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ENVIRONMENTAL NOISE FROM ALERTING SIGNALS (AVAS) OF ELECTRIC VEHICLES: COMPARISON WITH NOISE PREDICTION MODELS AT URBAN SPEEDS

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ABSTRACT

In the context of climate change and harmful impact of fossil fuels, electric vehicles (EVs) represent a strongly growing share of the light vehicle fleet, especially in urban areas. With their low propulsion noise, they offer a solution for reducing road traffic noise at urban speeds. In return, the arrival of an EV may be poorly detected audibly by a vulnerable user in a lively soundscape. Consequently, regulations require EVs to be equipped with an alerting signal (AVAS) below 20 km/h, with minimum sound level and some frequency characteristics. The study focuses on EV noise contribution from an environmental point of view when the AVAS is in operation. Based on experiments up to 30 km/h, it evaluates sound emission with several AVAS signals at EVs pass-by, considering laterality, global and frequency impact on acoustic indicators. While the modelling of EVs in national or European noise prediction methods is still an open subject, the results obtained on the tested vehicles with and without AVAS are compared with existing models for conventional vehicles (CNOSSOS-FR, NMPB) in the very low speed range that is becoming common in cities. The objective is to explore the relevance of an EV-specific model when AVAS is active.

Keywords: *Electric vehicle, AVAS, vehicle noise, noise prediction*

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1. INTRODUCTION

The automotive market is showing strong growth in the share of electrified vehicles (full electric and plug-in hybrids) to the detriment of light vehicles with internal combustion engines. As an example, the electrified market share was estimated at 17% in Europe in 2021 [1]. These vehicles are known for their low propulsion noise contribution, with rolling noise being the main noise source over a wide speed range. At very low speeds, their relative silence can present a risk to vulnerable road users such as pedestrians and cyclists. Consequently, a regulation now requires these vehicles to be equipped with an audible warning signal (AVAS), active below 20 km/h and in reverse gear. Many studies have focused on the perceptual aspects of these signals, with the aim of improving user safety. However, although the question has been raised, relatively little attention has been paid to assessing their contribution on environmental noise, with a trend to conclude that the impact is limited [2, 3].

The present study aims to analyse the characteristics of the sound emission of some EVs driving at low speed. In addition, the relevance of taking them into account differently from conventional vehicles in the noise prediction methods recommended in French and European regulations is explored, considering the AVAS contribution. Indeed, the emission models associated with these methods are representative of internal combustion engine vehicles (ICEVs) and the introduction of electric vehicles is not yet available. Noise levels measured on three Renault ZOE – offering several AVAS signals – and a Peugeot e-208, all at low speed, are compared with the NMPB2008 and CNOSSOS-FR models, respectively recommended in France for road infrastructure impact studies and for the production of strategic noise maps.

After a brief presentation of AVAS systems regulation, the Renault ZOE is experimentally investigated and the sound characteristics observed on the test vehicle at low speed with and without AVAS operation are summarised, considering the laterality of the signal, its temporal and frequency specificities, and the influence of speed or distance. In a next section, this is completed with tests involving two other ZOEs and another EV model (Peugeot e-208), for supporting the findings. Finally, the measured acoustic indicators are compared with the emission models of the NMPB2008 and CNOSSOS-FR prediction methods.

2. SOME REGULATORY FEATURES ON AVAS

Fully in effect since 2021, European regulations require new electric and hybrid vehicles to emit an artificial sound signal from start up to 20 km/h and in reverse gear [4, 5]. It is possible to temporarily deactivate this signal. The AVAS sound signal shall be continuous and inform the user on the vehicle behaviour by means of level and frequency shift synchronised with speed.

In forward motion, a minimum overall sound level of 50 dB(A) at 10 km/h (resp. 56 dB(A) at 20 km/h) is required on an ISO 10844 road surface, measured at a distance of 2 m from the track centre and at a height of 1.2 m, but without approximately exceeding the level of a conventional vehicle and in any case 75 dB(A). The fitting of an AVAS is not necessary if the vehicle alone already gives a noise level exceeding the previous minimum values by at least 3 dB(A).

In its frequency content, the AVAS signal must provide minimum sound levels in two one-third octave bands within the range 160-5000 Hz, at least one of which being above 1600 Hz.

3. EXPERIMENTAL FEATURES OF THE RENAULT ZOE AVAS SIGNALS

3.1 Experimental approach

To investigate the AVAS signal, acoustic measurements at vehicle passby were carried out at low speed on a test track, under surrounding conditions consistent with both the AVAS approval procedure [4] and environmental measurements under controlled conditions [6].

