LENS L-vehicles Emissions and Noise mitigation Solutions

D4.5
Suggested revisions to TA procedure for noise emission

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Deliverable No.	D4.5	
Deliverable title	Suggested revisions to TA procedure for noise emission	
Deliverable type	Report	
Dissemination level	Public	
Deliverable leader	RWTH Aachen University (ika)	
Contractual due date	31.05.2025	
Actual submission date	23.07.2025	
Version	1.0	
Written by	Carolin Schliephake (ika, RWTH Aachen University), Saeed Shariatinia (ika, RWTH Aachen University), Michael Dittrich (TNO), Juan Garcia (IDIADA)	31.05.2025
Reviewed by	Michael Dittrich (TNO) Francesco Sini (DUCATI)	12.06.2025 16.06.2025
Approved by	All partners	17.06.2025

Revisions table

Version	Date	Change
1.0	23.07.2025	First submission to the EC

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Table of contents

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Executive summary

This document constitutes Deliverable D4.5 of the LENS-EU project and focuses on proposed revisions to the type approval (TA) procedures for noise emissions from L-category vehicles (LVs). It provides a detailed analysis of existing regulatory frameworks—namely UN Regulations No. 41, 9, and 63—and identifies key areas where current procedures fall short in capturing noise emissions under real-world conditions. Drawing on comparative regulatory assessments and a broad set of measurement data collected within the project, the document formulates five main recommendations aimed at improving the effectiveness, consistency, and realism of noise testing.

Recommendation 1: Harmonize Type Approval Procedures Across L-Category Regulations

The analysis revealed considerable procedural differences between the applicable UN regulations. Standardizing aspects such as test mass definitions, test types, measurement zone lengths, and gear selection logic would improve comparability across vehicle categories and reduce ambiguity in the type approval process.

Recommendation 2: Reevaluate the RD-ASEP Boundary Conditions, Especially Engine Speed Limits

Current RD-ASEP requirements exclude many real-world high-noise scenarios, particularly those involving high engine loads at low vehicle speeds. Adjusting the control ranges—especially the upper engine speed threshold—would allow these situations to be properly captured and regulated.

Recommendation 3: Integrate Real-World High-Noise Manoeuvres into Regulatory Procedures

Several frequent and noise-intensive driving behaviours, such as aggressive acceleration or throttle bursts, are not adequately reflected in current test protocols. These manoeuvres should be formally defined and integrated into type approval routines to ensure realistic and representative acoustic assessments.

Recommendation 4: Harmonize Noise Testing Across Vehicle Subtypes and Drive Technologies

The application of ASEP and RD-ASEP provisions is currently inconsistent across LVs and drive concepts. A unified framework should be developed to ensure that hybrid systems, CVTs, and other modern technologies are fairly and comprehensively assessed.

Recommendation 5: Allow Flexible but Reproducible Testing Conditions Reflecting Urban Environments

ISO-standard test tracks provide controlled conditions but fail to reflect complex urban acoustics. Supplementary, well-defined urban test procedures – supported by portable measurement setups – should be permitted to increase real-world relevance while maintaining test reproducibility.

Noise emissions from LVs remain a persistent issue in urban soundscapes. The data collected under the LENS project highlight a clear mismatch between what is tested and what actually occurs on the road. The recommendations outlined in this deliverable aim to bridge this gap through regulatory modernization that is both technically robust and politically feasible. These proposals strike a balance between scientific accuracy, regulatory harmonization, and practical enforceability. Their adoption would represent a significant step toward a more effective noise control strategy across Europe for powered two- and three-wheelers, as well as quadricycles. The deliverable provides a critical assessment of existing procedures and outlines potential adjustments aimed at enhancing the accuracy, relevance, and representativeness of noise measurements. The ultimate goal of this deliverable is to contribute to the development of more robust and effective noise type approval

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

procedures, ensuring that they align with real-world vehicle usage and evolving regulatory expectations.

List of abbreviations

AA’	Virtual line on the test track (starting line)
a_{urban}	Calculated acceleration corresponding to L_{urban}
ASEP	Additional Sound Emission Provisions
a_{wot}	Calculated acceleration corresponding to L_{wot}
$a_{wot,ref}$	Prescribed reference acceleration
BB’	Virtual line on the test track (end line)
CC’	Virtual line on the test track (driving lane)
CRS	Cruise condition in Annex 3
COP	Conformity of Production
CVT	Continuous Variable Transmission
$(i)/(i+1)$	Selected gear (UN Regulation No. 63, Annex 3)
k	Gear weighting factor
k_p	Partial power factor (UN Regulation No. 63, Annex 3)
L_{ASEP}	Calculated sound pressure level in dB(A) in ASEP-condition
L_{crs}	Sound pressure level in dB(A) at CRS condition
L_{urban}	Calculated sound pressure level in dB(A) at a_{urban}
L_{wot}	Sound pressure level in dB(A) at WOT condition
LV	L category vehicle
m_{test}	Test mass of vehicle
$\mathrm{n}_{AA'}$	Engine speed at AA’
$\mathrm{n}_{BB'}$	Engine speed at BB’
NORESS	Non-Original Replacement Exhaust Silencing Systems (UN Regulation No. 92)
n_{idle}	Engine speed at idle
n_{rated}	Rated engine speed
n_{max}	Maximum engine speed
PMR	Power-to-mass ratio
P_n	Rated maximum power
PP’	Virtual line on the test track (microphone line)
RD	Real Driving
RW-DC	Real World Driving Cycle (from LENS Deliverable 3.5)
TA	Type Approval (namely UN Regulation No.9, No. 41 and No. 63)
$v_{\mathrm{AA'}}$	Vehicle entry speed
$v_{\mathrm{BB'}}$	Vehicle exit speed
v_{max}	Maximum vehicle speed
v_{test}	Vehicle testing speed (UN Regulation No. 63, Annex 3, reached at PP’)
WOT	Wide open throttle condition in Annex 3

