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Matching noise emission from French medium-heavy vehicles and CNOSSOS models

Marie-Agnès PALLAS^{(1)*}, Adrien LE BELLEC⁽¹⁾, David ECOTIERE⁽²⁾

⁽¹⁾Univ Lyon, IFSTTAR, CEREMA, UMRAE, F-69675, Lyon, France

⁽²⁾CEREMA, IFSTTAR, UMRAE, F-67035, Strasbourg, France

Abstract

The CNOSSOS-EU prediction method, mandatory since 2019 for noise mapping in compliance with the European Noise Directive, specifies the road vehicle noise equations to be used per vehicle category. French noise emission data differ significantly from the European model and a national decree was published in June 2018 to provide CNOSSOS corrective coefficients in accordance with the national NMPB2008 model. However, the European semi-heavy vehicle category is non-existent in both French emission model and databases, thus lacking to support the proposed coefficients at this stage. To provide missing information, detailed measurements under controlled conditions have been performed on a sample group of semi-heavy vehicles. The contribution of propulsion noise and rolling noise were separated and average emission equations were proposed by sub-category. For two traffic composition scenarios, mainly differing by the ratio of public transport vehicles, a noise emission model has been proposed to represent an average medium-heavy vehicle. The paper presents the approach and the models obtained. The representativeness of the European prediction model in its initial version published in 2015, in its French adaptation of June 2018 and in two further versions, is considered for both scenarios. Comparisons of frequency characteristics are emphasized.

Keywords: noise emission, trucks, CNOSSOS

1 INTRODUCTION

European Directive 2002/49/EC of 25 June 2002 on the evaluation and management of the environmental noise [1] requires Member States to produce noise maps assessing exposure to environmental noise, particularly in large urban areas and around major roads. It was completed in May 2015 by Directive 2015/996 [2] specifying a common assessment method for all Member States, CNOSSOS-EU, then marginally corrected at the beginning of 2018 [3]. This new method for noise mapping came into effect at the beginning of 2019. The adaptation of the model to the French road network and vehicle fleet was published in June 2018 [4].

The vehicle category 2 of CNOSSOS-EU refers to medium-heavy vehicles, which are not differentiated among heavy vehicles in the classification used by the French noise prediction method NMPB2008 [5]. Their actual noise emission on French roads is not documented. However, statistical pass-by measurements carried out on several roads pointed out discrepancies with medium-heavy vehicle noise prediction by CNOSSOS-EU [6]. Based on a series of controlled pass-by measurements involving a sample of medium-heavy vehicles driving at constant speed, average noise emission models have been determined for two scenario options of traffic composition of category 2, differing by the proportion of public transportation vehicles, with an effect on the propulsion noise contribution [7]. Then, the relevance of CNOSSOS-EU for predicting noise emission of a French average medium-heavy vehicle is raised. Several versions of CNOSSOS should be considered: CNOSSOS-EU currently in effect according to 2015 Directive, CNOSSOS-FR corresponding to its adaptation to French road network, an updated version of CNOSSOS-EU elaborated in 2018 after the detection of issues in the original version [8]. For further illustration, to this list is added the Dutch version recommended for noise mapping in the Netherlands from 2019 onwards [9].

*marie-agnes.pallas@ifsttar.fr

After a presentation of these CNOSSOS versions in section 2, the procedure that established the noise emission of a French average medium-heavy vehicle within the two scenarios is recalled (section 3). A confrontation of these average category 2 vehicles with the four versions of CNOSSOS is discussed, both considering global A-weighted levels and frequency spectra, focusing on urban speed conditions where propulsion noise is predominant (section 4).

2 NOISE EMISSION MODELS

The method CNOSSOS-EU published in 2015 [2, 3] is currently the reference European version. It was used as the basis for the French transposition and adapted to French traffic and road network specificities through corrective coefficients. An underlying mismatch of the European road emission model has recently been raised and an updated version of the reference CNOSSOS-EU version is being examined. Simultaneously, other Member States published their own transposition; the implementation in effect in the Netherlands is also considered here. These various versions are summarised in this section.

2.1 Reference CNOSSOS-EU method

The CNOSSOS-EU road noise emission model considers four vehicle categories, according to their mass and axle number [2]. Category 2 concerns medium-heavy vehicles, with a mass larger than 3.5 tons, two axles and twin tyres on the rear axle. It includes a wide variety of vehicles with various uses, bodies and equipment – i.e. delivery-, dump- and garbage trucks, tankers, buses and coaches – as long as they have only two axles.

