ACOUSTICAL IMPACT OF TRAFFIC FLOWING EQUIPMENTS IN URBAN AREA

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ABSTRACT : Noise in urban area is considered by populations as one of the most important nuisance. To decrease the traffic noise impact, French City planners looked for finding new noise reduction solutions by acting on the traffic flow itself. One of these, is the replacement of traffic lights by adapted roundabouts. The modelling of their acoustical impact can be performed in two stages: description of kinematics time histories and prediction of the acoustic emission evolution of vehicles travelling through the equipment. The paper deals with comparisons between predictions and measurements for light vehicles circulating under various classical urban conditions.

INTRODUCTION

Since many years, traffic noise has been considered by urban populations as one of the most crucial problem to be solved. In order to provide to local authorities adapted solutions, various research groups of the French Transportation Ministry were particularly involved on several programmes dealing with the impact of new road equipments on the urban acoustic environment. The first results presented in this paper could not have been obtained without the constant and essential collaboration between the researchers and the technical and environmental local departments.

The objective of the environmental policies of the main cities is to mitigate the urban traffic noise in order to reduce the sound pressure level in all the different parts of the city and its surroundings, as close to the ring roads as inside the historical centre. Function of the site and its use, it is possible to propose different types of actions: reduction of the vehicle speed, modification of the pavement, building of noise barriers or elaboration of a new traffic planning. The study dealt with in this paper has been carried out in the framework of this last item.

ACOUSTIC IMPACT OF THE TRAFFIC PLANNING MODIFICATION

The main aim of the traffic planning modification consists in increasing the free flow of traffic in conjunction with the reduction of the number of vehicles and their speed. In order to reach those goals, a first possibility consists in moving away the traffic from the city centre to external ring roads. Concerning large avenues inside the city where the vehicles speed can be high, another possibility can consist in transforming road crossings equipped with traffic lights or stop sign in roundabouts. This last solution is the most used in France.

Basically, if the traffic flow does not increase a lot, the equivalent sound pressure level LAeq will be reduced due to the reduction of the number of acceleration and deceleration periods which are the main contributors of the noise emission in urban areas. Therefore, this noise abatement will depend on the roundabout radius and the number of entry and exit slip roads. On one part, it is necessary to reduce the braking and acceleration periods through the only optimisation of the radius of curvature of the roundabout and on another part, it is fundamental not to create congestion zones along the various roads or streets merging into the ring.

In table 1 are presented results obtained on various roundabouts. Those results show an acoustic gain between 1 and 4 dBA with some variations that are mainly depending on the way of modification of the traffic free flow.

Table 1. Effect of a roundabout on traffic noise for various sites

Site	**Former infrastructure**	***Δ(LAeq)*** **for day period**	***Δ(LAeq)*** **for night period**
Malemort (19)	Road crossing equipped with traffic lights	- 2.0 dBA	-
Nantes (44)	Road crossing equipped with traffic lights	- 3 → - 4 dBA	- 2 → - 3 dBA
Egleton (19)	Road crossing equipped with a Stop sign	- 1 → - 3 dBA	- 1 → - 2.5 dBA

NB. Measurements carried out by the Regional Public Works Laboratories (LRPC) from Blois and Clermont-Ferrand

On the different experimental sites, an impact of the roundabouts on the vehicles speed has not been observed. In the case of those situations, the mean speed has only been reduced from 0 to 15 km/h.

These first experimental results show that this kind of road equipment has an acoustic impact, which is not negligible. Now, the question is: how to predict this impact? This is the aim of this study.

HOW TO MODEL THE ACOUSTIC IMPACT OF A ROUNDABOUT ?

To predict the impact of a roundabout on the noise emission of a single vehicle passing through: a passenger car in a first approach; it is necessary to model in a first step, the various kinematics time histories of the vehicle, that means: the evolutions of the speed (V), the acceleration (A), and the engine operating conditions (S). In a second step, the Sound Power Level, Lw for this vehicle can be directly obtained according to the following semi-empirical equation [1] :

$$Lw = 10 \cdot lg_{10}\left[10^{(a_0 + a_1 S + a_2 A)/10} + 10^{(a_3 \cdot lg_{10} V)/10}\right] \qquad (1)$$

Where S is in rpm, A in m.s^{-2}, V in km/h and a_0, a_1, a_2 and a_3 are regression coefficients issued from an inverse fitting procedure on a large number of measurements for various driving conditions through a Levenberg-Marquardt algorithm. The first term of this equation represents the engine noise while the second term represents the tyre-road noise.