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101056777

List of figures

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

List of tables

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

1 Introduction

The transition to cleaner and quieter urban mobility is a critical challenge facing both urban and rural municipalities. In recent years, the issue of environmental noise — especially from road traffic — has garnered increasing attention due to its detrimental effects on public health, quality of life, and urban ecosystems [1]. Among the various contributors to traffic noise, L-category vehicles (LVs) such as motorcycles, mopeds, and tricycles play a notable role, particularly in densely populated areas and along popular touring routes. Figure 1-1 shows the different subcategories within L-category. In this report, the term *LVs* refers to all vehicles classified under the European *L-category*. The designation *category* refers to the broader classification levels, such as L_1, L_2, L_3, etc. Within each category, the term *subcategory* is used to describe the more specific distinctions, as e.g., L1e-B or L3e-A3, illustrated in Figure 1-1.

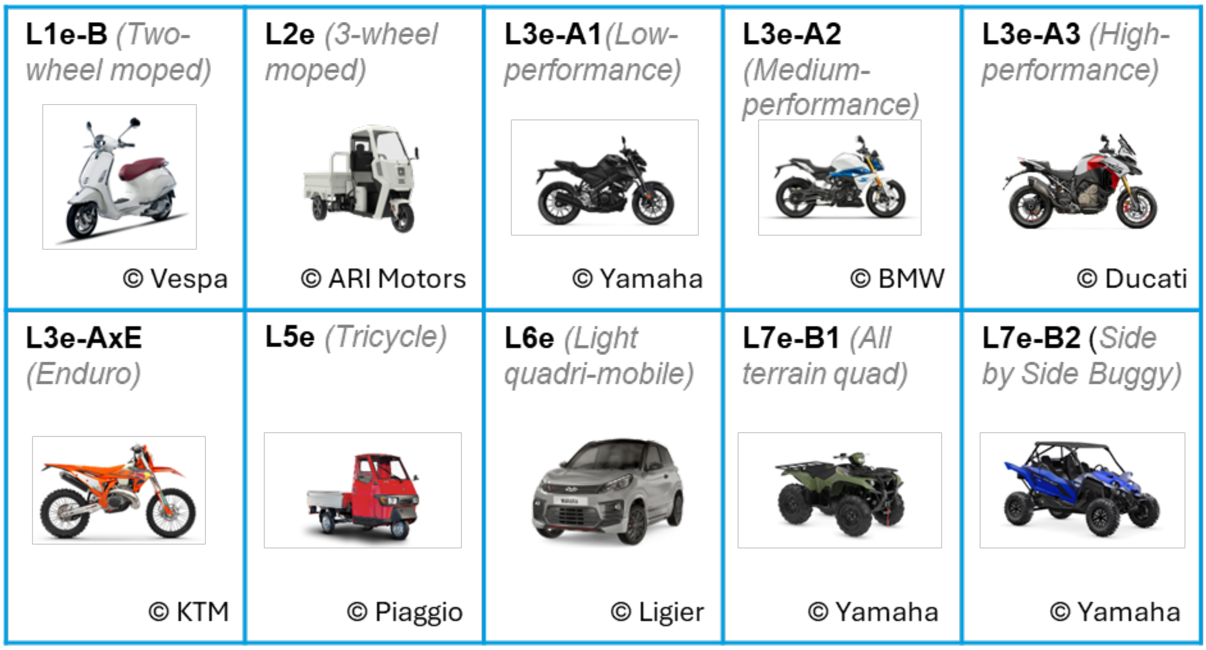


Figure 1-1: Overview of L-categories and its subcategories as well as respective vehicles

In order to address the noise emissions from LVs, regulatory bodies under the United Nations Economic Commission for Europe (UNECE) have established a series of type approval (TA) procedures intended to limit the permissible sound emissions of such vehicles. Currently, the primary legal frameworks guiding noise type approval for LVs are:

1. UN Regulation No. 9 [2] – Applicable to tricycles
2. UN Regulation No. 41 [3]– Applicable to motorcycles
3. UN Regulation No. 63 [4]– Applicable to mopeds

While these regulations provide a standardized approach, they are increasingly seen as insufficient for accurately reflecting real-world noise behaviour. It is important to note that these TA procedures

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

primarily apply to new vehicles at the point of market entry and do not address the current vehicle fleet. In practice, many vehicles could be easily modified or tampered with after purchase to produce higher noise levels, an issue that is not controlled by the initial type approval. The challenges related to tampering are addressed here [5; 6]. The LENS (*L-vehicles Emissions and Noise mitigation Solutions*) project, funded by the Horizon Europe program, is a collaborative research initiative that aims to redefine how we understand and manage noise and emissions emitted by LVs in real-world conditions [7]. LENS brings together leading experts, institutions and stakeholders from across Europe to develop and validate innovative approaches to measuring and assessing the environmental impact of LVs. Rather than relying solely on laboratory-based tests, LENS focuses on real-world driving conditions - ensuring that assessment methods reflect the complexities of traffic.

