DEUFRABASE: A German-French acoustic database on road pavements

Michel Berengier[a], Bettina Droste[b], Benoit Gauvreau[a], Denis Duhamel[c] and Markus Auerbach[b]

[a]Laboratoire Central des Ponts et Chaussées, Centre de Nantes - Route de Bouaye, BP 4129, 44341 Bouguenais cedex, France
[b]Bundesanstalt für Strassenwesen, Brüderstrasse 53, 51427 Bergisch Gladbach, Germany
[c]ENPC, UR Navier, 6 et 8 Avenue Blaise Pascal, Cité Descartes, Champs sur Marne, 77455 Marne la Vallée, France
michel.berengier@lcpc.fr

In the framework of a DEUFRAKO (German/French cooperation) project on the Prediction and Propagation of Rolling Noise (P2RN), it has been proposed to rank the different German and French road pavements with respect to noise for different long distance configurations representative of real road topographies, ground characteristics and meteorological situations. After identification of those typical 30 configurations, the attenuations between a reference point in the near field and several receiving points in the far field have been computed according to the most relevant and adapted modelling methods currently available. The main goal being the accuracy of the prediction and not the computation time, analytical (ray tracing) and numerical (BEM, Parabolic Equation) approaches have been implemented.
In the following, a technique permitting to estimate day and night LAeq and Lden has been used to classify the various pavements for the whole configurations. All those results have been gathered in a common database (DEUFRABASE) which will be directly available on the website of the authors' Institutes.
The paper deals with the description of the ranking procedures, how the database is implemented on the web and how to use it for road traffic noise prediction.

1 Introduction

In recent surveys, traffic noise is still considered as one of the most important source of discomfort by neighbouring populations of urban and high-trafficked roads. Even if acoustical reinforcements of building façades and noise barriers are most often used to control and abate traffic noise, low noise pavements, currently studied and/or developed in France and Germany should permit to reduce traffic noise of a few decibels. Some interesting abatements in terms of maximum pass-by sound pressure levels (LAmax) have been already identified for some pavement families and simple configurations only. From those first conclusions, it was interesting to analyze the behaviour of new types of pavements for more complex situations where ground and meteorological effects can widely influence traffic noise propagation. To simulate a large number of road and environmental configurations, ten cases corresponding to 30 different configurations have been selected. Depending on their complexity and in order to optimize the accuracy/computing time ratio, calculations have been carried out with analytical or numerical models. All the excess attenuations finally obtained are used as input data of a pavement ranking procedure in the far field, in terms of Lden. After implementation of this procedure to the whole current and future French and German pavements and for the various geometrical and meteorological conditions, a large set of data are obtained and gathered in a common database (DEUFRABASE) which will be directly accessible on the main partner websites.

2 Geometrical configurations and calculation procedures

In order to simulate realistic road, neighbouring grounds and meteorological situations, several characteristic parameters have been selected. They are presented in the following Tables 1 and 2. The data finally obtained after computation are introduced in the ranking process.

2.1 Configurations and input parameters

In the following configurations detailed in Table 1, case 1a,b is the reference standardized configuration [1].

Case	Geometrical configuration
1-a	Flat and homogeneous ground Short distance
1-b	Flat and mixed ground with an impedance discontinuity Short distance
1-c	Flat and homogeneous ground Long distance
1-d	Flat and mixed ground with an impedance discontinuity Long distance
2-a	Upslope and homogeneous ground
2-b	Upslope and mixed ground with impedance discontinuity
3-a	Downslope and homogeneous ground
3-b	Downslope and mixed ground with impedance discontinuity
4-a	Noise barrier and homogeneous ground
4-b	Noise barrier and mixed ground with impedance discontinuity

Table 1 Geometrical road configurations

Concerning the input parameters (cf. Table 2), the ground impedances Z are estimated, for the locally reacting surfaces, by the Delany and Bazley one-parameter (σ) model [2] or by the phenomenological three parameter (σ, Ω and q^2) model [3] for the porous road surfaces. σ representing the specific airflow resistivity, Ω the porosity and q^2 the tortuosity. The following values of the characteristic parameters have been considered: for the grass: $\sigma = 200$ kNsm^{-4} and for the Porous Asphalt (P.A.): $\sigma = 10$ kNsm^{-4}, $\Omega = 25$ %, $q^2 = 3.5$. The source height h_S is 0.05 m [4] and the temperature T is 20°C.

