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ACUSTIC COMFORT IN DIFFERENT THERMAL ENGINE VEHICLES – CASE STUDY FOR CITY SPEED LIMIT SCENARIO

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Abstract: *The paper presents the experimental approach for two different vehicles equipped with MAS and MAC thermal engines in terms of the acoustic degree of comfort in the front and rear side for the potential passengers in different scenarios. There were presented static and dynamic measurements at different speed limits and conclusions were traced regarding the found results and the possible causes for the obtained values and the relative comfort levels for passengers in the front and rear part of tested vehicles.*
Key words: *thermal engines, acoustic measurements, acoustic comfort, sound meter*

1. INTRODUCTION

In densely populated cities the quality of life of many people is significantly affected by noise, as it is difficult to relax, concentrate or communicate effectively in an environment where noise levels are high [1]. High noise levels are not only annoying, but even pose serious health hazards.

Before describing the effects of road traffic noise and types of noise mitigation, we need to understand the principles of noise. It is known that sound waves are vibrations of air molecules passing from a noise source to the ear of the person exposed to the noise. Noise has been defined as unwanted or excessive sound. Sound is often characterized in terms of the intensity (amplitude) and pitch (frequency) of the sound wave. A decibel (dB) is the unit used to indicate the intensity of a sound wave, which decreases with increasing distance from the noise source. Sound (noise) is often measured in decibels using an A-weighted scale (dBA). Sound becomes undesirable when it interferes with normal everyday activities (work, speech or recreation) and people react differently to noise. Some people are used to sleeping through noise, others cannot work without a source of noise, others have hearing loss, etc [2]. The following table shows typical noise levels measured from the sound source [2].

In modern society, noise can be caused by a variety of sources. Although noise in urban environments is nothing new, systematic research into noise pollution is relatively recent. The world's first major noise survey was carried out in London in 1960 [3]. In addition to the technical problems associated with such an investigation, presenting noise data in an understandable form is more complicated.

Studies in recent years have shown that some of the most widespread sources of noise in our environment are those associated with transport. Urban agglomerations in particular face increased noise from road traffic, but also from air traffic or rail traffic. However, the main contributor to high noise levels remains road traffic [4].

Tabel 1 **Noise levels (adapted from [2])**

Outdoor Sound levels	Sound level (dBA)	Indoor Sound Levels
	110	Rock band at 5 m
Jet Over-Flight at 300 m	105	
	100	Inside New York Subway Train
Gas Lawn Mower at 1m	95	

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	90	Food Blender at 1 m
Diesel Truck at 15 m	85	
Noisy Urban Area-Daytime	80	Garbage Disposal at 1 m
	75	Shouting at 1 m
Gas Lawn Mower at 30 m	70	Vacuum Cleaner at 3 m
Suburban Commercial Area	65	Normal Speech at 1 m
	60	*Electric Toothbrush*
Quiet Urban Area-Daytime	55	Quiet Conversation at 1 m
	50	Dishwasher in Next Room
Quiet Urban Area at Night	45	
	40	Empty Theater or Library
Quiet Suburb at Night	35	
	30	Quiet Bedroom at Night
Quiet Rural Area at Night	25	Empty Concert Hall
Rustling Leaves	20	
	15	Broadcast and Recording Studios
	10	Normal breathing
Reference Pressure Level	0	Threshold of Hearing

The National Environmental Policy Act (NEPA) of 1969 [5] was the first American and world law to provide authority and responsibility for assessing and mitigating adverse environmental effects, including highway traffic noise.

In the European Union, the first noise law was Council Directive 70/157/EEC of 6 February 1970 on the approximation of the laws of the Member States relating to the permissible sound level and the exhaust system of motor vehicles, followed by other directives including the 2002 Environmental Noise Directive which contributes to the identification of noise levels in the EU and the adoption of measures to reduce them to acceptable levels [6], and other legislation regulating noise pollution from specific sources [7,8].

Despite the recognition of the importance of reducing environmental noise, it has had a lower priority than other environmental issues such as air and water pollution. The negative effects of transport, i.e. the noise generally associated with it, have gained recognition in the last 40 years in the world, considering more than 55% of the population started living in cities or urban agglomerations [9,10].

Consequently, in recent years noise has become a major environmental problem in the European Region of the World Health Organization, as more and more people complain of being exposed to excessive noise. According to a European Union (EU) publication, studies show that people in EU countries are exposed to road traffic noise as follows:

- about 40% at levels exceeding 55 db(A);
- about 20% at levels exceeding 65 dB(A) during the day;
- over 30% at levels exceeding 55 dB(A) at night [11].