This public report is part of work package 4, which outlines the revised laboratory testing and comparison with TA and on-road results. This deliverable offers a critical review of the current TA methodology and outlines a set of proposed revisions aimed at aligning regulatory noise assessments more closely with everyday vehicle operations.

At the heart of the current methodology lies in Annex 3 for alle three regulations mentioned above, which defines a laboratory test procedure to measure vehicle noise under tightly controlled conditions. Typically, these tests involve 1 to 2 fixed operating points — wide open throttle (WOT) and constant speed driving (CRS). While this allows for reproducibility, it significantly narrows the assessment scope:

- **Limited representativity**: The selected test points do not capture the full performance envelope of modern powertrains, especially in motorcycles with high engine variability.
- **Potential for optimization loopholes**: Manufacturers may calibrate vehicles specifically to perform well under these limited test conditions, without ensuring low noise across the broader operational range.
- **Lack of context**: Real-world influences such as gear selection strategies, dynamic acceleration behaviour, and road gradients are not reflected.

To address these gaps, additional regulatory layers have been introduced: Annex 6 (ASEP – Additional Sound Emission Provisions) was implemented in UN Regulation No. 9 [2] to ensure that noise levels remain within acceptable bounds under a broader array of vehicle conditions, not just those measured during Annex 3 testing. Annex 7 (RD-ASEP – Real Driving ASEP) in UN Regulation No. 41 [3] pushes this even further by requiring compliance under driving conditions that resemble real-world urban and extra-urban usage. While ASEP and RD-ASEP represent significant progress, challenges remain in their consistent enforcement and interpretation, especially across different vehicle categories (e.g., mopeds vs. high-performance motorcycles).

Following this goal, the report is structured as follows: Chapter 0 evaluates the state of the art on Type Approval testing for LVs. In the end, the discrepancies between the different regulations are pointed out. Additionally, the Regulation regarding after-market exhaust systems (UN Regulation No. 92) is evaluated as this is one of the few possibilities to target current vehicle fleets. Afterwards, the measurements conducted within the project with respect to noise are introduced in Chapter 3. Measurement campaigns in real traffic and the manoeuvres from the LENS-deliverable D3.5 [8] are shortly introduced. As the deliverable D 3.5 focuses on driving patterns, this deliverable D4.5 only gives an overview. Afterwards and as a result from those measurements, suggested revisions are derived from in Chapter 4.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

In addition to the nomenclature defined previously, the following terminology shall be used with regard to driving conditions. The term *driving condition* – also referred to generically as *manoeuvre* – serves as a general descriptor for all possible operational states or scenarios applicable to LVs. Within this context, the following distinctions apply:

- When referring to an entire route in real-world usage: *real world (RW) driving profile*
- When referring to specific driving conditions tested under controlled circumstances (e.g., on an acoustic test track): *real world (RW) driving patterns*
- When referring to rider-specific influences or style: *driving behaviour*

This report is public, and therefore for a broader audience, both in relation to research and practical understanding of the current type approval procedure as well relevant noise phenomena currently not covered in the type approval of LVs.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

2 Review of the current type approval situation

Within the EU, type approval for noise is covered by Regulation 168/2013 [9] and its Amendment 134/2014 [10]. As mentioned in Chapter 0, three type approvals for noise emissions are defined for LVs. A more precise overview which Regulation is conducted for which subcategories, is given in the following Table 2-1. In this Chapter, all three regulations are explained, highlighting similarities and differences. The explanation of the three regulations is structured to proceed from the most complex regulation (UN Regulation No. 41 [3]) to the simplest regulation (UN Regulation No. 63 [4]) in terms of the number of measurements required. Afterwards, the differences between the TA procedures are highlighted as motivation for the proposed revisions in general. Finally, an introduction regarding the legislation for replacement exhaust silencing systems, UN Regulation No. 92 [11], is given. A brief introduction to the higher level regulation, which all three TA regulations must comply with, is given first.

Table 2-1: Overview of UN Regulation application with respect to subcategories [10]

Vehicle (sub-) category	Vehicle (sub-)category name	Applicable test procedure
L1e-A	Powered cycle	UN Regulation No. 63 [4]
L1e-B	Two-wheel moped	
L2e	Three-wheel moped	UN Regulation No. 9 [2]
L3e-A1	Two-wheel motorcycle ($engine\ capacity \leq 80\ \mathrm{cm}^3$)	UN Regulation No. 41 [3]
L3e-A2	Two-wheel motorcycle ($80\ \mathrm{cm}^3 < engine\ capacity \leq 175\ \mathrm{cm}^3$)	
L3e-A3	Two-wheel motorcycle ($175\ \mathrm{cm}^3 < engine\ capacity$)	
L4e	Two-wheel motorcycle with side-car	
L5e-A	Tricycle	UN Regulation No. 9 [2]