Any vehicle is modelled by a single omnidirectional point source, located 0.05 m above ground. Its acoustic power specified in the octave bands [63 Hz - 8 kHz] under reference conditions (constant speed, flat and dry road, air temperature of 20°C and a virtual road surface corresponding to an average of DAC 0/11 and SMA 0/11). If conditions deviate from these, correction coefficients shall be used.

In each octave band i , the total power radiated by the point source $L_{WT,i}$ is composed of a propulsion noise component $L_{WP,i}$ and a rolling noise component $L_{WR,i}$, depending on vehicle speed v :

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

where the operator \oplus stands for the energetic sum of both components and:

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

$$L_{WP,i}(v) = A_{P,i} + B_{P,i} \frac{v - v_{ref}}{v_{ref}} \quad (3)$$

The coefficients $A_{R,i}$, $B_{R,i}$, $A_{P,i}$ and $B_{P,i}$ are given in Table F-1 of the Directive [2], and $v_{ref} = 70$ km/h.

Corrective terms $\Delta L_{WR,road,i}$ and $\Delta L_{WP,road,i}$ are available for rolling noise and propulsion noise respectively, so as to take into account the effect of the road surface on vehicle noise emission:

$$\Delta L_{WR,road,i}(v) = \alpha_i + \beta \log\left(\frac{v}{v_0}\right) \quad (4)$$

$$\Delta L_{WP,road,i}(v) = \min\{\alpha_i; 0\} \quad (5)$$

the latter being designed to account for the effect of absorbing surfaces on propulsion noise. Values of the coefficients α_i and β are given in Table F-4 of the Directive for each vehicle category on various Dutch road surfaces. For each road pavement, it should be noticed that the corrective coefficients for medium-heavy vehicles are always identical to those of the heavy vehicles, reflecting a similar noise level impact of a road surface change for both categories.

The corrective coefficients α_i and β are the means of action to adapt the model to the French road surfaces.

2.2 French adaptation CNOSSOS-FR

The French prediction method NMPB2008 was implemented as a transitional method for the previous rounds of strategic noise map production, pending the availability of the common European method. The propagation part of CNOSSOS-EU is quite similar to the French approach, but the respective road noise emission models differ with regard to the vehicle classification and to the sound power levels, among other things. Indeed, NMPB2008 identifies only two types of vehicles: light vehicles and heavy vehicles [5], the former matching with CNOSSOS category 1 and the latter with category 3. In addition, it clusters and ranks road surfaces into three groups, R1, R2 and R3, from the quietest to the noisiest, each one split in drainage or non-drainage surfaces. NMPB2008 was built on a wide set of national measurements and is considered as representative of the vehicle fleet driving on the French road network.

An adaptation of CNOSSOS-EU to the French context has been proposed by calculating correction coefficients α_i and β that best match CNOSSOS to the NMPB2008 model, respectively for vehicle categories 1 and 3 and each road surface cluster [10]. For the undocumented French category 2, the adaptation has taken the same approach as Table F-4 of CNOSSOS-EU by replicating the correction coefficients of category 3 [4]. This French adaptation is named CNOSSOS-FR in this paper.

It should be noted that, in road and vehicle conditions similar to the reference conditions of CNOSSOS-EU, the use of uncorrected CNOSSOS-EU greatly undervalues French noise emission levels. This results in the production of quite significant correction terms, even for low-noise surfaces.

2.3 Corrected version of CNOSSOS-EU

Some errors have recently been identified in the derivation of the sound power coefficients given in Table F-1 of CNOSSOS-EU, partly resulting from a mismatch between the respective propagation models of Harmonoise/IMAGINE and of CNOSSOS-EU [8]. Among other issues, the need for an update of Table F-1 has been pointed out and discussed in 2018 within a European working group [11]. This affects the coefficient A for both the propulsion and rolling noise components, without changing the B coefficients and therefore the component dependence on speed [8]. For vehicle categories 2 and 3, upgraded coefficients provide higher overall sound power levels by 2 to more than 3 dB(A) depending on speed. This modified CNOSSOS version is named CNOSSOS-2018 in the present paper.