Concerning the meteorological conditions, the vertical sound velocity gradient $\partial c/\partial h = 0$ corresponds to a homogeneous condition which mainly occurs at sunset or sunrise. For calculation purposes, we shall keep $\partial c/\partial h = 0$ all over daytime. $\partial c/\partial h > 0$ concerns a favourable condition mainly occurring during night time. Depending on the geometrical configuration and the computation convergence, $\partial c/\partial h$ has been taken between 0.15 and 0.25 that corresponds to a rather strong effect.

Case	Input parameters
1-a	$Z \rightarrow \infty$; Z (Grass) and Z (P. A.) h_R = 1.20 m and d(S,R) = 7.50 m $\partial c/\partial h = 0$
1-b	$Z \rightarrow \infty$ and Z (P. A.) ; Z (Grass) h_R = 1.20 m and d(S,R) = 7.50 m d(S, disc) = 4 m $\partial c/\partial h = 0$
1-c	$Z \rightarrow \infty$; Z (Grass) and Z (P. A.) h_R = 2 m and d(S,R) = 200 m $\partial c/\partial h = 0$ and $\partial c/\partial h > 0$
1-d	$Z_1 \rightarrow \infty$ and Z (P. A.); Z_2 (Grass) h_R = 2 m and d(S,R) = 200 m d(S, disc) = 4 m $\partial c/\partial h = 0$ and $\partial c/\partial h > 0$
2-a	$Z \rightarrow \infty$ h_R = 2 m/receiver level d(S,slope) = 4 m h_{slope} = 1.5 m and θ = 8° $\partial c/\partial h = 0$ for d(S,R) = 50 m $\partial c/\partial h > 0$ for d(S,R) = 100 m
2-b	$Z_1 \rightarrow \infty$ and Z (P.A.) ; Z_2 (Grass) h_R = 2 m/receiver level d(S,slope) = 4 m h_{slope} = 1.5 m and θ = 8° $\partial c/\partial h = 0$ for d(S,R) = 50 m $\partial c/\partial h > 0$ for d(S,R) = 100 m
3-a	$Z \rightarrow \infty$ h_R = 2 m/receiver level d(S,slope) = 4 m h_{slope} = 1.5 m and θ = 8° $\partial c/\partial h = 0$ for d(S,R) = 50 m $\partial c/\partial h > 0$ for d(S,R) = 100 m
3-b	$Z_1 \rightarrow \infty$ and Z (P.A.); Z_2 (Grass) h_R = 2 m/receiver level d(S,slope) = 4 m h_{slope} = 1.5 m and θ = 8° $\partial c/\partial h = 0$ for d(S,R) = 50 m $\partial c/\partial h > 0$ for d(S,R) = 100 m
4-a	$Z \rightarrow \infty$ $\partial c/\partial h = 0$ h_R = 3 m and $h_{barrier}$ = 2 m d(S,barrier) = 4 m d(barrier,R) = 40 m
4-b	$Z_1 \rightarrow \infty$ and Z (P.A.); Z_2 (Grass) $\partial c/\partial h = 0$ h_R = 3 m and $h_{barrier}$ = 2 m d(S,barrier) = 4 m d(barrier,R) = 40 m

Table 2 Input parameters

2.2 Calculating procedures

Depending on the complexity of the situation, from geometrical and micrometeorological points of view, several theoretical approaches can be used [5].

For simple cases (1a, 1b, 1c and 1d) analytical models based on the ray tracing theory are adapted. With those models, heterogeneous grounds and noise barriers [6] with simple atmospheric effects (homogeneous and favourable conditions) can be easily investigated.