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

L5e-B	Commercial tricycle	
L6e-A	Light quad	UN Regulation No. 63 [4]
L6e-B	Light mini car	UN Regulation No. 9 [2]
L7e-A	On-road quad	
L7e-B	All-terrain vehicles	
L7e-C	Heavy mini-car	

The ISO 10844 standard [12] provides the fundamental requirements for the construction and validation of test tracks used in acoustic measurements, and it plays a critical role in the type approval (TA) process of LVs. These vehicles, which include mopeds, motorcycles, tricycles, and quadricycles, exhibit specific dynamics and noise emission characteristics that demand appropriately designed test environments. The standard prescribes detailed physical, geometrical, and acoustic specifications for these tracks to ensure that vehicle noise measurements are reliable, reproducible, and not influenced by varying road surface conditions. While the intention behind ISO 10844 is to enable consistency across different test sites, the highly controlled nature of these test tracks also raises questions about their ability to replicate realistic operating conditions. Therefore, the test tracks built according to ISO 10844 resemble laboratory conditions more than they do actual roads.

Before mentioning the road surface details, the standard also restricts the area around the test track, which must fulfil free-field conditions within a radius of 50 meters. This means that the zone must be free from large reflective objects such as buildings, fences, dense vegetation, or elevation changes that could influence the propagation of sound waves emitted by the test vehicle. The intention is to eliminate any acoustic reflections that might artificially alter the measured sound pressure levels at the microphones. By establishing such an acoustically neutral zone, ISO 10844 ensures that the test track behaves similarly to an idealized open space, where only direct sound paths between the vehicle and the microphones dominate the measurement. However, these conditions are not typical of real traffic environments, especially in urban areas. The absence of nearby surfaces that reflect or diffuse sound removes an entire layer of environmental interaction that would normally contribute to the acoustic character of a vehicle's noise emission. Figure 2-1 shows the overall layout of an ISO 10844 test track. Line AA' describes the entrance of the relevant measurement area perpendicular to the driving direction, line BB' the exit of the area. Line CC' corresponds to the centre of the vehicle/the vehicles driving path. In case of public road measurements, line CC' corresponds to the centre of the vehicle driving lane (right lane for right-hand traffic). The line PP' is the position of the microphone 7.5m perpendicular to the reference line CC' and 1.2m height.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Among the most critical specifications of ISO 10844 are those concerning the geometry of the surface, particularly gradient and cross-fall. The longitudinal gradient is limited to a maximum of 1 %, while the cross-fall, or transverse slope, must remain within the range of 1 % to 1.5 %. These tight tolerances are intended to eliminate any effects that topography may have on vehicle noise emissions, especially those that could alter the interaction between tyre and road. However, these specifications also create a road environment that is almost entirely flat, which is rarely the case in real-world settings. LVs, due to their small dimensions and relatively simple suspension systems as well as (close to) no enclosure of the drive train, are particularly susceptible to variations in road gradient and surface imperfections and consecutively to high noise events.

The unevenness, or surface irregularity, is another key parameter under ISO 10844. It includes requirements for both longitudinal and transverse surface profiles and is assessed based on measurements taken across predefined points on the track. There are two levels of compliance: one that applies to the average value over all measurement points and another that requires at least 80% of these points to meet the standard. These measurements must be conducted separately for the driving lane and the sound propagation area. The two different areas of the testing field are shown in Figure 2-1.