The impact on human health refers to the constant exposure to high noise levels which can cause a range of short and long-term health problems such as stress, poorer performance at work and school insomnia, concentration problems, reduced sleep quality and even long-term hearing impairment [12]. Noise pollution also adversely affects flora and fauna in urban areas. It can also affect animals, disrupting their normal behaviour, and a constant level of noise can also affect plant pollination.

Consequently, noise pollution from transport requires special attention in densely populated and industrial cities, as there is a tendency towards increased noise annoyance in urban regions. Noise that occurs on a busy city street spreads not only to the region adjacent to the street, but also deep into the housing complex.

Factors affecting noise levels from traffic on a busy city street [13, 14, 15] are:

- traffic volume,
- speed of vehicles in traffic,
- infrastructure (road gradient, radius of curves, nature of the road surface),
- traffic composition (number of trucks in the traffic flow),
- driver behavior,
- type of vehicles,
- type of speed reduction measures

In general, the amount of traffic noise increases with increasing traffic intensity, increasing vehicle speed and increasing number of heavy vehicles. It is known that vehicle noise is a combination of engine noise, exhaust noise and /or tyre noise. In addition, noise levels vary constantly depending on the number, type and speed of vehicles producing the noise in traffic. When measuring traffic noise on a road it is necessary to take these different noise levels into account.

Regulations and standards in many cities have required noise pollution to be limited. These include restrictions on permissible noise levels for vehicles and the areas in which they can travel [16].

The problem of the influence of noise pollution on the well-being of nature and people is a topical one and solutions are always being sought to improve the situation and protect people from traffic noise.

There are several ways to reduce traffic noise, including:

a) vehicle noise control (use of quieter engine technologies) [17]. Quieter engines and sound insulation systems incorporated in vehicles can help lower noise levels generated during operation. The promotion of low-emission vehicles leads to a shift towards zero-emission vehicles which can bring significant noise pollution benefits. Electric and hybrid vehicles can have a lower impact on the noise environment compared to vehicles with internal combustion engines [18].

b) noise-compatible planning. Smart urban planning can help reduce noise pollution. This includes, for example, establishing residential areas away from busy traffic arteries, designing green spaces and using noise-insulating building materials for buildings.

c) traffic management techniques. Traffic control can sometimes reduce traffic noise problems, and this can be done for example by:

- Banning certain types of vehicles (usually heavy vehicles) from certain streets and roads. This could be done through traffic control devices and signs. Banning trucks from a major road can produce a noise reduction of up to 8 dBA to 10 dBA.
- Allowing certain types of vehicles (again, usually trucks) to use certain streets and roads only during certain noise-sensitive times, such as daylight hours.
- Timing traffic signals to achieve a smooth flow of traffic and eliminate the need for frequent acceleration and deceleration.
- Reducing speed limits.
- Separating noisier vehicles from other vehicles and placing them further away from receivers (i.e. dedicated vehicle lanes).
- A common method of traffic calming, which Ashley (1994) [19] stated has several objectives (reducing vehicle speeds, improving safety, removing outside traffic and improving environmental quality) is to modify the road (horizontal or vertical alignment or road surface).

d) using rubberized asphalt to greatly reduce noise [20, 21, 22].

e) acquiring property rights/property to create buffer zones.

f) planting vegetation. In addition to the main role of sound barrier, these green barriers have other advantages such as: biodiversity, attractiveness, air purification and temperature management [23].

g) implementation of sound insulation measures in roads and buildings [24].

h) construction of noise barriers other than green barriers.

i) promoting individual responsibility and quieter driving practices [25]. Public awareness and education on the impact of noise pollution and education in the area of individual responsibility can lead to behavioural changes. Choosing to use less noisy means of transport or adopting quieter driving practices can contribute to overall noise reduction.

Reducing noise pollution from road traffic requires an integrated approach involving government, industry and individual factors. Cooperation between government authorities and the vehicle industry can lead to the development and implementation of innovative solutions to reduce noise pollution. Joint initiatives can include standardization of maximum noise levels and development of advanced vehicle technologies.

The combination of effective regulations, innovative technologies and public awareness can contribute to improving the quality of the noise environment in urban areas [26].