For more complex situations (cases 2 to 4) numerical approaches are needed. Different methods can be used to calculate the sound propagation in the atmosphere. One is based on a Boundary Element formulation [7-8] and the other on the Parabolic Equation formulation [9]. On one hand, the Boundary Element Method (BEM) is quite accurate for solving the equation of sound propagation in a homogeneous non refracting atmosphere but on the other hand, it can lead to time consuming computations for long distance propagation. Another advantage is that it can deal with very complex shapes such as grounds with irregular profiles and with the presence of obstacles such as noise barriers. On the other hand, the Parabolic Equation seems to be the most appropriate to solve the problem of acoustic propagation above a mixed ground with topographical irregularities both in a refractive and turbulent atmosphere.

The computed excess attenuations that are used in the ranking procedure have widely been presented in [10].

3 Ranking procedure

3.1 LAeq calculation

This ranking procedure is based on the calculation of LAeq in front of the façades, function of the pass-by sound pressure level LAmax. Knowing the LAeq for the various day, evening and night periods, Lden can be estimated for each situation and each pavement family. This procedure [11] needs the knowledge of the following minimum informations :

- The traffic distribution during the day [6:00-18:00], evening [18:00-22:00] and night [22:00-6:00] periods for each vehicle class : passenger cars (n_{PC}) and heavy trucks (n_{HT}),
- the reference speed of each vehicle class (V_{Ref}),
- the A-weighted pass-by maximum sound pressure level LAmax (in global or third octave values) at a reference microphone located in the road vicinity, 7.50 m from the right lane axis and 1.20 m above the road surface (Case 1-a), for each vehicle class, according to the SPB method [1],
- the number and width of traffic lanes,
- Different input parameters detailed in Table 2,

From the LAmax, the LAeq[T] for the reference period T can be obtained from the general equation [12] :

$$\mathrm{LAeq}[T](V) = \mathrm{LA}\max(V) + 10 \cdot \lg_{10}\left(\frac{\pi D}{V \cdot T}\right) \qquad (1)$$

where D is the distance between the right lane axis and the reference microphone, T the reference period which is taken equal to 1 hour and V the mean speed of the flow which depends on the situation (urban or suburban).

Using Eq.(1), a first calculation is carried out at the reference microphone for the whole frequency range representative of traffic noise [100 Hz - 4 kHz]. Then, excess attenuations [Att (propagation)] between the reference microphone and the various receivers are computed as described in section 2.2. The final LAeq[T] at the receiver is then calculated by the following Eq. (2).

$$\text{LAeq}[\text{T}](\text{receiver}) = \text{LAeq}[\text{T}](\text{ref}) + \text{Att}(\text{propagation}) \qquad (2)$$

Knowing the LAeq[1hour] for one vehicle representative of each vehicle family (PC and HT), the LAeq[T](receiver) for a typical traffic flow on the various day, evening and night periods can be obtained by summation of the respective energies of each vehicle as follows :

$$\text{LAeq}[\text{T}](\text{receiver}) = 10 \cdot \lg_{10}\left[\frac{1}{\text{T}}\left(n_{PC} \cdot 10^{0.1 \text{LAeq}(\text{receiver}),\text{PC}} + n_{HT} \cdot 10^{0.1 \text{LAeq}(\text{receiver}),\text{HT}}\right)\right] \qquad (3)$$

where n_{PC} and n_{HT} are, respectively, the number of passenger cars and heavy trucks in the traffic flow during the period T. LAeq (receiver),PC and LAeq (receiver),HT are the LAeq at the receiver located in the far field, for one representative vehicle of each family on the reference period of 1 hour. When the receiver is very close to a reflecting façade, the reflection effect (+ 3 dB) has to be introduced accordingly at the very end of the procedure.

This procedure has been validated for free field conditions, by comparison between theoretical results and several experiments for a large number of pavement families [11]. The agreement was always within ± 2 dB(A) at 200m both for spectral and global LAeq.