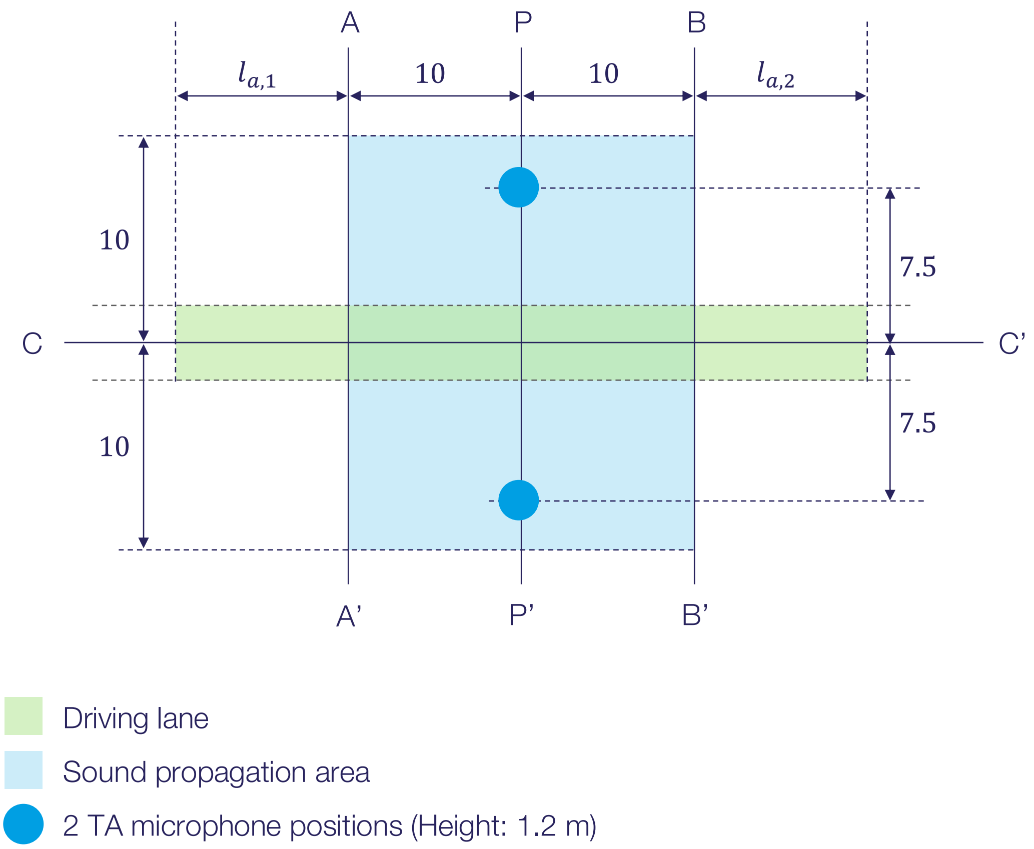


Figure 2-1: Dimensions of the test section according to ISO 10844 [12]

In the case of the driving lane, there are further distinctions between requirements during the initial approval of the track and those during its periodic verification. While these distinctions allow for some degradation of the surface over time, they still enforce a highly regular, smooth surface that again

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

departs significantly from the conditions found on roads. For the sound propagation areas, which influence how noise is transmitted and measured at defined receiver positions, the requirements apply only at the time of initial approval. This difference introduces an asymmetry in the standard's approach to long-term surface maintenance, potentially affecting the acoustic properties over time and thus the reproducibility of test results.

In addition to surface geometry and unevenness, ISO 10844 sets out strict limits on the acoustic absorption characteristics of the surface. Sound absorption is measured in third-octave bands from 315 Hz to 1600 Hz, and results are evaluated both as arithmetic means and against an 80 % compliance criterion. For the driving lane, the average absorption must not exceed 8 % in any third-octave band, and at least 80 % of the measurement points must remain under this limit. For the propagation area, the corresponding limits are slightly more relaxed at 10 %, yet still reflect an idealized surface condition rarely encountered outside test environments. These measurements must be conducted in accordance with ISO 13472-2 [13], and require between two and five measurement points, which further emphasizes the standard's focus on precision and repeatability. While controlling sound absorption is essential for accurate noise measurements, it also reinforces the notion that the test surface behaves more like a controlled acoustic laboratory than a public road.

Closely related to acoustic absorption is the specification for surface texture, defined by the mean profile depth (MPD). ISO 10844 stipulates that the driving lane must exhibit an average MPD of 0.5 mm with a tolerance of ±0.2 mm, and that this range must be met in at least 80% of the measured areas. The texture of the road has a significant influence on tyre-road interaction noise, and while this specification ensures a certain level of standardization, it again raises concerns about its representativeness. Most road surfaces — especially those encountered by LVs in city environments — show a much wider variation in surface texture, often due to wear, weathering, or substandard repair work. These conditions, while acoustic complex, are integral to the operational environment of such vehicles and their omission from the testing environment limits the relevance of test results for practical noise assessment.

The material properties of the test track surface are also strictly regulated under ISO 10844. The standard requires the use of dense asphalt concrete with a minimum thickness of 30 mm and explicitly prohibits the use of elastic or sound-damping materials. This ensures that the surface retains its acoustic characteristics over time and under varying weather conditions. Again, while this contributes to test repeatability and longevity of the track, it further distances the testing environment from actual roads, which may be constructed using a wide variety of materials including porous asphalt, concrete slabs, or even cobblestones in certain urban areas. LVs are more likely than other vehicle classes to traverse these less standardized surfaces, which means that acoustic data collected on ISO 10844-compliant tracks may not adequately reflect the noise emissions in actual use cases.

In summary, the specifications defined in ISO 10844 create a highly standardized and repeatable testing environment that is essential for ensuring comparability across different test locations and over time. This standardization is particularly important in regulatory contexts where small measurement deviations could influence compliance decisions. However, the controlled nature of the ISO 10844 test track — with its precisely defined surface characteristics, restricted environmental variability, and enforced free-field acoustic conditions — results in a test setting that diverges significantly from real-world operating conditions of LVs as, for example, there is no slope involved in the testing which of course has a high influence on noise emissions. These vehicles are often used on degraded pavements, in densely built-up areas, and under conditions where surface texture, irregularity, and

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

environmental acoustics vary considerably. While ISO 10844 ensures measurement precision and facilitates regulatory clarity, it simultaneously imposes laboratory-like conditions that may not accurately reflect the everyday acoustic performance of vehicles in actual traffic scenarios. It must be noted that within the scope of this project, neither the broader acoustic environment nor the detailed physical suitability of the ISO 10844-defined test track is subject to further investigation or validation. These elements are referenced here solely to provide necessary context for the following sections, which deal with the regulatory requirements as outlined in UNECE Regulations No. 41, 9 and 63. A clear understanding of the test track conditions is essential for interpreting these regulations correctly, but the evaluation of whether such test environments appropriately represent real-world conditions falls outside the objectives of this deliverable.