3.1.1 Test site

The test track is located on *Les Fromentaux* test centre of Transpolis facility, with free field conditions. The road surface is a DAC 0/10, available on a large width. It differs from the recommended surface for AVAS approval, which requires an ISO 10844 surface. However, it is a common road surface on French road network, representative of real life driving conditions and available in noise prediction methods.

The weather conditions were in accordance with the recommendations of the standards. The quality of the background noise, which is essential for the measurement of particularly quiet events, was measured at $L_{Aeq,T} = 40.9\ dB(A)$.

3.1.2 Experimental setup

Six microphones, separated into two subsets, are distributed on both sides of the track. On one side, three microphones are located 2 m from the lane centre, 5 m apart. On the opposite side, three other microphones are placed opposite the previous central microphone at 2 m, at varying distances from the track centre, respectively at 2 m (in accordance with [4]), 4 m and 7.5 m (in accordance with [6]). All microphones are at a height of 1.2 m.

Kinematic information is obtained through three infrared cells, resp. located in front of the three microphones aligned at 2 m, associated with reflective plates set on each vehicle side. The cell signals are used to detect the vehicle position in synchronisation with the acoustic signals and to determine its speed. A rangefinder completes this information to check the lateral position of the vehicle relative to the track centre.

3.1.3 Electric vehicle and AVAS

The electric Renault ZOE has an AVAS system, which can be switched off, and allows a choice of three sound signals: Voice Sport, Voice Pure or Voice Glam as named by the manufacturer. The scenarios tested in this study involve either Voice Pure (noted here as AVAS VP), Voice Glam (AVAS VG) or AVAS off.

3.1.4 Test conditions

For the three AVAS configurations considered (off, VP, VG), recordings were made as the vehicle drove at a constant speed between 8 and 30 km/h, in both directions, with the windows closed and the heating, ventilation ans air-conditioning (HVAC) system switched off. The AVAS signal is automatically interrupted beyond about 25 km/h, in accordance with the regulation. Due to the low noise levels, recordings identified as being disturbed by external noise events were discarded.

3.2 Sound features of the EV at low speed

The acoustic quantities analysed are primarily the time history $L_{AFast}(t)$ and the maximum value L_{Amax} of this quantity on the different microphones, in global levels and per third octave band.

3.2.1 Noise emission without AVAS

When driving without AVAS, no significant lateral difference was found and the vehicle can be considered acoustically symmetrical. The time history of the global noise level at 2 m exhibits two successive maxima associated with the passby of the two axles in front of the microphone, the second one being predominant despite the location of both the electric motor and the driving wheels at the front part of the vehicle. This is in agreement with other studies carried out on the noise sources of a Renault ZOE [7]. At the distance of 4 m, the discrimination between the axles passby is no longer noticeable. It completely vanishes at 7.5 m. Also incidentally, although the road surface differs here from that in the AVAS standard, the maximum levels observed at 2 m exceed the minimum regulatory threshold increased by the 3 dB gap at 20 km/h but remain insufficient at 10 km/h, thus justifying the need for the use of an AVAS in accordance with the regulation.

For all the distances investigated, a linear increase of the noise level L_{Amax} with $\log(speed)$ was observed. This agrees with the known acoustical behaviour of vehicles at higher speeds, including EVs [8]. At 7.5 m, the measures scattering is low and the regression slope calculated on the range [8-30 km/h] is 31.8 dB(A)/decade (red markers and line in Fig. 1), consistent with results available in the literature at higher speeds [8].

3.2.2 Noise emission with AVAS

The time signals with each AVAS selection is characterised by an amplitude modulation, which results in a significant scattering of the maximum noise levels, due to the combined effects of the vehicle position relative to the microphone and the fluctuating AVAS signal amplitude over time. The noise levels obtained in the configuration AVAS VP are generally larger and more scattered than those with AVAS VG. Higher levels are observed towards the right vehicle side compared to the left one, also