There are a number of methods for controlling road traffic noise and noise barriers are arguably the simplest, most effective and widely used of the alternatives. Turkey and many other countries have established their methods for noise control and national noise barrier standards such as: TS EN 1793-1,2,3 [27, EN 1794-1,2,3 [28] and ZTV-LSW 06 [29].

2. METHOD

The following instruments were used for noise measurements:
- calibrated sound level meter,
- Arduino equipment (telephone)
- Android application.

a) Sound level meter (SLM)

A sound level meter is a device used to assess sound pressure levels, which can include pure or complex sounds and noises. It consists of a microphone that can be directional or ambient, an amplifier, a voltmeter calibrated in decibels, and possibly a band pass filter, often with a bandwidth of one or one-third octave. More advanced models may include settings for sensitivity, maximum and minimum limits, digital display of pulsed sounds, recording in fractions of a second at medium sound levels and longer or shorter durations.

Sound level meters are commonly used in noise pollution research to measure various types of noise, including industrial, environmental and airborne noise. They are designed to simulate the human ear's response to sound so as to provide objective and repeatable measurements of sound pressure.

A sound level meter (Figure 1) was used for the measurements with a range of 30-130dB at frequencies between 31.5Hz-8KHz and an accuracy of +1.4dB. Calibration was performed with the CEM SC-05 A calibrator (Figure 2). This is a compact and easy to carry instrument, suitable for calibrating digital sound level meters equipped with a 2" diameter microphone. Its technical specifications are:

-selectable sound pressure level 94dB, 114dB respectively;

-accuracy +0.5dB;

-output frequency: 1000Hzt4% [29].

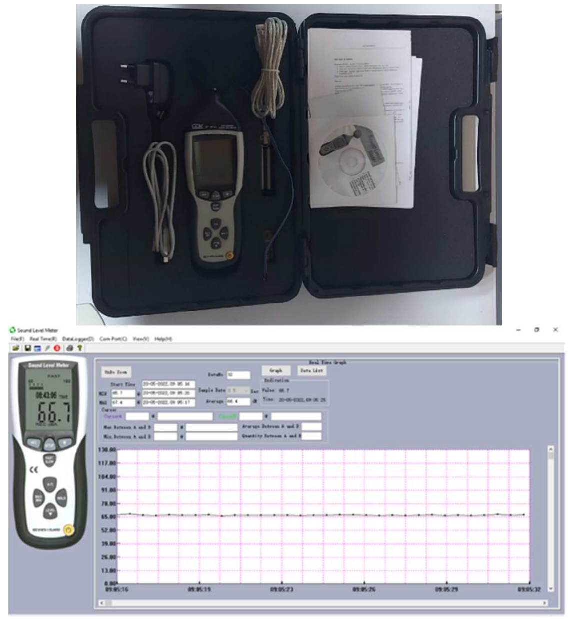

Fig. 1. Sound level meter equipment and its interface [30]

Fig. 2. Sound level meter calibrator and calibration operation

b) Arduino Nano equipment (S)

Arduino equipment is already widely deployed and used by manufacturers, testers and hardware enthusiasts. With an extensive range of functionalities, they allow the creation of a variety of projects, find limited only by the codes used and certain technical aspects. Due to their small size, they minimize power consumption, increasing their usefulness in tight spaces and making them more accessible for projects that require size limitations. An Arduino Nano board (Figure 3) and a MAX9814 sensor (Figure 4) were used to build this device.

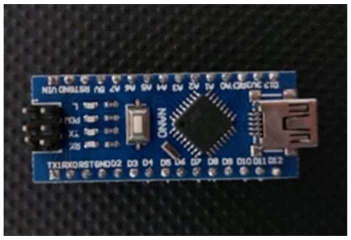

Fig. 3. Arduino Nano board

The technical features of the board include:
- use of the Atmel ATmega 328p microcontroller at a frequency of 16MHz.
- memory consists of 16KB or 32KB flash, depending on the version, of which 2KB is for the bootloader, 1 or 2KB of SRAM memory and between 512 bytes or 1KB EEPROM, depending on the MCU.
- the board is powered at 5V, but can vary up to 12V. The board has 14 digital pins, 8 analogue pins, 2 reset pins and 6 power supply pins (Vcc and GND). The analogue and digital pins can receive additional functions.
- The power consumption of the board is 19mA.
- PCB size is 18x45mm, with a weight of only 7 grams.

