New vehicule noise emission values to update the French 'Guide du bruit'

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French traffic noise prediction models are based on vehicle noise emission values defined by the "Guide du Bruit des Transports Terrestres", issued in 1980. A research programm was established in order to update these values and take into account developments in car and road technology.
The methodology followed to output emission values has been developed by successive steps, as the processing performed on the collected data went along. After several attempts the shape adopted for the emission formulas considers the vehicle pass-by LAmax as the sum of two subsource contributions: the power unit contribution which varies with acceleration and the road gradient, and the tire/road contribution which varies with speed and the road surface type.
The new emission values presented in this paper are now completely defined and ready to be used in noise prediction models.

1 Introduction

Traffic noise prediction models used in France are based on vehicle noise emission values defined by the French Guide du Bruit des Transports Terrestres [1]. These values, obtained from noise measurements in the 70s, had to be updated in order to take into account developments in car and road technologies. A research program, led by SETRA (Service d'étude technique des routes et autoroutes), was thus carried out and will soon be concluded by the publication of a new guide the GdBN08.

The methodological principles followed in this program have been outlined in a previous communication [2]. This paper details these principles and presents the results.

2 General approach

The various factors, other than speed, agreed to influence traffic noise are: vehicle type, traffic flow type, road gradient, and road surface. The GdBN08 method considers two vehicle categories (light vehicles less than 3.5t and heavy goods vehicles, 3.5t or higher), and three traffic flow types (steady speed, acceleration and deceleration).

The noise emission of a traffic lane depends on the vehicles' flow rate, sound power and speed. If an average sound power be defined for the vehicles, the noise emission of a traffic lane can be characterized by its sound power level per meter and per vehicle $Lw/m/veh$. In the GdBN08 a $Lw/m/veh$ is given for each vehicle category, through a power unit noise component Lp and a rolling noise component Lr, with the global noise emission being the energy addition of these: $Lw/m/veh = Lp \oplus Lr$.

Except for rare exceptions, the GdBN08 emission values have been determined on the basis of experimental results, that is of maximum pass-by levels (L_{Amax} in dB(A)), measured under traffic conditions (SPB procedure NF S 31-119, similar to ISO 11819-1) or controlled conditions (CPB procedure NF S 31 119-2).

In this paper the noise emission values are expressed in L_{Amax} levels at standard distance (7.5m horizontal, 1.2m high), more familiar to acousticians than $Lw/m/veh$ levels. The numerical correspondence between the quantities is $Lw/m/veh(v) = LAmax(v) - 10\log v - 4.4$ with v in km/h.

2.1 The power unit noise component

The power unit noise component Lp is assumed to address the set of the vehicles mechanical sources. It is given in the GdBN08 in function of speed, acceleration and declivity. The motor noise of an actual vehicle depends on the engine rpm and torque, i.e. on speed and gear ratio, acceleration and declivity. The determination of Lp in the GdBN08 is thus based on two types of information: the vehicles' noise emission laws, and the way the vehicles are driven in traffic (driving behaviour). The vehicles' noise emission laws have been determined from CPB measurements on tracks. The driving behavior has been determined from experimental observations or, for a few cases, from assumptions.

RESULTS FOR THE LV CATEGORY

The Lp values given by the GdBN08 for the LV category are summarized Fig 1. They depend on the traffic flow type but not on the road declivity (the GdBN08 considers declivities up to 6%). The speed range is [5 km/h – 130 km/h] for accelerating and decelerating traffic flows, and [20 km/h – 130 km/h] for steady speed traffic flows: it is considered that steady flow speeds do not occur below 20 km/h.

The Lp component for level road situations has been constructed using the noise emission laws of 14 vehicles of different motorizations and cubic capacities. The procedures used are described in [3]. The driving behavior, i.e. the percentage at which each gear ratio is used by actual drivers in steady speed traffic condition, was determined using a database on driving behavior available at INRETS [4]. The result is summarized in the histogram drawn Fig 2. For each measured vehicle, a power unit noise, representative of that vehicle running in steady speed traffic condition, was determined by taking the energy average of the vehicle power unit noise at the different gear ratios, weighted in proportion to the percentage each ratio is used at the considered speed. The Lp value for the LV category is then taken to be the energy average of these individual power unit noise values.