2.1 UN Regulation No.41

Regulation No. 41 of the United Nations Economic Commission for Europe (UNECE) [3] applies to L_3 category vehicles — two-wheeled motorcycles with an engine displacement exceeding 50 cm^3 and/or a maximum design speed above $45 \frac{km}{h}$. The regulation defines comprehensive noise measurement procedures and limits intended to ensure that these vehicles comply with internationally accepted acoustic standards. For vehicles equipped with multiple operating modes, such as different drive modes or power levels, compliance with all applicable requirements must be demonstrated for each mode under both Annex 3 and Annex 7 procedures.

The structure of UN Regulation No. 41 includes several annexes, each addressing a specific aspect of the TA process. Annex 3 describes the test methods for measuring sound emissions both under stationary and in-motion conditions. The stationary noise measurement prescribed in Annex 3 serves as a reference value, particularly for use by national authorities performing periodic checks of vehicles in use. While the stationary test is not directly tied to conformity of production, it establishes a valuable benchmark for enforcement outside of laboratory conditions. Annex 4 defines the layout of the test track, which must meet the requirements of ISO 10844. Annex 5 contains requirements for fibrous materials used in exhaust or silencing systems. Annex 6 specifies the applicable noise limit values, while Annex 7 introduces the so-called Real Driving Additional Sound Emission Provisions (RD-ASEP), aimed at ensuring noise compliance in real-world operating conditions.

Any modification that affects the vehicle type, exhaust system, or silencing components must be reported to the TA Authority. Depending on the nature and scale of the modification, the authority may decide to waive additional testing, deeming the acoustic impact negligible, or may require full reassessment through renewed testing procedures.

In terms of production compliance, Regulation No. 41 enforces strict acoustic consistency. The measured sound levels under TA conditions must not be exceeded by more than 3 dB(A) in any production vehicle. Specifically, the L_{wot} and L_{urban} values measured under Annex 3 shall remain within this tolerance. Furthermore, L_{urban} must not exceed the noise limits defined in Annex 6 by more than 1 dB(A), and L_{wot} shall not exceed L_{urban} by more than 6 dB(A). For Annex 7, which assesses real-driving behaviour, L_{ASEP} must also remain within 1 dB(A) of the TA value.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

2.1.1 Annex 3: Methods for measuring the emitted sound

Annex 3 defines the technical and procedural requirements for measuring sound emissions from L_3 vehicles, covering both stationary and in-motion test methods. Measurements are to be carried out with precision instrumentation: microphones must conform to class 1 specifications, with frequency weighting "A" and time weighting "F" applied throughout. The vehicle speed and engine speed must be monitored with high accuracy, while environmental parameters—such as ambient temperature, barometric pressure, wind speed, and relative humidity—must be recorded at a position representative of the microphone height. The test environment must meet specified meteorological conditions, including wind speeds below 5 m/s and temperatures between 5 °C and 45 °C. The background noise must also be classified to ensure it remains sufficiently below the sound levels of the test vehicle. Each side of the vehicle must be tested at least three times, with minimal deviation between runs.

The test track surface must comply with ISO 10844 and be dry during testing. Prior to measurements, the vehicle must reach its normal operating condition. The test mass must be determined according to the regulation: it is composed of the kerb mass (with at least 90% fuel and ready for normal operation), the driver, and any necessary testing equipment. The total additional load from driver and equipment is assumed to be 75 kg ± 5 kg. Tyre pressures must follow the manufacturer's specifications.

For in-motion tests, the vehicle must approach the measurement zone (blue in Figure 2-1) along a defined path: as close as possible to the CC' line, arriving at AA' and continuing through to BB'+20 m. Two types of dynamic tests are conducted: wide-open throttle (WOT) tests and constant speed (CRS) tests. During WOT tests, the vehicle must reach the AA' line at a constant speed, and the throttle must then be opened fully and rapidly, maintaining that position until the rear of the vehicle passes BB'. Pre-acceleration is permitted to ensure stable acceleration between AA' and BB'. The approach speed and selected gear must correspond to the target speed (v_{test}), which is expected to be reached at the PP' line.

In the constant speed tests, the objective is to maintain a constant v_{test} as the vehicle passes the PP' line. The test conditions differ depending on the vehicle's Power-to-Mass Ratio (PMR). For $\mathrm{PMR} \leq 25$, only WOT tests are required, and the target speed is $v_{test} = 40\frac{\mathrm{km}}{\mathrm{h}} \pm 1\frac{\mathrm{km}}{\mathrm{h}}$. Under WOT conditions, speed and engine speed constraints must be respected: the final speed at BB' must not exceed 75 % of the vehicle's maximum speed ($v_{\max}$), and the engine speed must not exceed its rated value n_{rated}. Gear selection must follow an iterative process to identify the lowest usable gear that satisfies these constraints; a flowchart provided in Appendix 1 guides this selection. If any of the two constraints mentioned are violated, a 10 % reduction in v_{test} is required.