For the test vehicle (Renault Clio 1.4) the coefficient values corresponding to the global LAw are detailed in table 2. If necessary, one set of a_i coefficients can be obtained following the same process for each 1/3 octave frequency band including those in which the main engine frequencies occur.

Table 2. Values of the regression coefficients for the test vehicle (Renault Clio 1.4)

Gear ratio	a_0	a_1	a_2^*	a_3
2nd gear	71.5818	0.0062	± 4.8575	11.3592
3rd gear	77.3353	0.0046	± 4.5917	11.231

* : The coefficient a_2 has to be positive for an acceleration process and negative for a deceleration process

Evaluation of the Cinematic and Acoustic Characteristics

In this first approach, we consider two configurations: the test vehicle is running through a simulated roundabout using a single gear ratio (second for a first measurement and third for a second one). The total distance is between 250 m and 300 m depending on the gear ratio. For each configuration, the initial speed is around 50 km/h, representative of the French official speed limit in urban area. After a "natural" deceleration (the driver's right foot out of the accelerator pedal), the vehicle merges into the roundabout with a speed around 20-25 km/h. Inside the equipment the vehicle speed is maintained constant. Then, after the exit of the roundabout, the vehicle regularly accelerates until reaching the official urban speed of 50 km/h.

Instantaneous speed and acceleration are measured using 5 emitting/receiving infrared cells. A 10-metre interval separates two consecutive cells. To determine the speed and the acceleration, reflectors are disposed on the other side of the test track, opposite to each emitting/receiving infrared cell (cf. Figure. 1).

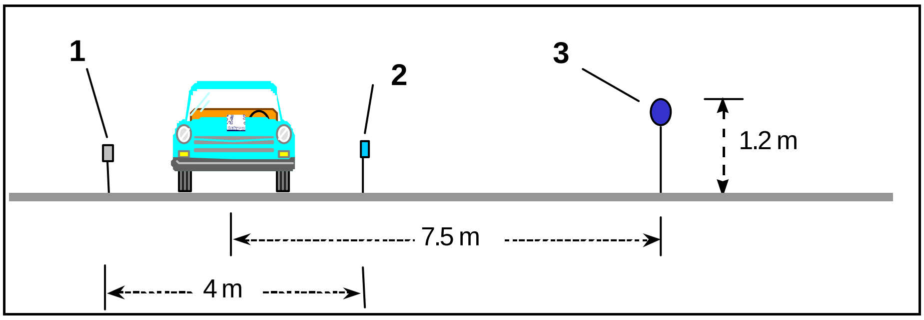


Figure 1. Experimental disposition for the cinematic and acoustic data measurements
1 *: Reflector ;* **2** *: Infrared cell ;* **3** *: Microphone*

Concerning the mechanical parameters, the operator notes the engaged gear. The engine operating condition (S) is then deduced from the speed values, the engaged gear ratio and the mechanical characteristics of the vehicle (transmission ratios of the gear box and of the axle) [2]. The variation law (equation 2) is linear and approximately identical to this identified by Oshino and Tachibana [3].

$$S = \frac{Cst}{r} \cdot V \qquad (2)$$

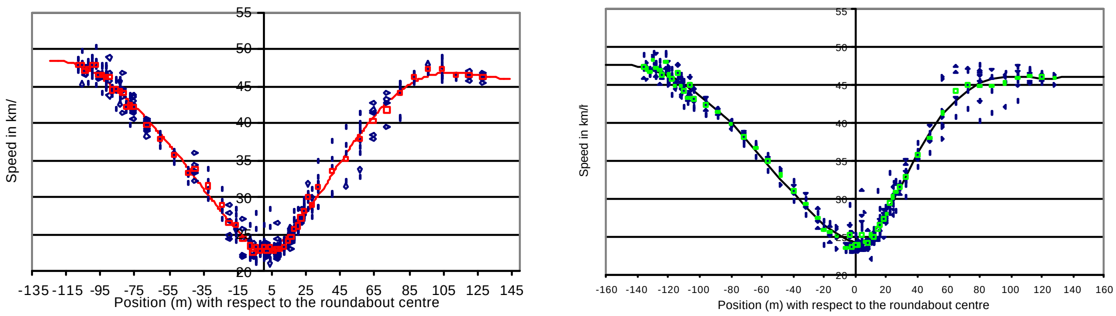
Where r is the gear ratio and $Cst \approx 154$ for our test vehicle.