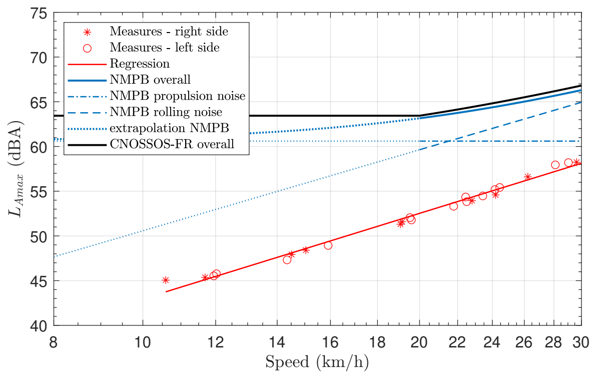

Figure 1. Maximum global noise levels at 7.5 m with Renault ZOE (AVAS off) and prediction models NMPB2008 and CNOSSOS-FR.

more pronounced for AVAS VP. These lateral differences are reduced near 20-25 km/h, likely partially masked by the increased contribution of rolling noise. This behaviour can be seen in Fig. 2 and Fig. 3 for measurements at 7.5 m. In the following, the processing is carried out considering both sides together for a given AVAS configuration.

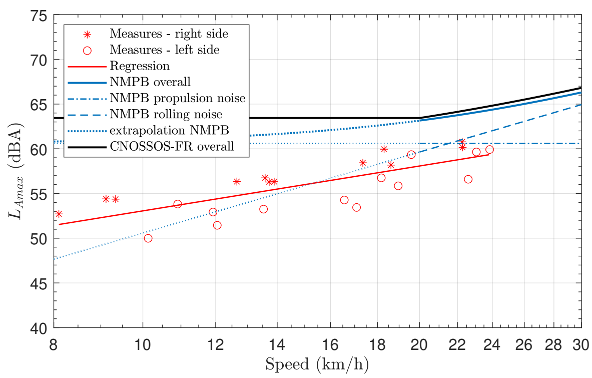

Figure 2. Maximum global noise levels at 7.5 m with Renault ZOE (AVAS VP) and prediction models NMPB2008 and CNOSSOS-FR.

A comparison of the spectra at the distance 2 m exhibits various frequency contents depending on the configurations tested (not displayed in this paper). For example at 12 km/h, the spectral content without AVAS is wideband without significant narrowband component, and a maximum level at 800 Hz consistent with a rolling noise

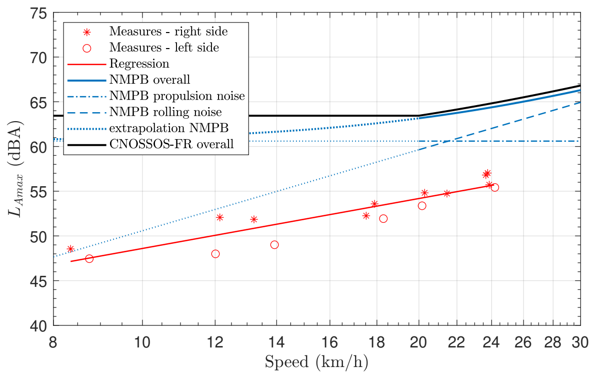

Figure 3. Maximum global noise levels at 7.5 m with Renault ZOE (AVAS VG) and prediction models NMPB2008 and CNOSSOS-FR.

contribution. In contrast, the spectrum of the EV with AVAS VP displays a strong predominance of the third octave bands 200-500 Hz including several tones. At the same speed, the spectrum with AVAS VG shows a set of tones spread on a wider frequency range, from 160 to 1600 Hz. The tone predominance reduces with the increasing speed, comparatively to the case without AVAS, almost fading at 20 km/h with AVAS VG while still remaining up to 25 km/h with AVAS VP.

As observed on L_{Amax} at 7.5 m, the vehicle noise level at 10 km/h increases by 10 dB(A) with the operation of AVAS VP and by 5.5 dB(A) with AVAS VG, relatively to 'AVAS off'. This rise is respectively 5.5 dB(A) and 1.5 dB(A) at 20 km/h.

4. COMPLEMENTARY TESTS WITH OTHER EVS

Other EVs, i.e. two Renault ZOE and a Peugeot e-208, have been tested independently on another test track in a simplified experimental context in comparison with the previous one. They are reported here in order to supplement and substantiate the noise levels previously observed, with other vehicles of the same type (Renault ZOE) and an EV model from a different car manufacturer (Peugeot e-208).

4.1 Experimental context

The experiment took place on the test track of Université Gustave Eiffel in Nantes, with a road surface DAC 0/8 complying with ISO 10844. This road surface is prescribed in standards for the control of vehicle noise emission at passby, including AVAS [4]. Not implemented on the national road network, it is not listed in the noise prediction methods NMPB2008 and CNOSSOS-FR.

