Experimental confrontation of medium-heavy vehicle noise emission to the CNOSSOS-EU prediction method

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Summary
CNOSSOS-EU is the common European assessment method recommended for environmental noise prediction. Concerning road traffic noise, the sound power emission of road vehicles is described by the contribution of a propulsion noise component and a rolling noise component, according to a common approach to all vehicle types but with coefficients specific to vehicle categories. Default input values are provided in the European Directive 2015/996. Member States are invited to adapt these values to be representative of their national conditions if necessary.
Vehicle category 2 concerns medium-heavy vehicles, having two axles and a minimum weight of 3.5 tons. The French reference prediction method NMPB2008 does not distinguish these vehicles within the overall heavy vehicle category and no noise emission database is presently available for this subcategory. A series of experiments has been started to collect noise data from medium heavy vehicles on French roads and vehicle fleet through SPB measurement on traffic vehicles. This is completed by CPB measurements on controlled vehicles, which offers the opportunity to separate propulsion and rolling noise contributions.
The first results of this experimental approach are presented. They suggest that the French reference method NMPB2008, relying on road train emission data, overestimates the actual noise emission from vehicle category 2, whereas default input values of CNOSSOS-EU clearly underestimates it. The relative share of rolling noise and propulsion noise contributions is discussed.

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1. Introduction

The European Directive 2002/49/EC of 25 June 2002 on the assessment and management of environmental noise [1] requires Member States to produce noise maps assessing exposure to environmental noise. It was supplemented in May 2015 by the Directive 2015/996 [2] specifying a common assessment method for all Member States (CNOSSOS-EU) to be implemented by 31 December 2018.The common assessment method addresses road, rail, industry and aircraft noise sources. For terrestrial noise sources the model features emission models and a common propagation model.
The study presented here concerns road traffic noise only, and in particular the noise emission model of medium heavy vehicles (category 2). Recent observations have highlighted significant discrepancies between French measurements carried out on category 2 vehicles and the levels assessed by the European CNOSSOS-EU model [3]. Moreover, since the CNOSSOS-EU model does not provide correction coefficients for pavements representative of the French road network, an adaptation of the method to the French road context is necessary. Thus, Cerema proposed adapting the European model to national road surfaces on the basis of the current French prediction method NMPB2008 [4]. However, it was not possible to propose pavement corrections for EU vehicle category 2 since there is no equivalent for this category in the French model. In the French model, category 2 is implicitly included in the category "PL" (heavy vehicles, more than 3.5t) but explicitly unrepresented in the French rolling noise database.

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A study has been started in order to:

- carry out pass-by noise measurements on medium-heavy vehicles to populate the French rolling noise database for this category,
- compare noise measurements on traffic or controlled vehicles with the French and European models in this category,
- propose a model appropriate to medium-heavy vehicles traveling on French roads if necessary.

The present paper is part of the current study and compares the noise prediction models with the actual noise radiated by medium-heavy vehicles measured on several road surfaces. Both traffic and controlled vehicle pass-bys have been measured. First, the main items of the French and European prediction methods are underlined (section 2). Section 3 presents the approach implemented on traffic vehicles and the main observations on the overall noise. Section 4 is devoted to the controlled vehicles and highlights the propulsion and rolling noise contributions. Both approaches include measurement/model comparisons.

2. Noise prediction models for heavy vehicles

2.1. The European CNOSSOS-EU method

The CNOSSOS-EU emission model considers four categories of road vehicles according to their mass and number of axles [2], including:

- category 2: medium tonnage vehicles with a mass exceeding 3.5t, equipped with 2 axles and twin wheels on the rear axle,
- category 3: heavy vehicles with a mass exceeding 3.5t and equipped with at least 3 axles.

Category 2, which is the focus of this study, includes delivery trucks as well as construction site trucks, buses and coaches, as long as they have two axles.

In the CNOSSOS-EU model, a vehicle is represented by a single point source, located 0.05 m above the ground. The sound power of the equivalent source is given in dB per octave band from 63 Hz to 8000 Hz, in reference conditions corresponding in particular to a constant driving speed, a flat and dry road, an air temperature of 20°C, a virtual reference road pavement corresponding to an average of DAC 0/11 and SMA 0/11. When the actual conditions differ from these reference conditions, corrective terms must be used.