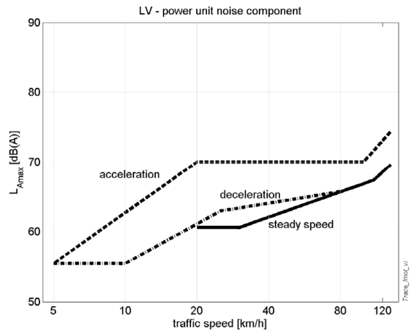

Fig 1 GdBN08 L_p component for the LV category

For accelerating conditions, a hypothesis was made regarding the driving behavior: at each given speed, the driver seeks for maximum engine torque and selects the gear ratio accordingly ("optimum" gear ratio). A power unit noise of each vehicle has been evaluated according. The corresponding Lp value for the LV category is the (energy) average of these individual levels.

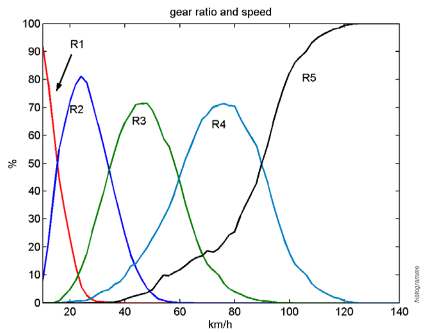

Fig 2 Percentage at which each gear ratio of a 5 gear LV is used at steady speed traffic condition.

For decelerating conditions the driving behavior hypothesis was that part of the drivers slow down using engine brake and thus select the gear ratio appropriate to the speed (the "optimum" gear ratio), while others just use the brakes (the gear ratio is then the one corresponding to the steady speed situation). For each vehicle, two power unit noise levels were thus evaluated (one for each behavior) and their energy average taken. The Lp value for the category is the (energy) average of these individual average levels.

The evaluation of power unit noise in uphill or downhill situation was addressed both experimentally (CPB measurement on tracks, SPB measurements in situ) and theoretically. A difficulty when comparing pass-by levels measured with and without gradient is to make allowance for possible differences due to factors other than the declivity (differences in rolling noise in particular). At high speed where the rolling noise predominates, the expected effect of a declivity on the overall noise is anyway small (only declivities lower than 6% are taken into account in the GdBN08). At low speed, the analyses of the measurement results could not conclude on whether or not declivities (less than 6%) have a noticeable effect on the power unit noise. In any case, the resulting effect on the overall noise was considered small enough to agree that the Lp values for the LV category could be given with no dependence on the road declivity.

RESULTS FOR THE HGV CATEGORY

The GdBN08 Lp values for the HGV category are formulated Table 1: the power unit noise component is given constant up to 70 km/h. The acceleration and declivity effects are taken into account through a corrective, speed independent, term ΔLm (cf. Table 2).

$5km/h \le v \le 70km/h$	$70km/h \le v \le 100km/h$
$73 + \Delta Lm$	$73.8 + 13\log(v/80) + \Delta Lm$

Table 1 GdBN08 Lp component for the HGV category. The values are in dB(A) and correspond to a LAmax.

	horizontal	uphill	downhill
	$0\% \le p \le 2\%$	$2\% \le p \le 6\%$	$2\% \le p \le 6\%$
steady speed	0	$2\times(p-2)$	$p-2$
acceleration	5	$5+\max\left[2\times(p-4,5);0\right]$	5
deceleration	0	0	$p-2$

Table 2 Corrective term ΔLm in dB(A) for the Lp component of the HGV category.

The Lp values for steady speed condition on horizontal road, were determined from CPB measurements performed on 7 different tractor-trailers, in the speed range [20 km/h, 80 km/h], with the instruction to the driver to select the gear ratio he felt best suited for the running speed [5,6]. The determination of the driving behavior was thus part of the measurement campaign. It was concluded that, due to the numerous gear ratios of a HGV, the Lp component can be considered as being speed independent in the low and medium speed range. The Lp results obtained were confirmed by a supplementary measurement campaign on 7 more tractor-trailers.