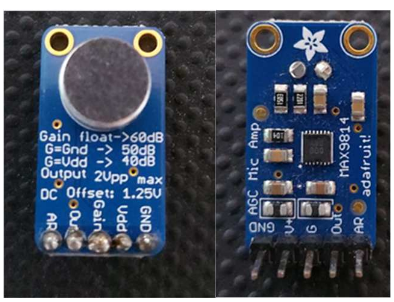

Fig. 4. Arduino MAX 9814 Sensor

The MAX9814 is a high quality, affordable microphone that features a built-in amplifier and automatic noise level control (AGC). This device includes a low noise preamplifier, a high frequency variable amplifier (VGA), an output amplifier, a microphone voltage generator and control functionality for the AGC circuit.
The device is functional over an extended temperature range of -40C to +85C.

c) Android Sound Meter app (T)
The third Smart Tools collection, which includes the Sound Meter app (Figure 3), integrates functionality for noise control and decibel (dB) level measurement. The Sound Meter app focuses on sound pressure level (SPL) measurement and uses the built-in microphone to assess noise volume in decibels (dB), providing a reference and generating a corresponding graph.

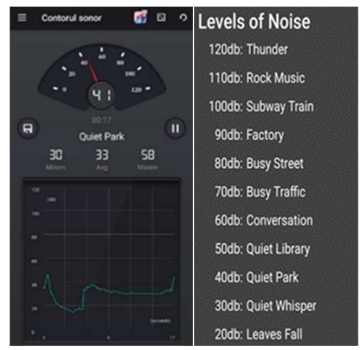

Fig. 5. App interface and its noise thresholds (Source: Android Sound Meter app)

Smartphone microphones are calibrated to capture frequencies in the human voice range (300-3400Hz) and noise levels between 40 and 60dB. The hardware capability limits the maximum values, so very loud sounds (more than 90dB) cannot be detected or recorded properly.
Measurements were carried out on two vehicles:
- MAS vehicle (diesel) is a Volkswagen Golf 7 powered by a 1.4 TSI 125 HP engine, year of manufacture 2017 (Figure 6) [31],
- MAC vehicle (benzine) is a Citroen Xsara Picasso powered by a 1.6 HDI 90 HP engine, year of manufacture 2008 (Figure 7) [32].

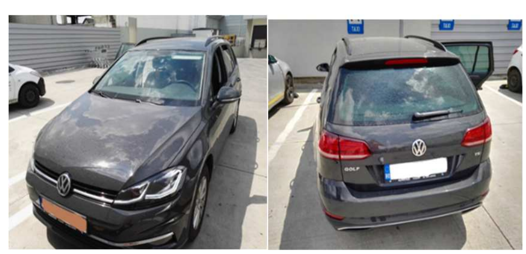

Fig. 6. MAS vehicle - front and rear view respectively

Fig. 7. MAC vehicle - front view, respective rear view

Noise measurements were made both at standstill (at the engine compartment and at the exhaust pipe) and in motion starting from a speed of 20km/h, then every 20 km/h, respectively. A further measurement was made at the maximum legal speed on the motorway of about 130 km/h (at the front and rear of the passenger compartment). On the move, measurements were taken over a distance of 20 km. The measuring devices were positioned on the dashboard for measurements in the front of the passenger compartment, and in the rear in the middle of the seat.

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3. RESULTS

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3.1. Results of stationary measurements

The results of the engine compartment and exhaust pipe measurements (Figure 8) at idling speed for the two vehicle types are given in the table below.

Fig. 8. Steady-state meters (from engine compartment, i.e. from exhaust pipe)

Table 2 Values obtained in steady-state

	Measuring instruments [dB]					
	MAS			MAC		
	SLM	T	S	SLM	T	S
Engine compartment	72,1	77	58	80	84	60
Exhaust pipe	60,4	67	40	67,1	75	44

3.2. Results of measurements in motion

The results of the measurements made in motion (Figure 9) for the two types of vehicles are given in the table 3 below

Fig. 9. Moving measurements

Table 3.1 Average values obtained for measurements in motion for MAS

Speed		Measuring instruments		
		SLM	T	S
20 km/h	**Front**	56,77	60,86	36,16
	Back	56,66	60,71	36,06
40 km/h	**Front**	57,82	61,86	37
	Back	58,82	62,91	38
60 km/h	**Front**	59,56	63,60	38,43
	Back	60,93	65,06	39,8
80 km/h	**Front**	63,64	67,83	42,77
	Back	66,24	70,36	45,37
100 Km/h	**Front**	73,27	77,46	52,27
	Back	69,05	73,24	48,05
120 Km/h	**Front**	77,10	81,19	56,02
	Back	70,37	74,43	49,30
130 Km/h	**Front**	77,48	81,91	56,48
	Back	71,27	75,40	50,27