The environmental conditions were in accordance with the standard specifications. For any measurement, the difference between background noise and vehicle passby noise was always larger than 10 dB(A). The measurements were carried out on the left side of the vehicles at passby with a microphone at 7.5 m from the lane centre and a height of 1.2 m.

The two Renault ZOE were fitted with the same commercial tyre model than in section 3 (Michelin Energy E-V of dimension 185/65 R15), these being specifically designed for that EV type. The Peugeot e-208 was equipped with its commercial tyres Michelin Primacy 4 of dimension 195/55 R16. A previous experiment proved that rolling noise with the Peugeot e-208 is quieter than with Renault ZOE on that road surface [8].

Only one AVAS signal of Renault ZOE was tested, available at constant speed up to about 24 km/h. Driving without AVAS was performed above 20 km/h. The AVAS of Peugeot e-208 cannot be manually switched off, its automatic shutdown occurs between 20 and 25 km/h.

4.2 Noise levels at pass-by

The maximum global noise levels recorded with both Renault ZOE are similar, whether with or without AVAS (Fig. 4). With AVAS the same orders of magnitude as for the ZOE in the previous section are found. Without AVAS, the Peugeot e-208 appears to be quieter than Renault ZOE by about 2 dB(A), consistent with the differences previously observed on rolling noise with these vehicles. With AVAS on their common range of tested speeds 15-20 km/h, the Peugeot e-208 gives slightly lower levels than ZOE, possibly at least partly influenced by its lower rolling noise. Over the whole speed range with AVAS, the EV models provide quite close noise levels.

5. COMPARISON WITH THE NOISE PREDICTION MODELS

Even if these low speeds are at the edge of the common use of noise prediction models, it is justified to consider their representativeness in the current urban context, where areas with a speed limited to 30 km/h are multiplied and "meeting zones" limiting the driving speed to 20 km/h are developing in cities of several European countries [9].

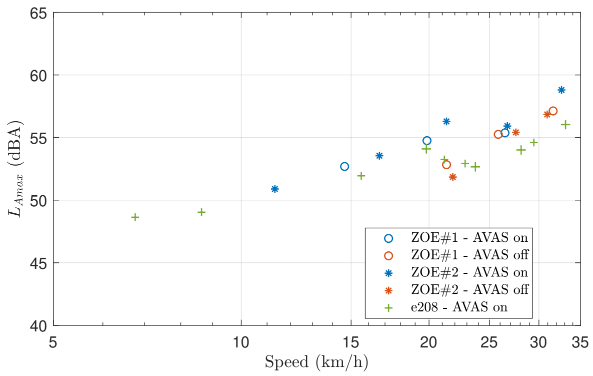

Figure 4. Maximum global noise levels at 7.5 m at passby of Renault ZOE#1 and ZOE#2 and of a Peugeot e-208 on an ISO road surface.

5.1 NMPB2008 method

The noise prediction method NMPB2008 is recommended for environmental impact studies in France. It includes a noise emission model of light vehicles, consisting of an "engine noise" component and a "rolling noise" component, both functions of speed [10]. The overall noise is the energetic summation of these two components. This model is representative of the noise emission of an average light ICEV. Developed in the early 2000s, it does not consider electric vehicles, still minor at that time.

At constant speed, the NMPB2008 noise emission equations are available at speeds beyond 20 km/h. The method assumes that under this speed, the vehicles are accelerating or decelerating, respectively on a starting or a stopping road section. For the needs of the present study at constant speed, considering on the one hand the NMPB2008 stating a constant engine noise at speeds under 30 km/h and, on the other hand, its rolling noise model compared to the noise behaviour observed on EVs without AVAS, the noise emission model of NMPB2008 has been here extrapolated similarly down to the speed 8 km/h.

In view of the road surface DAC 0/10 of the measurement track, the results are compared with the NMPB2008 noise emission model calculated for the road surface category R2 without sound absorption properties.

5.2 CNOSSOS-FR method

CNOSSOS-EU is the common European method for the production of strategic noise maps. Its transposition CNOSSOS-FR specifying the coefficients adapted to the French traffic and road infrastructures is inserted in a decree of 4 April 2006, recently updated [11]. The noise emission model for road vehicles at constant speed consists of a "propulsion noise" component and a "rolling noise" component, each being a function of speed and specified in octave bands from 63 Hz to 8000 Hz. The overall noise is calculated by summing energetically the two components over the frequency range. The coefficients of the noise emission equations determined for the French CNOSSOS-FR give global levels quite close to those of the NMPB2008 at speeds above 20 km/h.