For accelerating and decelerating conditions on level road, the power unit noise component was determined using SPB measurements at several points before (25 m, 25 m and 100 m distance) and after (100 m, 200 m and 400 m distance) a roundabout. The measured vehicle speeds ranged between 20 km/h to 80 km/h. For both situations, a rolling noise component was estimated by looking for a best fit between a rolling noise law $Lr(v) = a + 30\times\log v$ [1] and the pass-by levels measured in the high speed range ($v > 80$km/h). The Lp value was then determined by looking for a best fit between a $Lp \oplus Lr(v)$ law and the pass-by levels measured in the low speed range (20 km/h-40 km/h). The coherence between the law obtained and the pass-by levels measured at intermediate speeds was checked. The procedure was applied on two sites for the accelerating condition (800 tractor-trailers measured), and one site for the decelerating condition (300 tractor-trailers measured). The acceleration effect, as compared to the steady speed condition, was found to be a 5 dB(A) increase at all speeds; while deceleration was found to yield the same noise emission values than steady speed.

To determine the uphill influence on Lp at steady speeds, SPB measurements were performed on 5 sites with declivities p ranging from 3% to 6%. On each site SPB measurements were also performed on a zero declivity spot,

[1] (the 30 dB/decade corresponds to the rolling noise component's speed law for the HGV category, cf. infra)

which enabled to determine the rolling noise component $Lr(v)$ of that site. The Lp value of the site was then determined by looking for a best fit between the SPB values measured on the declivity spot and a $Lp \oplus Lr(v)$ law. It was found that Lp increases with the uphill declivity by the quantity $\Delta Lm = 2 \times (p-2)$ dB(A).

The downhill influence was obtained from SPB measurements performed on a site with a 6% declivity and by stating a proportionality law. A downhill declivity increases Lp by the quantity $\Delta Lm = p - 2$ dB(A).

2.2 The rolling noise component

The rolling component Lr depends on the road surface. This effect is addressed in the GdBN08 which considers three surface categories: a low-noise category R1 (thin asphalt concrete 0/6 and 0/10, porous asphalt 0/10), an intermediate category R2 (cold mix, dense asphalt concrete 0/10), and a noisy category R3 (cement concrete, surface dressing 6/10 and 10/14, asphalt concrete 0/14 and thin asphalt concrete 0/14).

RESULTS

The Lr dB(A) values given by the GdBN08 are summarized Table 3. The rolling noise component is considered to depend on the vehicle category and on speed, not on the road declivity or on the traffic flow type.

These Lr values are considered to be representative of 2 years old pavements. A correction term is given Table 4 to take into account the time evolution of the pavement rolling noise component. The correction is given for up to 10 years of age.

	LV	HGV
R1	$73.3 + 31.0 \times \log(v/90)$	$82.5 + 30 \times \log(v/80)$
R2	$77.3 + 30.1 \times \log(v/90)$	$85.6 + 30 \times \log(v/80)$
R3	$79.8 + 31.4 \times \log(v/90)$	$86.6 + 30 \times \log(v/80)$

Table 3 GdBN08 Lr component for road surfaces 2 years of age or less. Levels are in dB(A), v is in km/h.

	LV	HGV
R1	$+0.5 \times (a-2)$	$+0.3 \times (a-2)$
R2	$+0.25 \times (a-2)$	$+0.15 \times (a-2)$
R3	$+0.2 \times (a-2)$	$+0.12 \times (a-2)$

Table 4 GdBN08 increase, in dB(A), of the Lr component with age a in years. $2 < a \leq 10$.