3.2 Traffic data

The LAeq calculation needs the knowledge of the number of passenger cars and heavy trucks for every hour of the day. For this study, and to be as representative as possible of a yearly-averaged day, we only consider working days (from Monday till Friday). The data which are presented in the following Table 3 correspond to averaged light and heavy traffic distributions per driving lane based on measurements performed both in France on several points around the Nantes ring road and in Germany on nine different motorways. Table 4 finally details the vehicle distribution per lane for two representative road situations: (1 x 1) and (2 x 2) lanes.

Number of vehicles per lane	Percentage of HT	Distribution /type of vehicles	Global traffic (1 x 1)	Global traffic (2 x 2)
20 000	10 %	PC: 18 000 HT: 2 000	40 000	80 000
20 000	15 %	PC: 17 000 HT: 3 000	40 000	80 000
10 000	10 %	PC: 9 000 HT: 1 000	20 000	40 000
10 000	15 %	PC: 8 500 HT: 1 500	20 000	40 000

Table 3 Traffic classes

Number of lanes	PC distribution/lane	HT distribution/lane
(1 x 1)	100 %	100 %
(2 x 2)	Slow lane: 50 % Fast lane: 50 %	Slow lane: 90 % Fast lane: 10 %

Table 4 Vehicle distribution per lane

3.3 Pavement data

Table 5 shows all the French and German pavement surfaces which have been introduced in the ranking procedure. The average LAmax values have been measured at the reference point (7.50 m ; 1.20 m) according to the standard “Statistical Pass-By method”[1].

Pavement	PC LAmax (90 km/h)	PC LAmax (110 km/h)	HT LAmax (80 km/h)
TAC 0/6	72.7	75.3	-
PA 0/6	72.8	75.4	80.3
VTAC 0/6 – type 2	73.4	76.0	81.4
UTAC 0/6	74.1	76.7	83.5
PA 0/10	74.2	76.8	82.0
VTAC 0/6 –type 1	74.9	77.5	82.8
TLPA 0/8	*75.2*	*76.9*	*80.6*
VTAC 0/10 – type 2	75.3	77.9	82.6
PA 0/14	76.1	78.7	83.9
PA 0/8	*76.2*	*77.8*	*83.9*
VTAC 0/8 – type 1	76.2	78.8	82.6
TAC 0/10	77.6	80.2	85.6
SMA 0/5 ln	*78.0*	*80.3*	*87.5*
DAC 0/10 (F Ref)	**78.0**	**80.6**	**85.4**
SMA 0/8 ln	*78.3*	*80.3*	*85.6*
UTAC 0/10	78.3	81.0	84.4
SD	78.5	81.1	-
SD 6/8	78.6	81.2	-
CASS	78.6	81.2	85.3
SD 4/6	78.9	81.5	-
VTAC 0/10 – type 1	79.0	81.6	85.2
SD 6/10	80.0	82.6	85.9
DAC 0/14	80.0	82.7	86.2
SMA 0/8 S	*80.1*	*81.9*	*85.9*
GA 0/5 ln	*80.1*	*82.2*	*86.6*
VTAC 0/14	80.4	83.0	86.2
SMA 0/11	*80.8*	*82.9*	*86.9*
CC 0/16 Kamm	*80.9*	*82.7*	*87.9*
CC	*81.0*	*82.9*	*90.6*
EAC	*81.1*	*83.0*	*89.1*
CC	81.2	83.8	87.5
SMA 0/11 S	*81.4*	*83.4*	*87.5*
German Ref (Calc)	***81.5***	***84.1***	***-***
CCST	*81.6*	*83.6*	*89.7*
GA 0/5	*81.8*	*83.3*	*87.6*
EAC 0/5	*82.1*	*83.6*	*90.4*
SD 10/14	82.1	84.7	86.4
UTAC 0/14	82.1	84.7	-

Table 5 Pavement database (normal : French ; **normal bold : French reference** ; *italic : German* ; ***italic bold : German calculated reference***)

The meaning of the acronyms is given in Table 6.