For vehicles with $\mathrm{PMR} > 25$, two cases are distinguished:

- $\mathrm{PMR} \leq 50$ $\quad v_{test} = 40\frac{\mathrm{km}}{\mathrm{h}} \pm 1\frac{\mathrm{km}}{\mathrm{h}}$
- $\mathrm{PMR} > 50$ $\quad v_{test} = 50\frac{\mathrm{km}}{\mathrm{h}} \pm 1\frac{\mathrm{km}}{\mathrm{h}}$

In both cases, $v_{BB'}$ must remain below v_{max}. Reference accelerations ($a_{\mathrm{wot,ref}}$ and a_{urban}) are calculated from logarithmic functions of PMR as shown in Table 2-2, and gear selection follows

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

detailed logic based on whether the transmission is locked or automatic. In the case of locked gears, the following procedure applies:

- If two gears result in an acceleration that lies within the ±10% tolerance band around the reference acceleration value $a_{\mathrm{wot,ref}}$, the gear that produces the acceleration closest to the reference shall be selected.
- If only one gear meets the ±10% requirement, that gear shall be used.
- If no single gear fits within the tolerance band, two adjacent gears shall be selected such that the lower gear i yields an acceleration greater than $a_{\mathrm{wot,ref}}$ and the next higher gear $i+1$ yields an acceleration lower than the reference. This allows the calculation of a weighted result between both gears.
- If the engine reaches its rated speed (as defined in the regulation) before the vehicle crosses the BB' line, the next higher gear must be used, even if the reference acceleration is not achieved in that gear.
- If the vehicle has more than one gear, the first gear must not be used in the WOT (wide open throttle) test — even if the required reference acceleration is only attainable in the first gear. In such cases, the second gear shall be used to ensure a more realistic driving condition.

For vehicles with non-locked gears, such as fully automatic transmissions without manual gear control, the following rules apply:

- The gear selector must be placed in a position that enables fully automatic operation
- The test procedure may include a gear change, but gear changes that lead to higher gears and lower acceleration values are not permitted, as they would not reflect maximum noise conditions.
- Additionally, gear changes into gears that are not typically used in real-world traffic conditions must be avoided to maintain representativeness. This prevents noise measurements being conducted under artificially low-load conditions that are not representative of actual urban or highway driving.

For the CRS test, which is only mandatory for vehicles with a $\mathrm{PMR} > 25$, the gear selected, and gear selector position shall be the same as the WOT test.

Table 2-2: Overview of testing conditions for WOT test in UN Regulation No. 41, Annex 3

	$\mathrm{PMR} \leq 50$	$\mathrm{PMR} > 50$
v_{test}	$40\frac{\mathrm{km}}{\mathrm{h}} \pm 1\frac{\mathrm{km}}{\mathrm{h}}$	$50\frac{\mathrm{km}}{\mathrm{h}} \pm 1\frac{\mathrm{km}}{\mathrm{h}}$
$a_{\mathrm{wot,ref}}$	$2.47 * log(\mathrm{PMR}) - 2.52$	$3.33 * log(\mathrm{PMR}) - 4.16$

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

a_{urban}	$1.37 * log(\text{PMR}) - 1.08$	$1.28 * log(\text{PMR}) - 1.19$

Intermediate calculations are the following: Acceleration values of the actual measurements (a_{wot}) are not measured directly but are calculated based on vehicle speeds at defined points (AA', PP'. BB'). If multiple gears are tested, a weighting factor *k* is applied to average the measurements conducted in the different gears via

$$L_{wot} = L_{wot(i+1)} + k * (L_{wot(i)} - L_{wot(i-1)})$$ Eq. 2-1

$$L_{crs} = L_{crs(i+1)} + k * (L_{crs(i)} - L_{crs(i-1)})$$ Eq. 2-2

If the vehicle was only tested in one gear (i), the results for the two measurement procedures are

$$L_{wot} = L_{wot(i)}$$ Eq. 2-3

$$L_{crs} = L_{crs(i)}$$ Eq. 2-4

The TA result, with is the L_{urban}, is then derived based on the partial power factor k_p and a linear interpolation between the L_{wot} and the L_{crs} value

$$L_{urban} = L_{wot} + k_p * (L_{wot} - L_{crs})$$ Eq. 2-5

For vehicles with a $\text{PMR} < 25$ the final TA result equals to L_{wot} as only accelerated driving is performed.

The stationary test is carried out with the neutral gear. If neutral is not possible, the rear wheel must be suspended to allow free rotation. The microphone must be placed 0.5 m ± 0.01 m from the reference point of the exhaust pipe at a 45° ± 5° angle to its vertical plane, and its height must match the height of the pipe reference point (but be at least 0.2 m above the ground). A schematic overview is given in Figure 2-2.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

