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# Noise emission assessment of a hybrid electric mid-size truck

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ABSTRACT

In the attempt to improve urban environmental conditions, city or national incentives encourage the use of cleaner vehicles, including hybrid electric vehicles. This paper explores the actual noise impact of this alternative drivetrain technology on the noise emission of a mid-size delivery truck powered by a parallel hybrid powertrain, compared with an equivalent internal combustion engine truck on the basis of pass-by noise measurements. It investigates jointly the overall emission, the main noise sources and the vertical directivity of the vehicle. The essential benefit results from the existence of a full-electric mode below 50 km/h, with a significant noise reduction which may exceed 8 dB(A) at low constant speed. Even if smaller, this noise advantage is still valuable when the vehicle is accelerating or braking. Due to weaker noise emitted upwards, the benefit should be even greater for residents living on upper building floors. The rolling noise associated with the drive wheel/road contact is the main noise source in all driving situations in electric mode, and beyond 50 km/h in the configurations with engine.



## 1. Introduction

City centers are increasingly faced with deteriorating environmental conditions, in particular poor air quality. In order to reduce air pollution due to road traffic, many local authorities have instituted traffic restrictions, like in European Low Emission Zones (LEZ) [1], on one hand banning primarily the heaviest, oldest and dirtiest vehicles, and on the other hand encouraging cleaner vehicle types including those equipped with hybrid drivetrains [2]. These measures may incidentally alleviate road traffic noise. From another perspective, the development of night or early-morning rounds for the delivery of goods or for service operations such as waste removal may contribute to relieve diurnal congestion within city centers and favor task efficiency [3]. Then, there is the critical point of noise pollution associated with mid-size truck traffic in these otherwise quiet periods and with a higher resident sensitivity to noise disturbance at early hours. This does not only concern the phases of goods unloading or handling, but also the running (moving-off and passing-by) of the vehicles [2]. The electric hybrid technology, in addition to reducing fuel consumption and the emission of polluting gases and particles, also impacts on noise emission. But this latter point, though often put forward, has not been evaluated so far for heavy vehicles on a wide range of running conditions.

Over the past decade, the development or the updating of environmental noise prediction models motivated investigations on heavy vehicle noise emission and the provision of appropriate noise emission data (for example [4,5]). Besides, efficient traffic noise mitigation required a deeper understanding of the truck noise source contributions, grasped for instance through microphone array processing [6–8]. The resulting knowledge on truck noise is essentially focussed on conventional trucks equipped with an internal combustion engine. The recent spread of hybrid and electric vehicles concerns primarily passenger cars, thus concentrating noise impact studies on light vehicle categories [9–12]. Since heavy vehicle manufacturers gradually offers these alternative powertrain types, further investigation is needed. The present study carries out the acoustical assessment of a mid-size hybrid truck in real urban use conditions, and compares it with an equivalent conventional diesel engine truck,[1] assessed identically. It is part of the French national research project GEODE (Optimized Energy Management), aiming at developing a mid-size truck equipped with a new parallel hybrid drivetrain, optimized regarding energy consumption. Vehicle noise emission is tested during constant speed pass-bys, acceleration and braking phases. Measurement involves standard 7.5 m A-weighted maximum noise pressure levels $L_{Amax}$ [13,14] and time history describing the overall vehicle noise emission, as well as a microphone array for the identification of the main noise sources. In addition, the vertical distribution of the noise radiation around the vehicle cross-section informs us of the

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[1] Conventional diesel engine forms the common drivetrain configuration in this category of trucks.

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possible benefits towards higher building storeys. Noise resulting from the use of the auxiliary service equipment is beyond the scope of this paper.

## 2. Characteristics of the trucks

The two mid-size trucks investigated are $4 \times 2$ van body solo rigids (gross vehicle weight 19 tons), belonging to the range Premium Distribution (Renault Trucks)/Volvo FE (Volvo Trucks). They differ mainly in their powertrain technology, but have both a six-cylinder engine and a common engine speed range of 600–2300 rpm. The exhaust is located on the lower left side, just behind the steering wheel. Both trucks are fitted with similar tires (*long haul fuel saving*) but of different brands, with a specific design to the steer axle and to the drive axle. The trucks are loaded with a mass 50 kg/kW, in accordance with most standards of heavy vehicle noise measurement.