If the European method proposes an additional vehicle category open for future needs, for example electric vehicles, it is not currently filled out. Only vehicles with internal combustion engines are taken into account, defined in category 1 for light vehicles. The emission equations are valid for speeds larger than 20 km. Below 20 km/h, the original CNOSSOS-EU method indicates that the power levels are identical to those calculated at 20k m/h.

For the comparison of measurements carried out with the electric vehicle, the CNOSSOS-FR model is taken for the road surface category R2 without sound absorption properties.

5.3 Comparison of measurements with the models

For the three driving conditions of the Renault ZOE (AVAS off, AVAS VP, AVAS VG), we consider the regression line calculated on the maximum noise level recorded at vehicle passby, as a function of $log(speed)$. This line is compared to the total noise (propulsion + rolling) given by the NMPB2008 and the CNOSSOS-FR methods. Both models provide close predictions at 20 km/h, but differ at lower speed.

When the AVAS signal is switched off, the slope of the regression line from the measurements and that of the rolling noise component of the NMPB2008 are similar (Fig. 1). However, the two parallel lines are differing by more than 7 dB(A). Various factors may be involved in this discrepancy. It should be remembered that the NMPB2008 rolling noise model is based on statistics per pavement class, including several road pavement techniques with numerous surface implementations and traffic vehicles [10]. Texture measurements previously carried out show that the Transpolis road surface implementation is relatively quiet within its class.

Thus, a prediction of the noise emission without AVAS at this site with the extrapolated NMPB2008 total model would lead to an overestimation of the measured situation at 7.5 m by more than 15 dB(A) at 10 km/h and by more than 10 dB(A) at 20 km/h. These differences are even higher with the CNOSSOS-FR model (+18 dB(A) at 10 km/h and about +11 dB(A) at 20 km/h). Obviously, the propulsion noise from ICEVs is strongly detrimental in this case. This overestimation is spread over all third octave bands.

When operating, the AVAS VP increases the emission levels. However, the predictions by the overall NMPB2008 model still overestimate the measured average by 8 dB(A) at 10 km/h and 5 dB(A) at 20 km/h. In the frequency domain, the quality of the prediction is uneven, depending on the third octave band. If we consider the contribution of the NMPB2008 rolling noise alone while disregarding a misadapted propulsion component, the deviations in global level below 20 km/h are sometimes positive and sometimes negative, for an average deviation close to 0 over the speed range considered here. As for the overall CNOSSOS-FR model, it overestimates the measured situation by more than 10 dB(A) at 10 km/h.

Finally, the configuration with AVAS VG leads to larger discrepancies between the measurements and the prediction models than the previous situation. An overestimation of 12.4 dB(A) by NMPB2008 and of 14.8 dB(A) by CNOSSOS-FR at 10 km/h (about 9 dB(A) at 20 km/h) is noted.

6. CONCLUSION

According to the current regulation, the sound alerting systems (AVAS) are now an intrinsic part of the use of electric vehicles at low speed. The operation of this signal significantly alters the noise levels at 7.5 m radiated by the electric vehicles tested in this study, by 5 to 10 dB(A) at 10 km/h, less at 20 km/h. This increase is not insignificant. Consistency has been observed between several EVs of the same model. Beyond AVAS features, the differences in global levels between the two EV models tested are quite low, likely partly driven by rolling noise differences.

The noise prediction models NMPB2008 and CNOSSOS-FR, based on ICE vehicle noise emission, overestimate the noise emission from EVs with AVAS by 8 to 12 dB(A) at 10 km/h for NMPB2008 extrapolated to this speed, and by 10 to 15 dB(A) for CNOSSOS-FR at the same speed. At 20 km/h, the overestimation is about 9 to 10 dB(A) with both methods. In the cases tested, the noise levels of the EVs with AVAS in operation are far below those predicted by the methods for ICEVs. For a more comprehensive view of the electric vehicle fleet, a similar analysis should be carried out on other EV models.

Considering strategic noise maps, which lead to action plans, the noise levels in this low speed context have no impact on any need for mitigation. However, the reported overestimations could mask or misrepresent the relatively calm situation in urban areas with strictly limited traffic speeds, either in a current or future context of strongly increasing EV share or if the access conditions to the area are restricted to electric or hybrid vehicles. The issue then lies in the correct identification of quiet areas in agglomerations and their preservation in accordance with the EU directive.

7. ACKNOWLEDGMENTS

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