In each octave i, the total sound power $L_{WT,i}$ radiated by the equivalent point source is the sum of a propulsion noise component $L_{WP,i}$ and a rolling noise component $L_{WR,i}$, both functions of vehicle speed v:

$$L_{WT,i}(v) = L_{WR,i}(v) \oplus L_{WP,i}(v) \qquad (1)$$

The operator $\oplus$ represents the energetic sum and:

$$L_{WR,i}(v) = A_{R,i} + B_{R,i} \log\left(\frac{v}{v_0}\right) \qquad (2)$$

$$L_{WP,i}(v) = A_{P,i} + B_{P,i} \frac{v - v_0}{v_0} \qquad (3)$$

The coefficients $A_{P,i}$, $B_{P,i}$, $A_{R,i}$ and $B_{R,i}$ are tabulated in [2] and v_0 is a reference speed.

Corrective terms are important parameters, in particular those relating to road surfaces which constitute the main lever for adapting the method to the French surfaces. Road surface corrective terms of rolling noise $\Delta L_{WR,road,i}$ and propulsion noise $\Delta L_{WP,road,i}$ are respectively defined by:

$$\Delta L_{WR,road,i}(v) = \alpha_i + \beta \log\left(\frac{v}{v_0}\right)$$

$$\Delta L_{WP,road,i}(v) = \min\{\alpha_i; 0\}$$

where the correction on propulsion noise renders the absorption effect of a porous road surface.

2.2. The French NMPB2008 method

NMPB2008 is the French road noise prediction method. In addition to its use for impact assessment studies, it has been implemented for the production of strategic noise maps before the availability of CNOSSOS-EU. Beside light vehicles (LV), NMPB2008 considers only one category of heavy vehicles (HV), with a tonnage greater than 3.5t [5]. Representing any vehicle as a point source located at a height of 0.05m [6], it provides global noise emission equations for three categories of road pavements (R1, R2, R3) [5], the spectral distribution being specific either to non-drainage or drainage road surfaces.

The global noise level is the energetic sum of a power unit noise component and a rolling noise component (in accordance with equation 1), each component level increasing linearly with $\log(v)$ (thus differing from equation 2 for power unit noise).

The noise emission data supporting the NMPB2008 model are based on i) a large set of measurements available in the French rolling noise database for the rolling noise component and ii) derived from measurements on a sample of controlled vehicles for the power unit noise. Actually, the heavy vehicle data collected concern only trucks with 4 axles or more. There is no database available for heavy vehicles with fewer axles. Thus, this NMPB2008 HV category identifies with category 3 of CNOSSOS-EU. Other subcategories of heavy vehicles (like 2-axle trucks or buses) are treated as equivalent to this one, the method being declared still acceptable as far as their proportion in the traffic remains moderate [7].

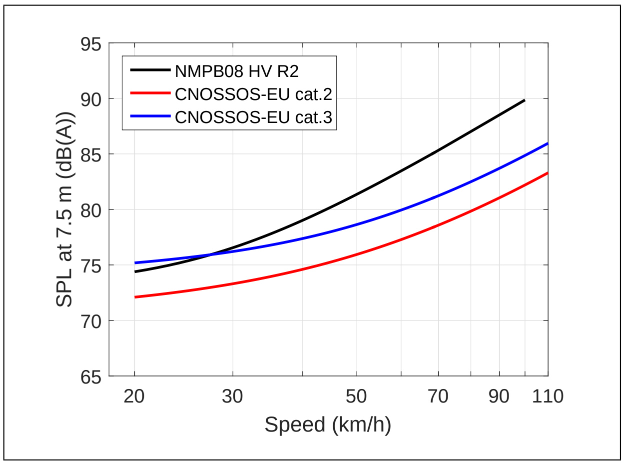

Figure 1. Global overall emission noise prediction by NMPB2008 for a heavy vehicle on a category R2 non-drainage road surface (black), for a vehicle of category 2 (red) and category 3 (blue) of CNOSSOS-EU in reference conditions.

2.3. The adaptation of CNOSSOS-EU to French roads and the issue of vehicle category 2

The acoustic quantity used throughout this paper is the L_{Amax} at the standard position (distance 7.5m, height 1.2m) for an individual vehicle passing-by at a constant speed.