2.4 Dutch adaptation CNOSSOS-NL

The adaptation of CNOSSOS-EU for noise mapping implementation in the Netherlands includes own sound power coefficients for the respective propulsion and rolling noise components, designed in accordance with the general equations (1)-(3) and the reference conditions specified in the European directive. A specific set of coefficients A_R , B_R , A_P and B_P is given in table 2.2.b of the Dutch method [9], providing own speed-dependent sound power levels for the different vehicle categories.

2.5 Comparison of the models for vehicle category 2

By likening the reference surface of CNOSSOS-EU to the non-drainage group R2 of the French classification, the previous models are compared for vehicle category 2, namely:

- CNOSSOS-EU, CNOSSOS-2018 and CNOSSOS-NL in reference conditions
- CNOSSOS-FR for a non drainage R2 surface

The quantities represented are A-weighted sound power levels (L_{WA}).

For a dense road surface, CNOSSOS-EU and CNOSSOS-FR noise emission models have identical propulsion noise components and differ by their rolling noise contribution. CNOSSOS-2018 is different from the preceding ones both in the propulsion and the rolling noise components, as well as CNOSSOS-NL. CNOSSOS-EU gives the lowest global propulsion and rolling noise contributions, while CNOSSOS-FR provides the highest rolling

noise contribution with the steepest speed increase. CNOSSOS-NL gives the highest propulsion noise prediction. The total noise shows variable differences between models over the speed range, according to the predominance of the propulsion noise and the rolling noise contributions in the octave bands (Figure 1).

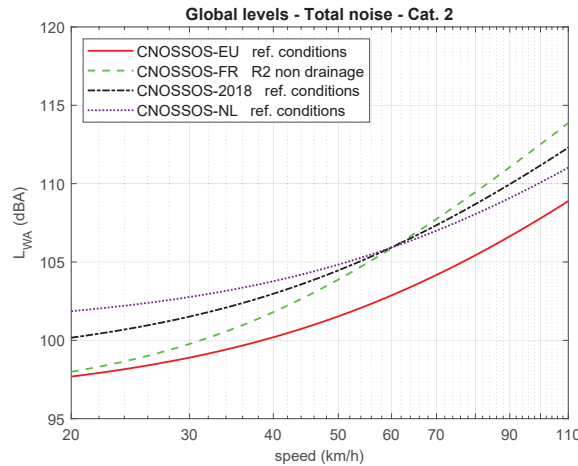


Figure 1. Comparison of the overall noise emission models for vehicle category 2, A-weighted global sound power levels

3 NOISE EMISSION OF AN AVERAGE MEDIUM-HEAVY VEHICLE

To fill the gap in knowledge about the actual noise emission of medium-heavy vehicles on French road network, an experimental study has been conducted to determine a representative noise emission equation of this vehicle category. It relies on controlled pass-by noise measurements carried out on a set of vehicles, used to build a model for the noise emission from an average medium-heavy vehicle in two traffic mix scenarios. This section summarises the procedure followed to obtain the propulsion and rolling noise contributions of one vehicle, then the determination of the average model in each of the two traffic scenarios. More details are available in [7].

3.1 Analysis of a controlled vehicle

All the controlled medium-heavy vehicles have been measured under very close conditions and similarly analysed. For each of them, the gear ratios and the axle ratio were known. The pass-by measurement procedure was based on standard NF S 31119-2 [13], similar to ISO 11819-1 [12] but for controlled vehicles. Infrared cells provided information on the vehicle speed. Constant speed pass-bys were carried out in 5 or 10 km/h steps from 15 to 90 km/h. As far as possible two different engaged gears were tested for each speed setpoint, the *adapted gear* (most natural gear for the speed) and the *inferior gear* (one gear lower, thus involving a larger rpm). Knowledge of the powertrain mechanical characteristics made it possible to calculate the engine rpm from the speed. The acoustic quantity considered is the maximum A-weighted noise pressure level on the microphone at roadside.