Acronym	National Acronym	Meaning
TAC	BBM	Thin Asphalt Concrete
PA	BBDr/*OPA*	Porous Asphalt
VTAC	BBTM	Very Thin Asphalt Concrete
UTAC	BBUM	Ultra Thin Asphalt Concrete
TLPA	*ZWOPA*	*Two-Layer Porous Asphalt*
SMA	*SMA*	*Stone Mastic Asphalt*
DAC	BBSG	Dense Asphalt Concrete
SD	ES	Surface Dressing
CASS	ECF	Cold-Applied Slurry Surfacing
GA	*GA*	*Gussasphalt*
CC	BC/*ZB*	Cement Concrete
EAC	*WB*	*Exposed Aggregate Concrete*
CCST	*ZBKR*	*Cement Concrete treated with Synthetic Turf*

Table 6 Pavement determination (normal : French ; *italic : German*)

In Table 5, the numbers after the pavement acronym corresponds to the minimum/maximum size of the aggregates and the type is linked to the porosity properties. "type 1" means a porosity Ω lower or equal than 15 % and "type 2" a porosity Ω between 15 % and 25 %.

As an example, VTAC 0/6 – type 2 means a Very Thin Asphalt Concrete with aggregate sizes between 0 and 6 mm and, porosity close to 20 %.

3.4 Prediction code

Concerning the code, it has been written with *Python*™ programming language [13]. This tool is used because it is independent from the computer *Linux, Mac® or Windows®* operating systems. For the calculation, for each geometrical configuration we need the three following input files:

- SPB measurement spectrum,
- Excess attenuation,
- Hourly traffic distribution,

Afterwards, the procedure is divided in two parts. In the first part, a script calculates the LAeq for all given geometries, ground and atmospheric characteristics, pavements and traffic data, according to the structure detailed in Fig.1.

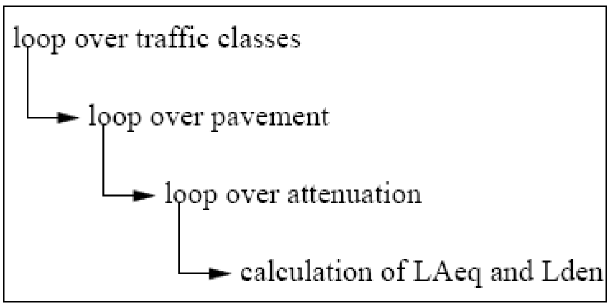

Fig.1. Structure of the code

Fig. 2. shows how the input files are introduced in the calculation procedure.

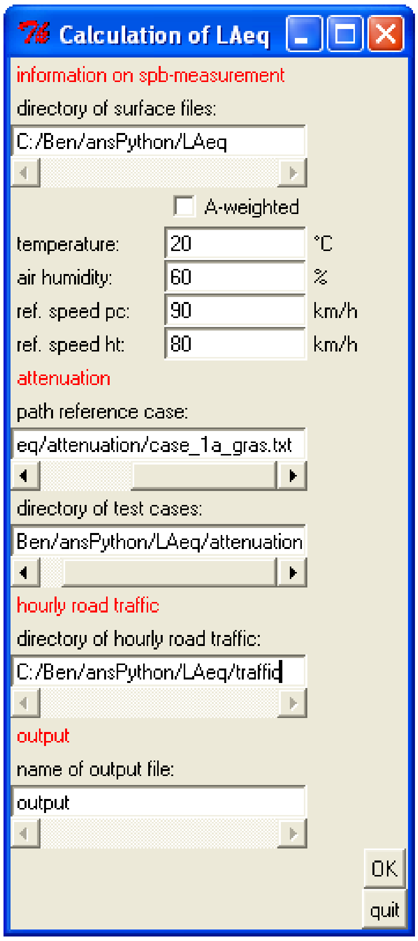

Fig.2. Input page

In the second part, a script visualizes the different results in bar plots: LAeq spectral evolution for one configuration on a selected period, hourly LAeq distribution for various geometrical configurations and pavements with the final Lden evaluation and finally, the Lden evolution for all the pavements and for each geometrical configuration. Fig. 3. and 4. give examples of the two last types of representation.