In a basic comparison of CNOSSOS-EU and NMPB2008 vehicle noise emission models, the virtual reference road surface of CNOSSOS-EU may be assimilated to a non-drainage R2 road in NMPB2008. Everything else being equal, road age differences are disregarded here (a 7-year old pavement would require a -0.45 dB(A) correction for heavy vehicles in NMPB2008). Figure 1 displays the noise levels derived respectively from NMPB2008 for a heavy truck, from CNOSSOS-EU for a category 2 and a category 3 vehicle, highlighting significant discrepancies between the French and the European models under otherwise similar conditions.

Furthermore, Annex F-4 of the European Directive 2015/996 tabulates coefficients to be applied for correcting vehicle noise emission on 14 types of road surfaces, listing identical coefficients for the categories 2 and 3 in every case. Unfortunately, these road surfaces are not representative of those used in France and an adaptation of CNOSSOS-EU to the French road context is required.

In accordance with the CNOSSOS-EU approach, it was proposed to determine appropriate correcting coefficients for the three road surface categories (R1, R2, R3, either drainage or non-drainage) in use in the French NMPB2008, for the CNOSSOS-EU vehicle categories 1 and 3 which coincide with the two NMPB2008 categories respectively. This has been carried out in each octave band by fitting the road corrected CNOSSOS-EU equation to the ad hoc NMPB2008 equation, as described in [4]. In the present paper, we call CNOSSOS-FR the model coming from the approach developed in section 5 of [4].

Since there is no specific NMPB2008 model available for cat.2 vehicles and, as will be shown later, the NMPB2008 HV model does not match actual cat.2 noise levels correctly, this fitting procedure is not possible for this category.

Table I. Road surface, speed range and number of cat.2 vehicles measured on each site.

Site number	Road surface	Speed range (km/h)	Nb veh.
1	BBTM 0/6 t.2	39-89	12
2	DAC 0/10	36-88	29
3	SMA 0/10	65-92	34

3. Noise emission from medium-heavy traffic vehicles

We consider pass-by noise measurements carried out on traffic vehicles on three different road surfaces. After describing the experiment and dataset, as well as the quantities supporting the comparison, the confrontation measurements/models is presented and discussed.

3.1. Experiment and measurement sites

The experiment is conducted in the same way on each site, in accordance with the Statistical Pass-By (SPB) procedure specified in the standard ISO 11819-1. The sound pressure is measured by a roadside microphone located at 7.5 m from the lane axis. The A-weighted maximum sound pressure level (L_{Amax}) is determined, in global level and octave bands, at the pass-by of isolated cat.2 vehicles running at constant speed on the road. This approach gives an overview of the overall noise emission from traffic vehicles but does not separate propulsion and rolling noise contributions. The vehicle speed is determined from two laser beams successively cut by the vehicles. Three sites with different road surfaces have been investigated. The road surface BBTM 0/6 type 2 is a partially absorbing surface. The road surfaces DAC 0/10 and SMA 0/10 are dense surfaces, the former being a very common surface in France. Details on the dataset available for each measurement site are given in Table I.

3.2. Approach supporting the measurements/models comparison

For each measurement site, a comparison is presented in figures displaying:

- the measurement results represented by a points cloud, each point corresponding to the L_{Amax} of one traffic cat.2 vehicle at the pass-by speed;
- the NMPB2008 model for the appropriate road surface category;
- a derivation of the CNOSSOS-FR model for cat.2 and the appropriate road surface category, as described below;
- the CNOSSOS-EU model for cat.2 with a specific correction adapted to the road surface and based on *Deufrabase*, as described below.

Comparison basis with NMPB2008 In the French NMPB2008 classification, all road surfaces involved on the three measurement sites are considered as non-drainage. The pavement BBTM 0/6 type 2 is related to the R1 category, whereas DAC 0/10 and SMA 0/10 belong to the R2 category.

Comparison basis with a derivation of CNOSSOS-FR (labelled CNOSSOS-FRa here) As a temptative compromise until a better knowledge of medium heavy vehicles on French roads is available, we apply here the same corrective coefficients as those calculated for category 3 in [4] to the general CNOSSOS-EU cat.2 equation. Thus, this follows the same approach as the road surfaces listed in Annex F-4 of the European Directive. The road surface categories are identical to NMPB2008.

Comparison basis with CNOSSOS-EU (labelled CNOSSOS-EUcorr here) In the absence of available correcting terms, the question of how to directly compare the CNOSSOS European model – involving a virtual reference road surface – with actual SPB measurements on the site road surfaces is raised. The objective here is to introduce a correction term as close as possible to the reality of each site surface. It should be noted that this corrective approach differs from that of the French adaptation developped in [4], which considers quite broad road surface categories for strategic noise maps and impact studies. In the present illustration, a correction specific to each of the three road surfaces is desired.