Table 3.2 Average values obtained for measurements in motion for MAC

Speed		Measuring instruments [dB]		
		SLM	T	S
20 km/h	**Front**	67,60	63,52	42,78
	Back	67,80	63,76	43,02
40 km/h	**Front**	73,78	69,74	49,04
	Back	71,83	67,74	47,05
60 km/h	**Front**	73,83	69,78	49,17
	Back	75,66	71,53	50,92
80 km/h	**Front**	77,15	72,95	52,26
	Back	76,37	72,25	51,56
100 Km/h	**Front**	81,68	77,49	56,75
	Back	77,57	73,37	52,63
120 Km/h	**Front**	81,94	77,85	57,24
	Back	76,28	72,24	51,63
130 Km/h	**Front**	83,96	79,52	59,17
	Back	79,21	75,08	54,73

From the steady-state measurements it can be seen that in the exhaust area the noise reaches values equivalent to a normal conversation.
From the analysis of the results of the noise measurements made with the two vehicles in motion (Tabel 2 and figures 10), it can be seen that the speed of 20 km/h reaches the noise threshold equivalent to a normal conversation for MAS, and the diesel cars reach values of almost 70 dBA at this speed (Figure 10). As the speed increases, it is observed that the noise at the front is higher than at the rear of the vehicle for both cars. This is explained by the presence of the power unit in the front of the vehicle (Figure 11), and at 60 km/h the noise exceeds the threshold equivalent to a normal conversation (Figure 12). It can be seen from Table 3 that at a speed of 80 km/h the noise approaches the noise threshold at which psychological disturbances occur, this being reached at a speed of 100 km/h. As the vehicle speed increases for both MAS and MAC, the noise difference between the front and rear of the passenger compartment becomes more pronounced. Figure 13 show that vehicles equipped with MAC engines are noisier than those equipped with MAS engines.

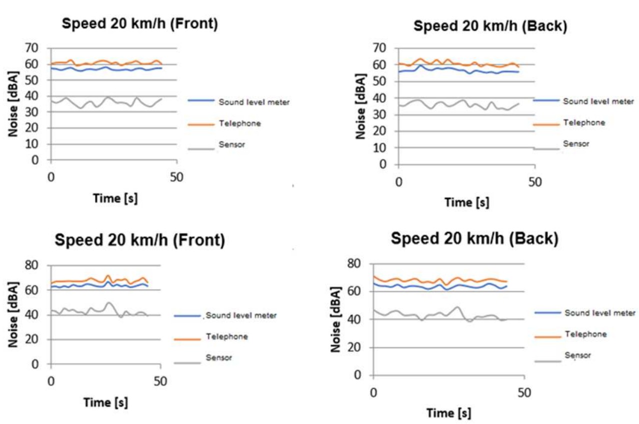

Fig. 10. Plot for front and rear measurements at 20 km/h for MAS and MAC respectively

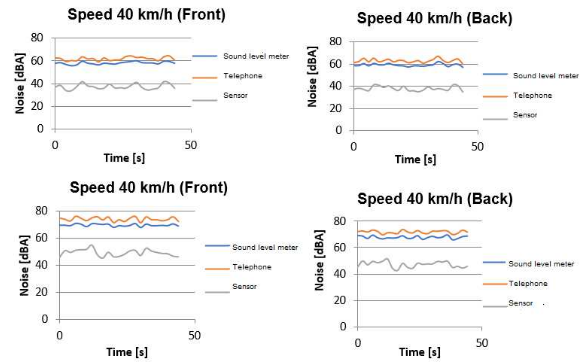

Fig. 11. Plot for front and rear measurements at 40 km/h for MAS and MAC respectively

Due to the origin of the sound and engine constructive characteristics, in the same conditions, from Figure 10 it can be seen that the MAC vehicle has a higher degree of noise influence than the MAS vehicle.
From Figure 11 it can be observed that the noise differences between the two vehicles are relatively small to inexistent in exploitation in the front part of the car, probably due to the insulation materials applied to the interior of the vehicles. Also, for both vehicles there are clear differences between the front and rear of each vehicle, the likely cause being that the influence of ambient noise was not addressed using the older technology of insulating materials in the case of used vehicles (for example Active Noise Control device).