Data computed for all those combinations (around 130 000) constitute the common French/German DEUFRABASE.

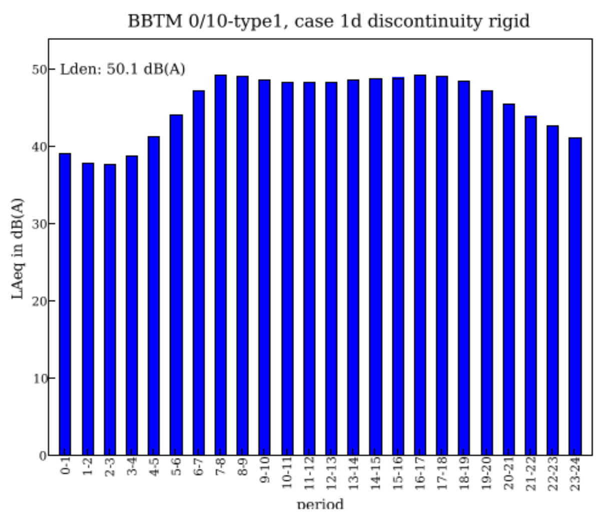

Fig.3. Hourly LAeq distribution: flat and mixed ground

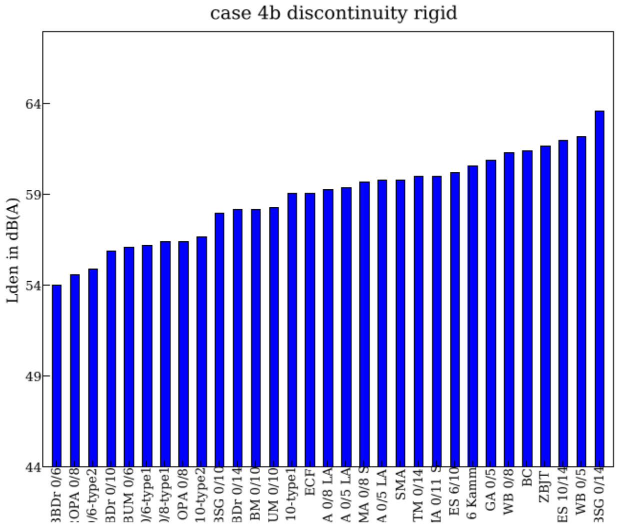

Fig.4. Lden evolution of the pavement database: noise barrier and mixed ground

4 How to use DEUFRABASE?

This database, built to be used by road companies, road authorities, consultants, engineers, etc. will be directly implemented in a first step on the BASt web-server (www.bast.de) and in a second step on the LCPC one (www.lcpc.fr) and freely accessible.
On the official BASt Homepage a separate page is dedicated to the DEUFRAKO-project. It can be found under "special subjects → traffic engineering → Prediction and propagation of rolling noise (P2RN)". From this page a link will direct the user to the page for the rolling noise calculation.

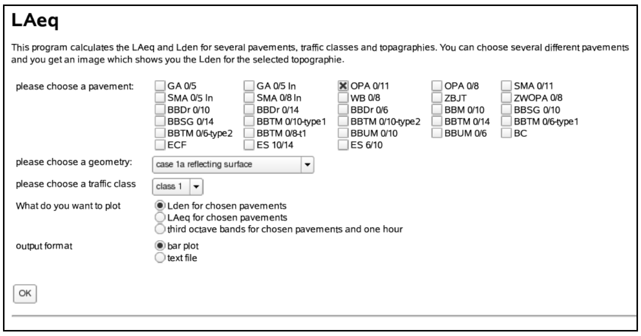

Fig.5. First β-version of the DEUFRABASE Home page

On this page (Fig. 5.), the user can choose one or more surfaces, one geometry and a traffic class. Then, he has the possibility to choose what kind of information he wants to get: Lden for the selected pavement, LAeq for each selected pavement for a whole day or spectra of the selected pavements for one particular hour. In addition to bar plots, as shown on Fig. 3. and 4., the output can be also a text file (.txt) including all the data.