For this field context, the procedure is based on *Deufrabase*, an open tool developed by IFSTTAR and BASt and based on the existing rolling noise measurement databases available in France and Germany [8][9]. It offers the possibility of calculating several acoustic indicators to evaluate and compare traffic noise on 32 road surfaces – representative of the surfaces in use in both countries – under various traffic conditions and environmental configurations.

The rolling noise correction terms are determined as follows:

1. *Deufrabase* is used for the CNOSSOS-EU reference road surface (resp. the measuring site road surface) with the following parameters:
   - receiver at 7.5 m without surface discontinuity and without temperature gradient,
   - one lane per direction,
   - traffic with one heavy vehicle per direction (default speed 80 km/h), no light vehicle,
   - calculated indicator $L_{Aeq,1h}$

   The reference road surface of CNOSSOS-EU being virtual, therefore not listed in *Deufrabase*, it is approached by the SMA 0/11 surface. The result obtained via *Deufrabase* is the third octave spectrum from 100 Hz to 4000 Hz, at 80 km/h. The spectrum per octave band is then deduced, from the octave 125 Hz to the octave 4000 Hz[1].
2. The difference between the L_{Amax} of both road surface, all other things being equal and regardless of the volume of traffic, is equal to the difference of the $L_{Aeq,1h}$. Therefore, the correction term per octave band at 80 km/h is the difference between the respective "*Deufrabase* spectra" of the measurement site road surface and the reference road surface.
3. The coefficient β reflecting the effect of speed on the corrective term, is identical at all frequencies in CNOSSOS-EU. For the three sites tested here, the actual value of β is unknown. It is assumed to be equal to 0, which is in accordance with the hypothesis stated for NMPB2008 that speed modifies the level but not the shape of the spectrum [7].

The heavy vehicles represented in the French databases referring only to vehicles of category 3, a further assumption used here implies that the differences in noise behaviour between road surfaces are similar for categories 2 and 3.

As for propulsion noise, the corrective terms concern only surfaces with sound-absorbing properties. The correction principle of the CNOSSOS-EU method consists in applying to propulsion noise the same correction coefficient (relative to the reference road surface) as that of rolling noise, in the only octaves where absorption occurs ($\alpha_i < 0$). A disadvantage of this approach is that it does not make a distinction between the variation of rolling noise due to roughness changes with respect to the reference surface and the one due to the absorption effect. It seems more appropriate here to ascribe to propulsion noise the sole effect of absorption. This is estimated by comparing two similar pavement types having the same mix design and granulometry, one dense and the other absorbent. Following the same principle as CNOSSOS-EU, only octave bands where this term is negative will be corrected.

Thus, the corrective terms for a BBTM 0/6 type 2 pavement (with absorption properties) are determined with *Deufrabase* by difference of the BBTM 0/6 type 2 and SMA 0/11 spectra for rolling noise, and by difference of the BBTM 0/6 type 2 and BBTM 0/6 type 1 (almost reflective) spectra for propulsion noise.

[1] The third-octave 5000 Hz contribution is extrapolated, with only a minor effect.

Corrective terms for the measurement sites in this report are listed in Table II. As SMA 0/10 pavement is not yet widely used in France, thus not yet listed in *Deufrabase*, it will be directly compared to the reference road surface, without corrective term.

3.3. Confrontation of the measurements to the models

The sound pressure levels measured at the traffic cat.2 vehicle pass-bys are displayed on Figures 2 to 4 for each site respectively, together with the models described in section 3.2. We can note the wide dispersion of noise levels on sites 2 and 3 despite a limited speed range. This may be compared with the diversity of traffic types on these sites (about 50 % of van-type trucks and 30 % of tank/dump trucks on site 2, 68 % of van-type trucks and 20 % of tank/dump trucks on site 3, versus 83 % of van-type trucks on site 1). Although a connection exists between truck type and noise level, this relation is not systematic.

This dispersion comes from the noise contribution of octaves 250 Hz and 500 Hz (Figure 5). A previous study suspected the involvement of the drive wheel zone to this behaviour [10].