In accordance with CNOSSOS prediction model the analysis has been carried out in octave bands from 63 Hz to 8000 Hz. The vehicle noise emission equation in each octave band i was determined by optimising parameters of a noise level model $L_{Amax,i,mod}$, using a least squares criterium between the set of measured levels $L_{Amax,i,meas}$ and the model $L_{Amax,i,mod}$:

$$\min \|L_{Amax,i,meas} - L_{Amax,i,mod}\|^2 \quad (6)$$

In this model, given by Equation (7), the total noise is the sum of a propulsion noise component depending on

engine speed (Equation 8) and of a rolling noise component depending on vehicle speed (Equation 9).

$$L_{Amax,i,mod}(N, v) = L_{A,prop,i}(N) \oplus L_{A,roll,i}(v) \quad (7)$$

$$L_{A,prop,i}(N) = L_{0,A,prop,i} + \alpha_{A,prop,i} \log \left(\frac{N}{N_{ref}} \right) \quad (8)$$

$$L_{A,roll,i}(v) = L_{0,A,roll,i} + \alpha_{A,roll,i} \log \left(\frac{v}{v_{ref}} \right) \quad (9)$$

where N_{ref} and v_{ref} are respectively the reference engine speed and the driving speed, and the operator \oplus stands for energetic summation.

Thereafter, considering the commonly used *adapted gear* driving conditions, a one-to-one relationship links vehicle speed to engine rpm $N_{adapt}(v)$. Thus, the noise emission equation of the vehicle at *adapted gear* depends on the sole variable v , using the previously optimised coefficients $L_{0,A,prop,i}$, $\alpha_{A,prop,i}$, $L_{0,A,roll,i}$ and $\alpha_{A,roll,i}$ (Equation 10). In practice, the propulsion noise component has discontinuities – and consequently the overall noise – at speeds where a gearbox shift occurs since implying large engine rpm changes.

$$L_{Amax,adapt,i}(v) = \left[L_{0,A,prop,i} + \alpha_{A,prop,i} \log \left(\frac{N_{adapt}(v)}{N_{ref}} \right) \right] \oplus \left[L_{0,A,roll,i} + \alpha_{A,roll,i} \log \left(\frac{v}{v_{ref}} \right) \right] \quad (10)$$

The same operation has been performed with each vehicle tested. All vehicles had an internal combustion engine and were tested at one of two sites with a DAC 0/10 road surface. The propulsion and the rolling noise components of each vehicle in *adapted gear* have been used to determine average contributions from the set of vehicles.

3.2 Vehicle subcategories and traffic scenarios

The total number of vehicles tested is still limited, since seven vehicles could be assessed in depth. Several types of medium-heavy vehicles have been investigated, with various functions, makes, models and tyre types and wears. They have been grouped in subcategories, designated with the generic names *van truck* (intended for the delivery of packaged goods), *dump truck* (used for the transport of bulk materials for public works) and *bus* [7]. This classification was motivated by noticing some homogeneity within a subcategory but significant differences between them. A mean emission law has been determined in each subcategory by energetically averaging propulsion noise components on the one hand and rolling noise components on the other hand per octave band, on the shared speed test range. Concerning propulsion noise, averaging tends to smooth out the vehicle-specific discontinuities spread over the speed range. Propulsion noise differences provide an obvious subcategory ranking *dump trucks* > *van trucks* > *bus* and may exceed 8 dB(A) between the average *dump truck* and the *bus*. *Van trucks* approximately lie at mid-range within this extent [7].

The determination of the noise emission model representative of French vehicles of category 2 results from assumptions on the traffic mix, weighting the noise emitted by each subcategory. Two traffic composition scenarios of category 2 have been retained, defined by a proportion n_v of *van trucks* (including refrigerator trucks), a proportion n_d of *dump trucks* (including tank-, flatbed-, container-, refuse trucks) and a proportion n_b of *buses* (urban buses and coaches), with $n_v + n_d + n_b = 1$ (Table 1). They result from punctual subcategory counting performed at four varied locations and differ mainly by their ratio of public transport vehicles [7]. Critical for the average propulsion noise component, the traffic mix has a negligible effect on the average rolling noise component.

3.3 Vehicle noise emission models

For each traffic mix scenario, the next step consists in calculating the optimal coefficients $\hat{A}_{P,i}$ and $\hat{B}_{P,i}$ (resp. $\hat{A}_{R,i}$ and $\hat{B}_{R,i}$) of an emission model given by the CNOSSOS equation (3) (resp. equation (2)), fitted to the previous average propulsion (resp. rolling) noise component.