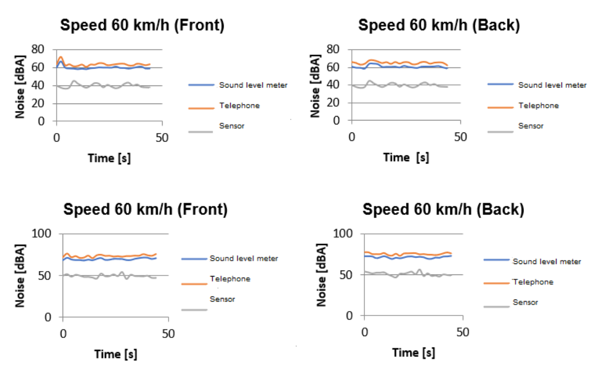

Fig. 12. Plot for front and rear measurements at 60 km/h for MAS and MAC respectively

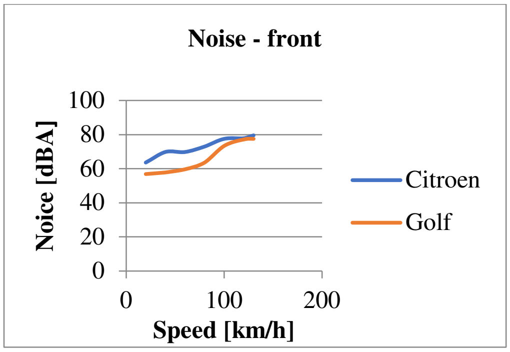

Fig.13. Noise graph of both vehicles in the front and rear passenger compartment (average values)

The same scenarios applies for higher levels of speed, all the measurements being executed inside the city and normal traffic conditions.
The tests conducted at 60 km/h speed (Figure 12) indicated that the front part of the vehicle was better insulated that the back part for both vehicles, in both cases the degree of potential discomfort in terms of noise control being higher for the passengers in the back side.

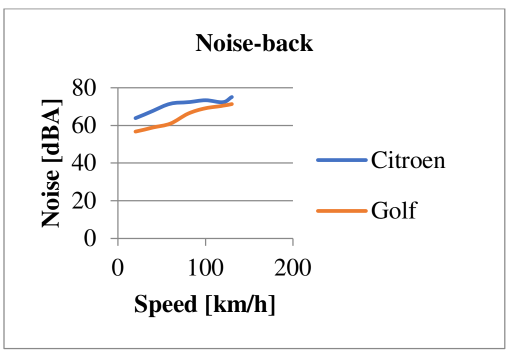

Fig.13.1. Noise graph of both vehicles in the back and rear passenger compartment (average values)

7.CONCLUSIONS AND RECOMMENDATIONS

Diesel engines usually produce more noise due to the time when the exhaust valve opens. Since the internal pressure inside the cylinder chamber is usually higher in diesel than in petrol engines, the noise is therefore higher during combustion. The pressure inside the cylinder is higher because of the way ignition, which is achieved by compression of the air and diesel mixture, compared to petrol, which is spark ignition.

Another reason why the MAC engine is noisier may be that it is not as well soundproofed as the MAS engine.

Another reason why the Citroen car is noisier than the Volkswagen is the year of manufacture, the Citroen is manufactured in 2007 and the Volkswagen is manufactured in 2017, this shows that the cars have become quieter.

Also it was determined in an experimental fashion that for both vehicles the noise levels uniformed at higher speed values and in terms of noise comfort the passengers in the back side experienced higher degrees of comfort by comparison with the front part of each of the tested vehicles.

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POLUAREA FONICĂ ÎN DIFERITE AUTOVEHICULE CU MOTOARE TERMICE – STUDIU DE CAZ PENTRU SCENARIUL LIMITĂRII VITEZEI ÎN ORAȘ

Lucrarea prezintă abordarea experimentală pentru două vehicule diferite echipate cu motoare termice MAS și MAC în ceea ce privește gradul de confort acustic în partea din față și din spate pentru potențialii pasageri, în diferite scenarii. Au fost prezentate masuratori statice si dinamice la diferite limite de viteza si au fost urmarite concluziile privind rezultatele gasite si cauzele posibile ale valorilor obtinute si nivelurile relative de confort pentru pasageri în partea din față și din spate a vehiculelor testate.

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