### 2.1. Hybrid truck

The hybrid truck (Fig. 1) is equipped with a parallel hybrid powertrain and may be operated in two modes. In the hybrid mode, both the diesel engine (power 300 hp) and the electric motor power the vehicle. The power distribution scenario depends on several parameters, among which the battery charge, and thus may differ for two pass-bys at the same speed. The truck has also a *low noise* mode, where only the electric motor runs. The running range in this mode is about 1 km, as long as several conditions are fulfilled, including the battery energy supply and the motor temperature. The hybrid truck gearbox offers 12 gear ratios. The tires stem from the range Michelin X® Energy™.

### 2.2. Internal combustion engine truck

The conventional Internal Combustion Engine (ICE) truck is regarded as the reference vehicle for the noise emission comparisons. The engine power is 320 hp. The automatic gearbox offers 6 gear ratios and the truck is equipped with tires from the range Goodyear Marathon.

## 3. Experimental setup and methodology

Pass-by noise measurements were performed with each truck running on a test track in both directions and in various real use conditions. The road surface was dense asphalt concrete 0/10. Several infrared cells provided instantaneous speed along the track. Three acoustic devices were operated simultaneously, providing complementary information on the vehicle noise emission (Fig. 2).

**Fig. 1.** Parallel hybrid truck.

### 3.1. Standard 7.5 m microphones

Three microphones, separated by 10 m, were located on one side of the track at standard position 7.5 m from the track center and 1.2 m high (Mic1 to Mic3 in Fig. 2). An additional microphone was laid identically on the opposite side (Mic4 in Fig. 2). The measurement procedure is similar to controlled pass-by standard [14], extended also to pass-bys with acceleration or braking: in each configuration, the third-octave and global maximum A-weighted noise pressure levels ($L_{Amax}$) on each microphone were recorded.

### 3.2. Microphone cross-array

A microphone array is an acoustic measurement device composed of a set of several space-distributed microphones; associated with an appropriate array processing method, it behaves like a directive equipment, allowing us to focus the listening on any finite area of the vehicle, as well as to track the moving sources. Its spatial and frequency properties depend both on the array geometry and the selected processing parameters [15]. It provides acoustic images pointing out the main noise sources location and affords quantitative information on the sources contribution. In this study, the noise source analysis is performed per third-octave frequency band, and the A-weighted global noise levels come from the summation of the third-octave results.

The 41-microphone cross-array is composed of two orthogonal line arrays, as shown in Fig. 3. The center microphone is 1.17 m high. The array is located at the track edge, about 2 m from the passing-by truck side. At vehicle pass-by, it allows us to localize the noise sources on the vehicle side, both horizontally from front to rear and vertically from ground to top. Each line array consists of two nested 13-equispaced-microphone subarrays, with respective uniform spacing 5 cm and 15 cm. The selection of either spacing depends on the frequency range investigated: the wider spacing from low frequency to third-octave 1250 Hz, the shorter one for third-octaves from 1600 Hz to 4000 Hz.

When focusing on a given point $M$ of the passing-by vehicle side in order to listen to a possible noise source located at that point, cross-array processing is carried out in two steps for each frequency band:

(i) Each appropriate equispaced line subarray is individually focused on point $M$ using delay-and-sum beamforming for spherical waves, including on one hand −25 dB Chebyshev shading for better source interference rejection and on the other hand dedopplerisation for correction of moving source distortion and tracking; it provides then the time signals $S_H(t,M)$ and $S_V(t,M)$ respectively for the horizontal and the vertical line arrays outputs.
(ii) Both line array output time signals are cross-correlated throughout the source tracking duration $T$:

$$S_+(M) = \frac{1}{T}\int_t^{t+T} S_H(t,M)S_V(t,M)dt. \tag{1}$$

The quantity $S_+(M)$ is homogeneous to the mean square value of the noise pressure signal coming from a point source located at the focus point $M$ and received at the reference distance $r_{ref} = 2$ m. It can then be expressed in dB (or dB(A) if using physiological A-weighting):

$$L_+(M) = 10\log\left(\frac{|S_+(M)|}{p_0^2}\right) \tag{2}$$

with $p_0 = 2.10^{-5}$ Pa.