DETERMINATION OF THE CATEGORIES R1, R2 AND R3

The determination of the road surface categories is based on a statistical analysis of SPB measurement results gathered in a database supervised by the LRPC of Strasbourg. The database provides individual speed law $L_{A\max}(v)$ in dB(A) corrected for 20°C temperature, for more than 400 road sections regarding the LV category and more than 100 road sections regarding the HGV category. The procedure is outlined in [2]. In a first step, for each road technique (and each vehicle category), a representative $L_{A\max}(v)$ speed law is established from individual speed laws of the road sections within the technique. The road techniques are then grouped into 3 categories, and a representative $L_{A\max}(v)$ speed law is established for each category. In this process, each road technique is given an identical weight, independent of the number of sites measured within the technique. The resulting $L_{A\max}(v)$ are given within the speed ranges 70 km/h-130 km/h for the LV category and 70 km/h-90 km/h for the HGV category.

DETERMINATION OF THE Lr COMPONENT

The rolling noise component $Lr(v)$ of each vehicle and each surface category has been deduced from the global noise $L_{A\max}(v)$ law of the surface category and the power unit component $Lp(v)$, at stea dy speed, of the vehicle category. It is obtained by "energy subtraction" between $L_{A\max}(v)$ and $Lp(v)$ in the high speed range (for the VL category, $Lp(v)$ is ‘linearized’). The resulting $Lr(v)$ law is then considered to be valid in the low speed domain.

The aging effect has been addressed for each road surface and vehicle category. For the LV category, it has been evaluated through statistical analysis of the $L_{A\max}(90km/h)$ values as function of the age of the road section when the measurement was performed.

The aging effect for the HGV category is deduced from the LV’s aging effect: $\Delta L(a, HGV) = 0.6 \times \Delta L(a, LV)$. This correspondence is based SPB measurement performed over 224 road sections for both LV and HGV categories [7]. Each road section is characterized by a L_{Amax} LV(90km/h) for the LV category ans a L_{Amax} HGV(80km/h) for the HGV category A linear fit taken between these quantities shows that the: L_{Amax} HGV(80km/h) increases by 0.6dB(A) when the L_{Amax} LV(90km/h) increases by 1dB(A), with an error lower than +/-0,8 dB(A) for about 50% of the road sections and lower than +/-2,4dB(A) for about 95% of the road sections. An attempt to consider several road surface categories, each associated to a specific relationship, did not lower the errors significantly.

2.3 Global noise emission values

The global noise emission is obtained by adding energetically the components:

$$L_{A\max,global} = 10\log\left[10^{0.1 \times L_p} + 10^{0.1 \times L_r}\right]$$

The noise emission values for a steady speed traffic flow on horizontal road are drawn Fig 3 for the LV category and Fig 4 for the HGV category.

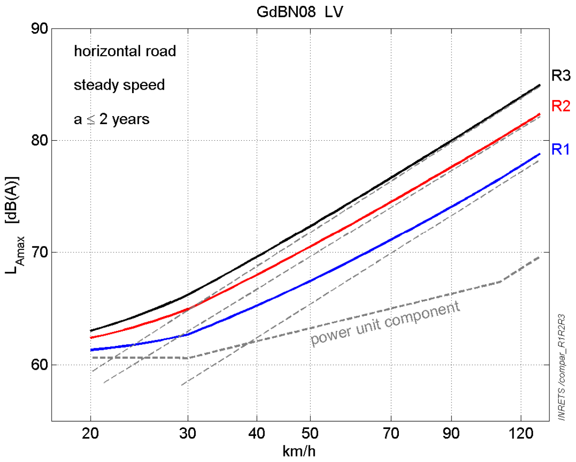

Fig 3 GdB08 global noise in dB(A), for the LV category. Level road, steady speed condition

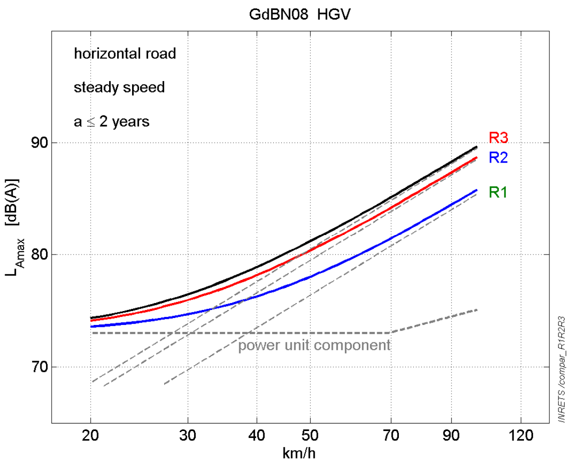

Fig 4 GdB08 global noise in dB(A), for the HGV category, level road, steady speed condition