For all three sites the NMPB2008 model overestimates the actual cat.2 vehicle global noise levels, with a greater difference for site 1. The frequency analysis points out that this occurs in most frequency bands. However, it was verified elsewhere that the model agrees with vehicles of category 3 (heavy vehicles with at least three axles) on sites 2 and 3, which is in accordance with the heavy vehicles underlying the French model, although still a little too high on site 1. This latter finding would mean that site 1 offers a rather low-noise road surface within the R1 category. Anyway, it turns out that medium-heavy vehicles are not well represented by the NMPB2008 model on the sites investigated, with a global overvaluation of 2-5 dB(A) at moderate and high speeds.

On the contrary, the original CNOSSOS-EU model significantly undervalues the cat.2 global noise levels on the three sites by 3-6 dB(A), mostly due to medium frequencies. In particular, the rolling noise component seems clearly understated, which has also been verified for the heavier vehicles (cat.3), confirming the need for a significant correction of the European model for French roads.

Finally, the CNOSSOS-FRa model correctly depicts both R2 sites in global levels in the limited speed range investigated, despite differences in some frequency bands. The overvaluation of about 2 dB(A) observed over the measurement speed range on site 1 comes from frequency bands above 1000 Hz.

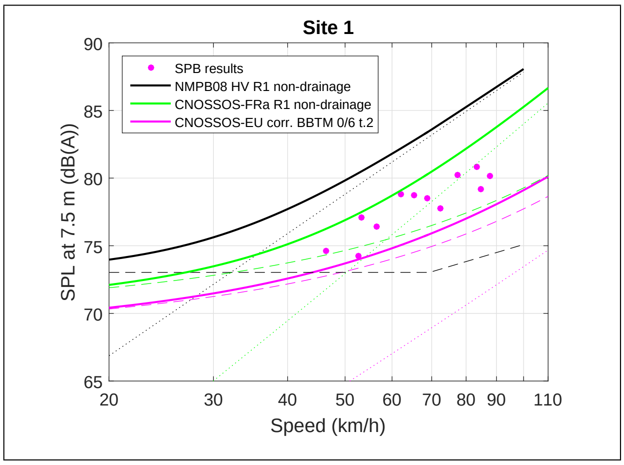

Figure 2. Confrontation of the global SPB results to the various models for site 1. Overall sound pressure level (solid curve). Rolling noise component (dotted curve). Propulsion noise component (dashed curve).

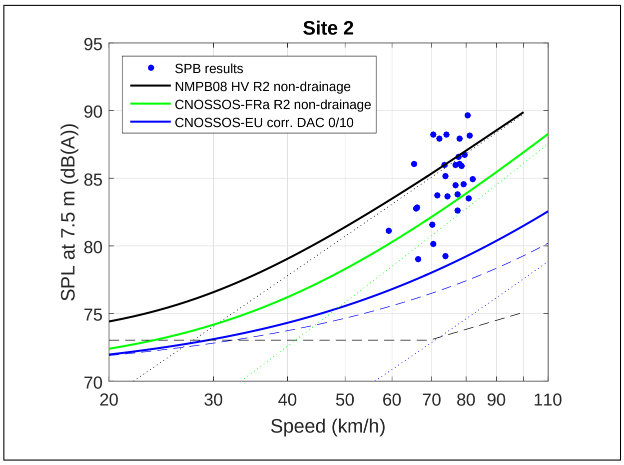

Figure 3. Idem for site 2. The propulsion noise components are identical for CNOSSOS-EU and CNOSSOS-FRa.

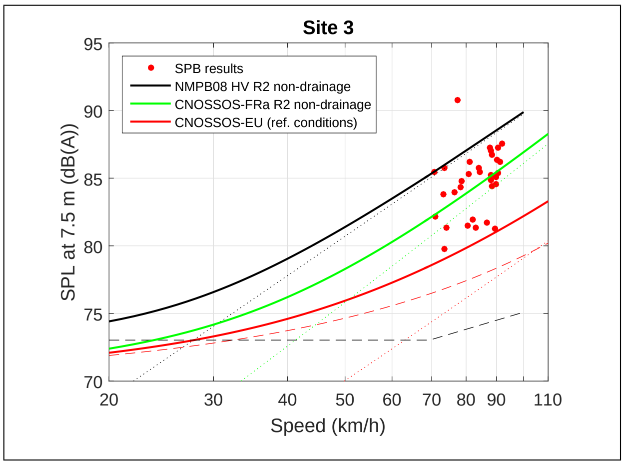

Figure 4. Idem for site 3. The propulsion noise components are identical for CNOSSOS-EU and CNOSSOS-FRa.