Concerning the acoustic data, three microphones are located in the acoustic field close to the track (7.50 m from the road axis and 1.20 m above the ground). A 10-metre interval separates two consecutive microphones. The maximum Sound Pressure Levels, *LAmax* are recorded in global and in third-octave band spectra over the range 80 Hz - 5 kHz.

For this first set of experiments, the measurements have been carried out on the reference LCPC test track in Nantes. The road pavement was a 0/10 mm bituminous concrete.

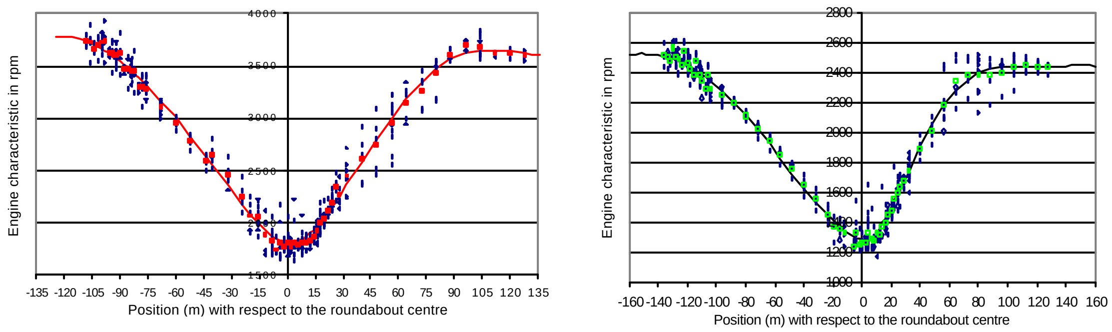
<u>Cinematic time histories</u>

For the conditions mentioned above, it made possible to draw the various time histories of each characteristic (speed, acceleration/deceleration and engine operating condition), for each gear ratio, function of the distance. On the curves shown in figures 2, 3 and 4, we note on one hand, that similar behaviours can be observed for the three characteristics, for the two different gear ratios. On the other hand, we note that the speed and the engine characteristic evolutions are rather smooth while the acceleration/deceleration patterns are more complex. In this last case, it seems noticeable that these time histories can be splitted in several well-identified domains (cf. Figure 4).



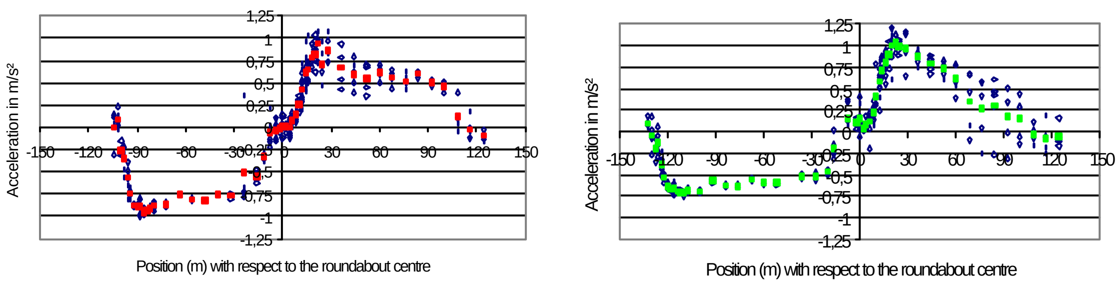
(a) (b)

Figure 2. Evolution of the speed time histories : (a) 2nd gear ; (b) 3rd gear



(a) (b)