Effect of road surface on level roads

The road surface effect, i.e. the noise level difference between traffic over a R3 category road surface and traffic over a R1 category road surface (both less than 2 years of age), is drawn Fig 5 for steady speed traffic condition and level roads. The effect exceeds 2 dB(A) for speeds higher than 25 km/h for the LV category or 35 km/h for the HGV category.

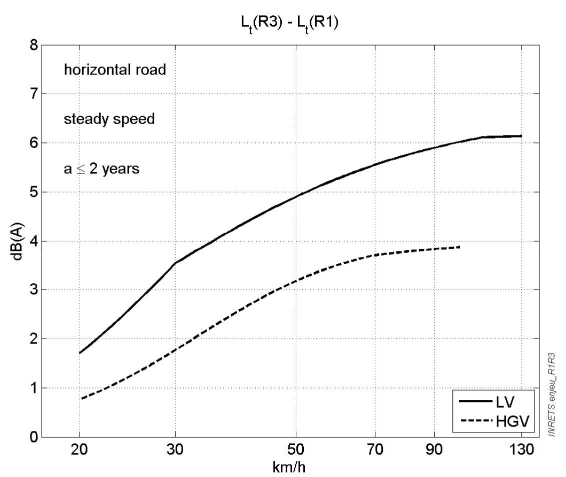

Fig 5 GdBN08. Noise level difference between a traffic on a R3 road surface and a traffic on a R1 road surface (both surfaces are less than 2 years of age)

Effect of acceleration and deceleration on level road

An accelerating flow is noisier than a steady speed flow. The amount of noise increase depends on speed and on road surface. The acceleration effect on noise is drawn Fig 6 for traffics on a horizontal R2 road surface.

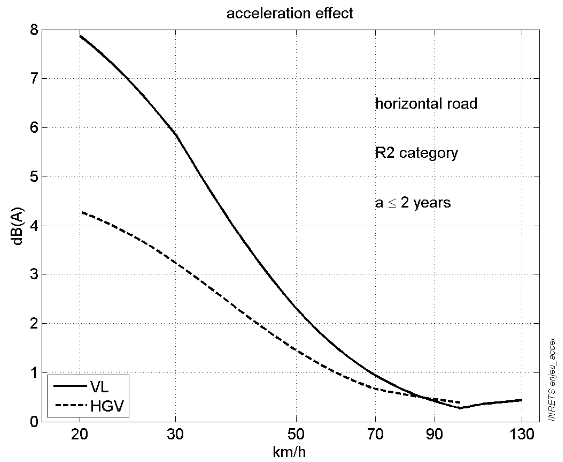

Fig 6 GdBN08. Noise level difference between an accelerating traffic flow and a traffic flow at steady speed. Both traffics run on a R2 category road surface, less than 2 years of age.

The LV global emission values for a decelerating flow are rather close to those given for a steady speed flow. The HGV global emission values for a decelerating flow are identical to those at steady speed (except on a uphill situation, cf. Table 2).

3 Conclusion

The traffic noise emission values are given by the GdBN08 for two vehicle categories, LV and HGV, through a power unit noise component and a rolling noise component. The first depends on speed, acceleration and road declivity; the second depend on speed and road surface. This decomposition enables to cover all usual traffic conditions (steady speed, acceleration, deceleration) and road configurations (declivity, road surface) with relatively few formulae. These values are now ready to be used in prediction models.

Acknowledgments

The authors want to acknowledge the contributions of MM. Francis Besnard and Vincent Guizard from SETRA, Mrs Nathalie Fürst from CERTU, co-authors of the GdBN08 book.

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