4. Noise emission from controlled vehicles

4.1. Measurement procedure

The measurement setup is similar to the one used for SPB, with a microphone at a distance of 7.5 m and a

Table II. Corrective coefficients α_i applied to CNOSSOS-EU for the road surfaces of sites 1 and 2 (CNOSSOS-EUcorr).

		octave (Hz)					
		125	250	500	1000	2000	4000
site 1	rolling noise (dB)	-2.2	-2.9	-3.5	-6.1	-7.3	-6.3
	propulsion noise (dB)	-0.7	-0.7	-1.0	-1.5	-2.0	-2.0
site 2	rolling noise (dB)	0.4	-1.5	-1.4	-1.6	-1.4	-0.6
	propulsion noise (dB)	0	0	0	0	0	0

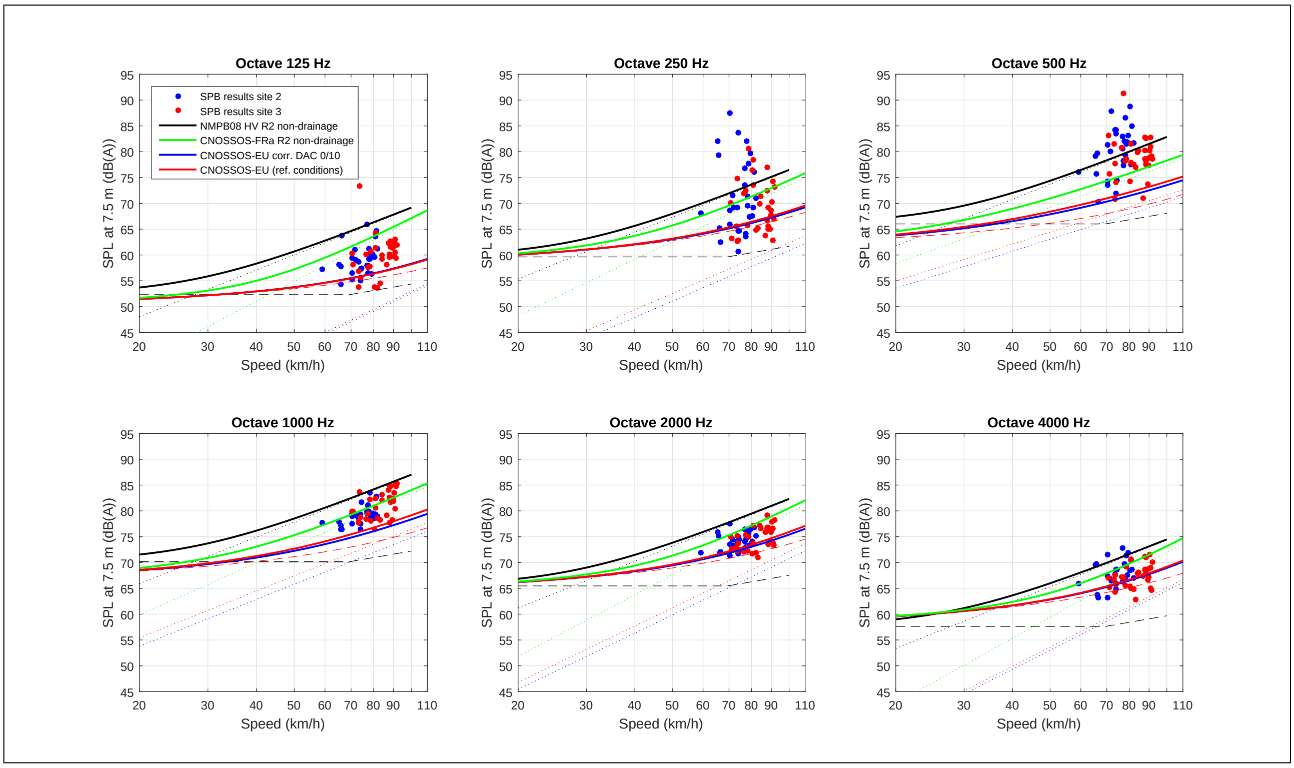

Figure 5. Confrontation of the SPB results to the various models in octave bands, for sites 2 and 3. Overall sound pressure level (solid curve). Rolling noise component (dotted curve). Propulsion noise component (dashed curve). The propulsion noise components are identical for CNOSSOS-EU and CNOSSOS-FRa.