Table 1. Proportion of vehicles in each subcategory of the traffic mix

| Scenario | n_v | n_d | n_b |
|-----------------------------|-------|-------|-------|
| Low public transport ratio | 61 % | 34 % | 5 % |
| High public transport ratio | 27 % | 20 % | 53 % |

The noise emission model associated with each scenario, extrapolated up to 110 km/h, is drawn in Figure 2 (left). Since differences between scenarios affect the propulsion noise only, the overall noise differs acoustically at low speed but not at high speed. In any case, the propulsion noise dominates up to more or less 50 km/h, then rolling noise prevails. This seems reasonable at the light of road noise knowledge. On the contrary, CNOSSOS-EU global rolling noise reaches propulsion noise contribution at about 100 km/h only and rolling noise is of the same order of magnitude as propulsion noise at the best, even at the frequencies where its contribution is known to be strong.

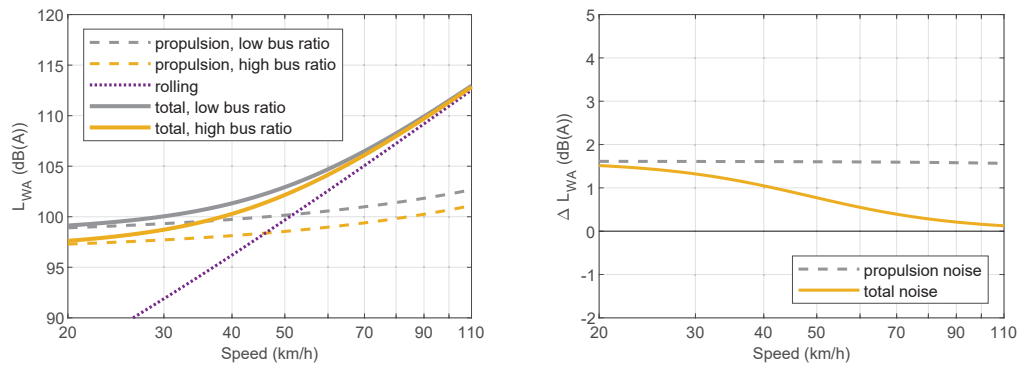


Figure 2. Noise emission models for an average vehicle of category 2 in two traffic mix scenarios. Left: A-weighted global sound power levels. Right: noise level difference between the scenarios.

The propulsion noise difference between the scenarios is almost constant over the whole speed range, equal to 1.6 dB(A) in global levels. This gives a varying difference on total noise, from 1.6 dB(A) at low speed and decreasing to become insignificant at high speed. It remains over 1 dB(A) up to 40 km/h (Figure 2, right). The scenario issue therefore concerns mainly urban areas and city centres. The rolling noise component is typical of the two DAC 0/10 surfaces of the test tracks. A statistical approach covering R2 road surfaces is still needed to refine the relevant rolling noise model for class R2.

4 CONFRONTATION OF THE AVERAGE MEDIUM-HEAVY VEHICLE TO CNOSSOS NOISE EMISSION

Considering the road surface of the test sites, both scenarios are compared to CNOSSOS-EU, CNOSSOS-2018 and CNOSSOS-NL in reference conditions, and to CNOSSOS-FR with the road surface group R2 non-drainage, regarding global noise levels (Figure 3 left). A focus is done on the key contribution of the propulsion noise at low speed through the noise spectra at 20 km/h (Figure 3 right). The relevance of the CNOSSOS versions with the average models associated to the two scenarios depends both on traffic mix and speed.

CNOSSOS-EU is well adapted to the scenario with a high public transport ratio up to 40 km/h but undervalues the other scenario by 1 to 1.5 dB(A). In this speed range, this relies mainly on the propulsion noise contribution. Its propulsion noise spectrum at low speed is relevant over the dominant frequency range 500-4000 Hz.

Differences occur mainly at both ends of the spectrum, either overpredicting or underestimating the noise emitted by the average vehicle in these secondary frequency bands. In both traffic mix scenarios, CNOSSOS-EU in reference conditions undervalues the vehicle noise emission at high speeds, up to 4 dB(A) at 110 km/h and road corrective terms are required for prediction improvement.