5 Conclusion

Currently, the acoustic characteristic of road pavements were only known in terms of pass-by LAmax in the near field of the road (7.5 m) or in terms of CPX index [14] in the tyre near field. Such results are very interesting but need to be completed to characterize the pavement acoustic impact in the neighbours' vicinity. That was one of the aims of this project "P2RN". After validation of the excess attenuation predictions, a special tool has been built to help the user in identifying the noise impact of road pavements whatever the geometrical configuration of the road and the receiver location. After calculation of a very large number of possible combinations, a common French and German database (DEUFRABASE) is born. It permits by a few "mouse clicks" to obtain basic information which can be helpful to select the right pavement for a specific situation.

Acknowledgments

The authors would thank ADEME and the German Federal Ministry of Economics and Technology for their financial support in the frame of the DEUFRAKO Programme.

References

[1] EN-ISO 11819-1, "Acoustics - Method for measuring the influence of road surfaces on traffic noise - Part 1: The Statistical Pass-By Method", (1997)
[2] M. E. Delany, E. N Bazley, "Acoustical properties of fibrous absorbent materials", *Appl. Acoust.* 3, 105-116 (1970)
[3] J.F. Hamet, M. Bérengier, "Acoustical characteristics of porous pavements : a new phenomenological model", *Internoise 93*, Leuven, Belgium, (1993)
[4] J.F. Hamet, M.A.A Pallas, D. Gaulin, M. Bérengier, "Acoustic modelling of road vehicles for traffic noise prediction: Determination of the sources heights", *16th ICA*, Seattle, USA, (1998)
[5] M. Bérengier, B. Gauvreau, Ph. Blanc-Benon, D. Juvé, "Outdoor sound propagation: A short review on analytical and numerical approaches", *Acta Acustica united with Acustica* 89, 980-991 (2003)
[6] K.B. Rasmussen, "A note on the calculation of sound propagation over impedance jumps and screens", *J. Sound and Vib.* 84, 598-602 (1982)
[7] M. Bonnet, "Boundary integral equation methods for solids and fluids", Chichester, England, (1995)
[8] F. Anfosso-Lédée, P. Dangla, M. Bérengier, "Sound propagation above a porous road surface with extended reaction by boundary element method", *J. Acoust. Soc. Am.*, 122, 731-736 (2007).
[9] B. Lihoreau, B. Gauvreau, Ph. Blanc-Benon, I. Calmet, M. Bérengier, "Outdoor sound propagation modeling in realistic environments: Application of coupled parabolic and atmospheric models", *J. Acoust. Soc. Am.*, 120, 110-119 (2006).
[10] M. Bérengier, D. Duhamel, B. Gauvreau, B. Droste, M. Auerbach, "A Benchmark on analytical and numerical models for road traffic noise propagation", *ICA 2007*, Madrid, Spain, (2007)
[11] M. Bérengier, Y. Pichaud, J.-F. Le Fur, "Effect of low noise pavements on traffic noise propagation over large distances: influence of ground and atmospheric conditions", *Internoise 2000*, Nice, France, (2000)
[12] M.C. Bérengier, J.F. Hamet, "Acoustic classification of road pavements : ranking differences due to distance from the road", *Heavy Vehicle Systems, Int. J. of Vehicle Design*, 6, 13-27 (1999)
[13] http://www.python.org
[14] ISO CD 11819-2, "Acoustics - Method for measuring the influence of road surfaces on traffic noise - Part 2: The Close Proximity Method", (2007)