height of 1.2 m. The noise emission from a controlled vehicle is measured over all operating conditions at constant speed, from 15-20 km/h to the maximum speed. For each pass-by, the vehicle speed and the gearbox engaged are recorded. Knowing the technical features of the vehicle (gear ratios, axle ratio, tyre dimensions), the actual engine speed can be obtained for each pass-by. At first, the most adapted gearbox ratio is selected for the pass-by speed, representative of a normal use of the vehicle. Then if possible within the engine operating range, at least another engine speed is investigated for any given vehicle speed by varying the gear ratio engaged (either lower or upper), in order to widen the engine speed range for a better powertrain noise separation. All measurements were completed on DAC 0/10 surfaces.

4.2. Separation of the powertrain and rolling noise contributions

We consider the maximum A-weighted pass-by noise pressure level L_{Amax}. This quantity depends on the vehicle speed as well as on the powertrain operating conditions and we model it through the contribution of two components: the power unit noise L_{Apowt} (function of the engine speed N) and the rolling noise L_{Aroll} (function of the vehicle speed v).

$$L_{Amax}\left(N,v\right) = L_{Apowt}\left(N\right) \oplus L_{Aroll}\left(v\right) \tag{4}$$

with:

$$L_{Apowt}(N) = L_{0,Apowt} + \alpha_{Apowt} \log \frac{N}{N_{ref}} \tag{5}$$

$$L_{Aroll}(v) = L_{0,Aroll} + \alpha_{Aroll} \log \frac{v}{v_{ref}} \tag{6}$$

where N_{ref} and v_{ref} are respectively the engine speed and vehicle speed references. For each vehicle, the coefficients α_{Apowt}, $L_{0,Apowt}$, α_{Aroll} and $L_{0,Aroll}$ are calculated by minimizing the mean square error between the set of measured values $L_{Amax,meas}(N, v)$ and the model defined by Eq. (4), (5) and (6), in each octave band. Only results in global levels are illustrated in this paper.

4.3. Approach supporting the measurement/model confrontation

The choice of the adapted gear operating mode defines a one-to-one relationship between the engine speed and the vehicle speed, under normal use conditions. Thus, for each vehicle we get:

- a powertrain noise equation in adapted gear,
- a rolling noise equation,
- the overall noise, given by the energetic summation of both contributions.

over the whole vehicle speed range.

As previously for the SPB measurements (section 3.2), these equations are respectively compared with the propulsion noise, rolling noise and overall noise of:

- the NMPB2008 model for HV on the non-drainage R2 road surface category;
- a derivation of the CNOSSOS-FR model for cat.2 and the non-drainage R2 category;
- the CNOSSOS-EU model for cat.2 with a specific correction adapted to DAC 0/10 and based on *Deufrabase*.

4.4. Confrontation of the CPB measurements to the models

Four 2-axle medium-heavy vehicles (vehicle category 2) – including public transportation, construction site and delivery vehicles – have been investigated and the results are illustrated in Figure 6. Considering the low vehicle sample size, this has no statistical value at this level but can only be viewed as a first indication.

Except for one vehicle, the rolling noise contributions are not very different from one vehicle to another despite their diversity (Figure 6, bottom left). Whereas CNOSSOS-EU (resp. NMPB2008) clearly undervalues (resp. overvalues) most rolling noise components, the derivation CNOSSOS-FRa is a rather acceptable representation of the general trend.

There is a wide dispersion of the power unit noise levels, which may exceed 10 dB(A) at a given speed due to the variety of vehicle types (Figure 6, bottom right). As a first approximation, the propulsion noise components of the models are not inconsistent with this limited measurement set.

Considering the overall vehicle noise levels, the dispersion introduced by the propulsion noise is found on the total noise at low and medium speeds (Figure 6, top left). Globally, model CNOSSOS-FRa is the most consistent with this four vehicle set, mainly for its behaviour at higher speeds.

At this stage, this CPB confrontation confirms that the first model contribution to adjust is the rolling noise component. A correction of the propulsion noise component – basically not adjustable in the CNOSSOS-EU method – seems of secondary importance.

5. Conclusions and perspectives

The results obtained on both the SPB and CPB measurements show a large dispersion of the noise levels radiated by the vehicles, originating mainly from the octaves 250 Hz and 500 Hz. The wide diversity of vehicle types included in category 2 is suspected to be an important parameter.