Figure 3. Evolution of the engine characteristics : (a) 2nd gear ; (b) 3rd gear

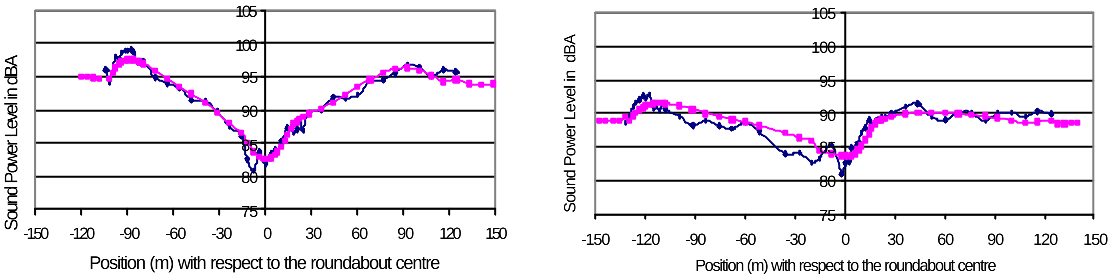


(a) (b)

Figure 4. Evolution of the acceleration time histories : (a) 2nd gear ; (b) 3rd gear

Acoustic characteristics

According to equation 1, and after experimental identification of the cinematic characteristics of the vehicle, it is possible afterwards, to simulate the evolution of the sound power level *LAw*. For the two selected gears, the curves represented on figure 5 (a) and (b) show that there is a quite nice agreement between the predicted and the measured values



(a) (b)

Figure 5. Evolution of the Sound Power Level, LAw : (a) 2nd gear ; (b) 3rd gear
(■-■) : Measurement ; (■-■) : Prediction

These two curves show in a first interpretation that lower is the gear ratio, higher is the impact of the acceleration/deceleration process. The *LAw* magnitude being 15 dBA for the 2nd gear ratio while it is only 8 dBA for the 3rd gear ratio.

From the *LAw* values for one single test vehicle, along the route on each side of the roundabout, we can estimate the cumulated sound pressure level *LAp* at different receiver points more or less near the equipment, assuming that there is one identical vehicle every 10 m. In that condition, after consideration of the propagating laws between the vehicle source and the receiver [4], differences close to ± 1 dBA have been found between the prediction and the measurements.

As a first application of this modelling technique, we tried to compare two “theoretical” configurations: a roundabout with respect to a straight avenue. In both cases, the “theoretical” vehicles were operating on the same gear ratio (second or third) all along the route. Those situations, with an important engine noise level, are not totally representative of real situations. Nevertheless, they show the possibility to identify theoretically the impact of this road equipment on the acoustic environment. Table 3 compares the different Sound Pressure Levels at a distance of 7.50 m.

Table 3. Comparison between a roundabout and a straight avenue for a “theoretical” situation

Gear ratio	***Lp* (dBA) Straight avenue**	***Lp* (dBA) Roundabout**	***ΔLp* (dBA)**
2nd gear	73.9	65.3	8.6
3rd gear	67.7	63.3	4.4

Due to the low gear ratios, the effect is very strong. In realty, for more representative gear ratios, basically 3rd and/or 4th ratio, for which the engine noise is equivalent or lower than tyre-road noise [5], the effect should be a little reduced (around 2-4 dBA). This, seems rather consistent with the LAeq measurements carried out on various roundabouts, and reported above in table 1.Those preliminary results are encouraging in the perspective of the extension of the calculation to other more realistic urban situations.

CONCLUSION AND OUTLOOKS

According to the new French regulations concerning the traffic noise impact in urban area, local authorities have to take specifically into account this problem which is considered by populations has one of the most important.

Function of the geographical situation, City centre or outskirts, the mitigation of traffic noise can be differently considered. The most usual practical solutions are: modification of the pavements by new low-noise mix designs, reduction of the vehicles speed, building of noise barriers when it makes possible, and finally, action on the traffic flow planning. Concerning this last solution, experiments performed on test sites and in several French cities showed that an acceptable acoustic gain can be obtained. This encouraging result incites local responsible authorities to go on working in that direction in order to improve always their citizen's quality of life.

Knowing the difficulties encountered to set an *in situ* experiment in urban conditions; from a physical point of view, the possibility of modelling the acoustic behaviour of such traffic flowing equipments takes on a quite particular interest. Among others, it should permit to compare the multiple various situations with an equivalent number of vehicles, and thus, to determine the solutions which could be the best for the people. In addition, this approach could allow to reach our final objective which concerns the acoustic classification of the more representative urban traffic flowing equipments.

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