}$$

$$Q = R_p + (1 - R_p)F(w) \tag{3}$$

α = statistical absorption coefficient, Z_m=surface impedance, θ=angle of incidence, ρc=characteristic impedance, for full description of $F(w)$ please see [4].

Comparison of ρ, R_p and Q results at a receiver

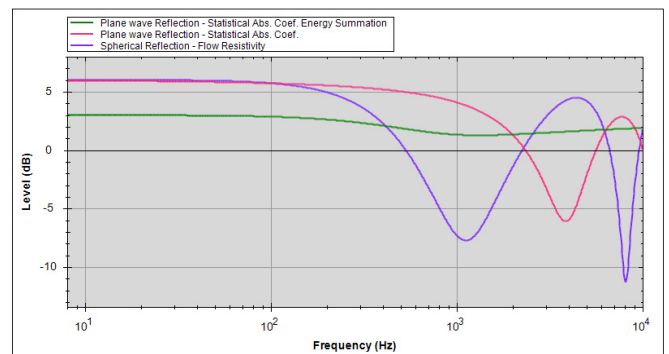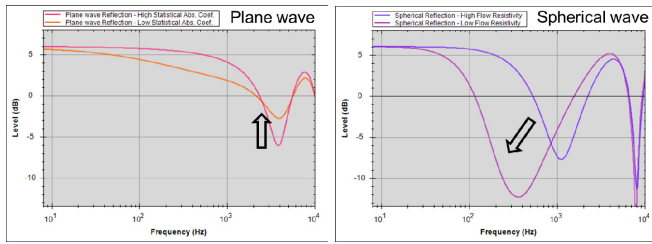All examples presented here were calculated using Olive Tree Lab – Terrain.

Figure 2: Statistical (ρ green), Plane (R_p, red) and Spherical (Q, purple) wave, Reflection Coefficients applied to the same material. Relative levels at the receiver.

From harder to softer materials, Rp vs Q

Figure 3: Comparison of performance between Plane (left) and Spherical (right) wave, Reflection Coefficients, from harder to softer materials. Relative levels at the receiver.

### Ground Wave: Source-Receiver on a surface where there is no plane wave sound reflection
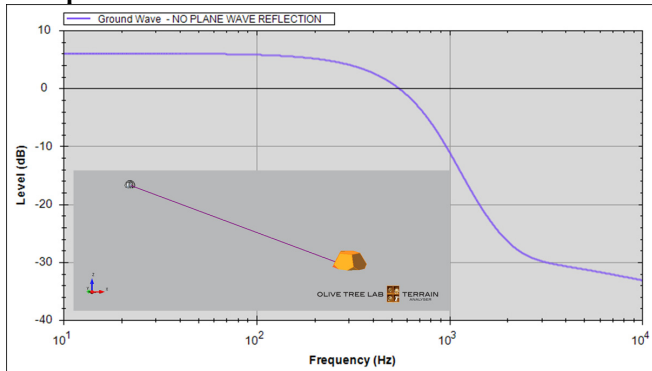
Figure 4: When both source and receiver lie on the same surface (flow resistivity of 10 kPa s m^{-2}), no plane wave reflection takes place, however, there is an "attenuation zone" due to the Ground Wave.

Finite size reflector correction using Fresnel zones
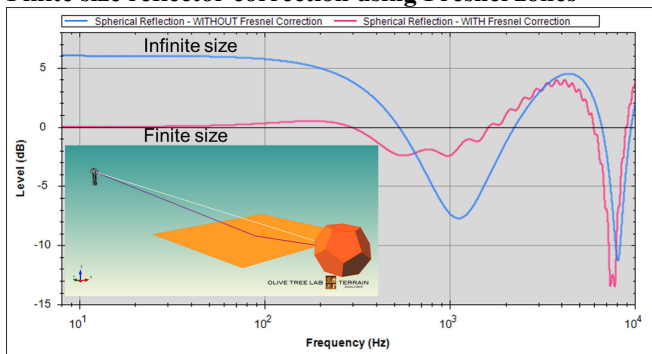
Figure 5: Comparison of relative levels at the receiver when finite size of reflector is taken into account.
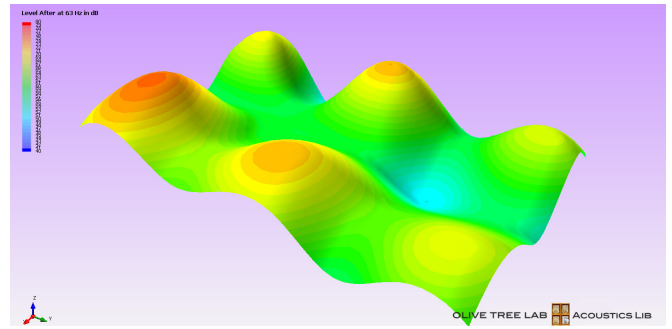
Impulse Response, Rp vs Q
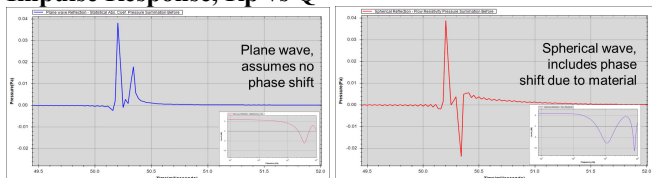
Figure 6: Comparison of IR at the receiver, between Plane (left) and Spherical (right) wave, where plane wave assumes no phase shift. Phase shift is evident with spherical wave, based on material properties and angle of incidence.

Spherical wave reflection , room resonances

Spherical wave propagation predicts room resonances [10].

Figure 7: Spatial sound distribution in a room showing room resonaces, based on spherical wave propagation in a room with finite impedance, using Olive Tree Lab-Terrain.

Conclusions

Nowadays technology allows the replacement of simplified calculation methods with advanced calculation methods, which offer the acoustical community of engineers and scientists with accuracy, practicality and efficiency.

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