On the basis of the present partial dataset considering roadside noise levels, NMPB2008 for heavy vehicles – supported by a wide cat.3 vehicle dataset – is not appropriate for cat.2 vehicles. Considering the European method, an upgrading of the rolling noise contribution of CNOSSOS-EU is clearly required for medium-heavy vehicles on French roads, even for road surfaces quite similar to the one of the reference conditions. The exploratory CNOSSOS-FRa derived from the French cat.3 correction terms determined in [4] could be an acceptable compromise for medium-heavy vehicles on the roads tested.

A confirmation with wider datasets is still needed for determining a representative average behaviour of medium-heavy vehicles on French roads and deriving an actually compatible model with the European method.

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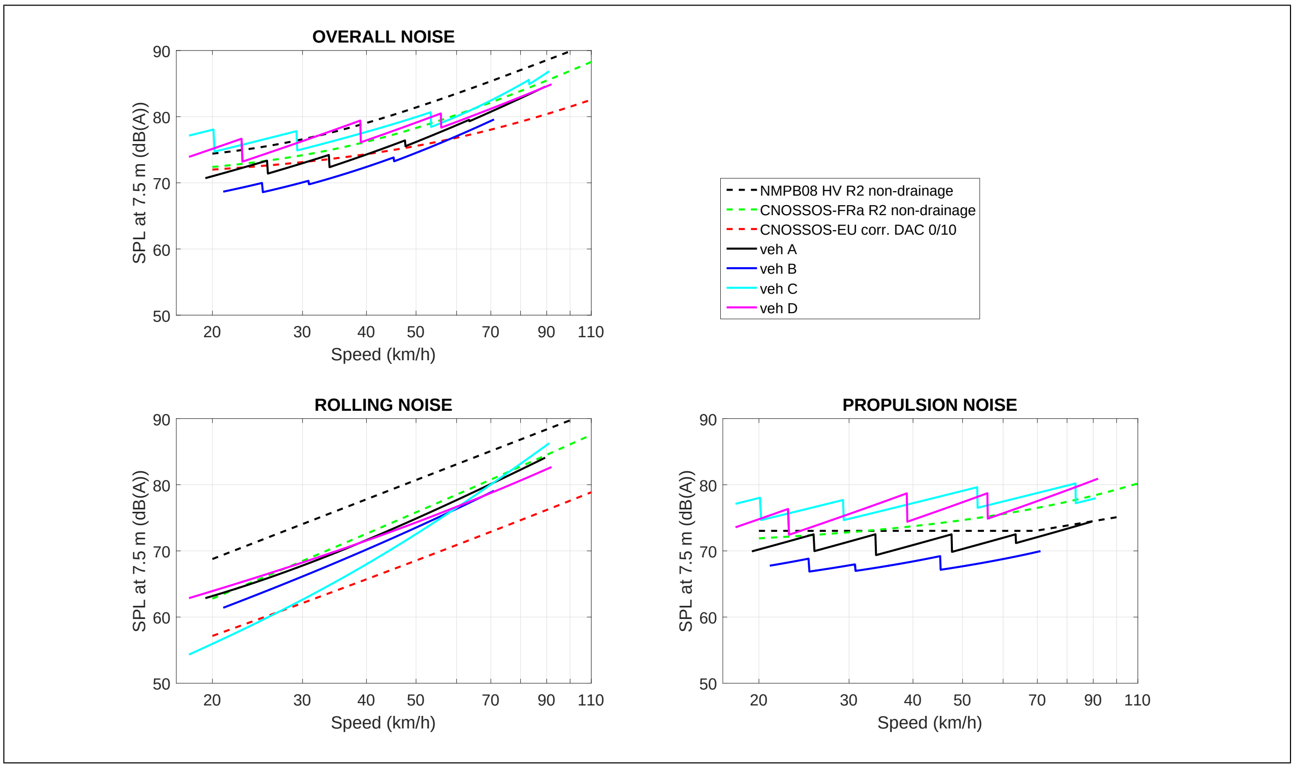

Figure 6. Confrontation of CPB results to the various models. Overall sound pressure level (top left). Rolling noise component (bottom left). Propulsion noise component (bottom right). The propulsion noise components are identical for CNOSSOS-EU and CNOSSOS-FRa.

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