CNOSSOS-2018, the corrected version proposed in the European working group, overestimates the overall noise emission, up to 1.6 dB(A) at low and medium speeds with a low public transport ratio and up to 2.8 dB(A) if this ratio is high. In the former case, the overestimation comes from most of the frequency range. The propulsion noise level increase with speed is too rapid with respect to the average experimental result. Thus, if considering the basic flexibility of CNOSSOS approach, its adaptation to the French average vehicle of category 2 would be tricky in this case since corrective terms provide no mean of reducing propulsion noise level contribution, then the overall noise level.

The comments made for CNOSSOS-2018 are still heightened with the Dutch model CNOSSOS-NL and it seems that the average medium-heavy vehicles differ significantly in both countries, in particular regarding the higher propulsion noise contribution.

CNOSSOS-FR is now recommended for new noise mapping rounds in France. Its ability to correctly figure the noise situation is essential. Its propulsion noise component is identical to the one of CNOSSOS-EU and the above comments on CNOSSOS-EU propulsion apply here. On the present experimental test basis and considering the overall noise for the road category R2 non-drainage, it happens to be an acceptable compromise for both scenarios prediction in urban conditions. In a typical urban scenario with a high public transport ratio, overestimation is lower than 1 dB(A) at 20-30 km/h and smaller than 2 dB(A) over the whole speed range. If the public transport ratio is low the noise prediction error remains within ± 1 dB(A) up to 50 km/h and does not exceed 1.3 dB(A) at medium and higher speeds.

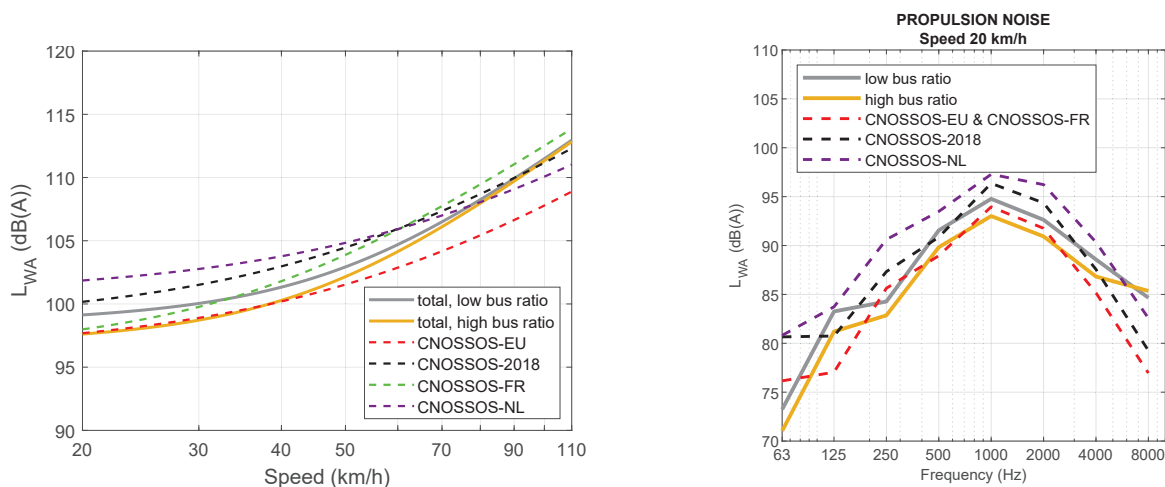


Figure 3. Comparison of the CNOSSOS noise emission models to the average medium-heavy vehicle of the two scenarios. Left: overall A-weighted global sound power levels. Right: sound power spectrum of the propulsion noise contribution at 20 km/h

5 CONCLUSIONS

The noise prediction method CNOSSOS-EU allows the production of road strategic noise maps based on noise emission models per vehicle category. The medium-heavy vehicles are not classified in the French noise database, which was an issue for adapting the European method to the French context. Thus, based on a series

of measurements carried out on controlled vehicles at pass-by and on two scenarios of medium-heavy traffic mix, average noise emission in accordance with the CNOSSOS model has been set for each case. This result has been compared with the noise emission prediction of CNOSSOS. In the present context of the European method likely to be updated, several versions of CNOSSOS have been considered, including the one currently in effect in France. It turns out that the latter gives noise prediction levels with an error not exceeding 2 dB(A), even less according to the scenario. However, a future CNOSSOS version involving a higher propulsion noise contribution would make an adaptation through the sole correction on rolling noise inappropriate.

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