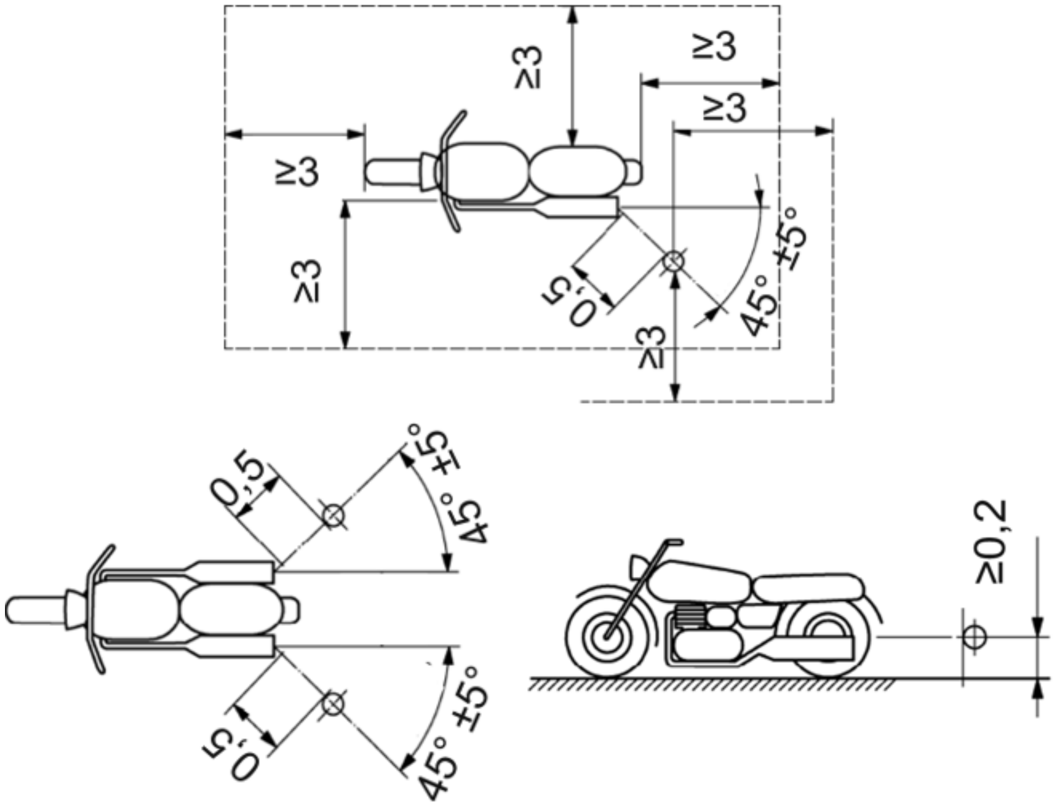


Figure 2-2: Schematic of the stationary noise test setup [14]

The target engine speed for the stationary test depends on the rated engine speed defined as

- $n_{rated} \leq 5000\text{min}^{-1}$ 75% of n_{rated}
- $n_{rated} > 5000\text{min}^{-1}$ 50% of n_{rated}

For a vehicle which cannot reach, in a stationary test, the target engine speed defined above, 95 % of the reachable maximum engine speed in a stationary test shall be used instead as target engine speed. The speed must be increased gradually from idle, held steady within ± 5%, and then the throttle released abruptly. The sound pressure level is measured during the constant speed phase, and the maximum A-weighted value is used. Three consistent measurements within 2 dB(A) must be obtained. If multiple modes exist, each must be tested separately.

2.1.2 Annex 6: Noise Limits

Annex 6 of Regulation No. 41 defines the maximum permissible sound levels for vehicles of category L_3, depending on their power-to-mass ratio (PMR). These limits serve as an upper boundary for the type-approval process and provide a critical benchmark against which measured noise emissions under Annex 3 procedures ($L_{urban}$and L_{wot}) are evaluated. The Power-to-Mass Ratio (PMR) is calculated as:

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

$$PMR = \frac{P_n}{m_{test}} * 1000$$ Eq. 2-6

Where P_n is the rated net power of the vehicle (in kW), and m_{test} is the test mass in kilograms. Depending on the resulting PMR value, the maximum permissible noise emission limits are as follows:

Table 2-3: Maximum sound levels for UN Regulation No. 41 (Annex 6)

PMR	Maximum sound level values in dB(A)
$\text{PMR} \leq 25$	73
$25 < \text{PMR} \leq 50$	74
$\text{PMR} > 50$	77

These values represent absolute limits that measured results must not exceed under the L_{urban} and L_{wot} test procedures defined in Annex 3. Notably, for Conformity of Production (CoP) assessments, L_{urban} must remain within 1 dB(A) of the applicable limit in Annex 6. Furthermore, L_{wot} shall not exceed L_{urban} by more than 6 dB(A). These tolerances ensure consistency between initial type-approval testing and the performance of vehicles produced in series.

2.1.3 Annex 7: RD-ASEP

Annex 7 of Regulation No. 41 introduces the RD-ASEP (Real Driving Additional Sound Emission Provisions), a complementary test procedure designed to assess vehicle noise emissions in real-driving-relevant operating conditions that go beyond those strictly defined in Annex 3. RD-ASEP applies only to vehicles of category L_3 with a $\text{PMR} > 50$, targeting higher-performance motorcycles that are more likely to generate significant noise emissions under a broader range of real-world scenarios. Considering, e.g., the national fleet in Germany, those are the majority my bikes within the current fleet [15].

The range which is covered by ASEP is shown in Figure 2-3. The reference point shows the result from the WOT testing in gear i. The green area is the range covered by the ASEP procedure. The ASEP limits are shown as the boarder of the green area, divided into two slopes. Slope A, which is covering the engine speeds below the exit speed of the vehicle at BB' (with the front of the vehicle) $n_{PP',wot,i}$ is defined as 1 dB per $1000\ \text{min}^{-1}$ and Slope B, which is covering the higher engine speeds, as 5 dB per $1000\ \text{min}^{-1}$. Any point measured must therefore be within the green area. Further explanation is given in [16]. AS RD-ASEP is covering a wider vehicle range and therefore a broad range of engine speed, the green area just expands from ASEP to RD-ASEP. The limit value calculation, and therefore the schematic overview from Figure 2-3 does not change much.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

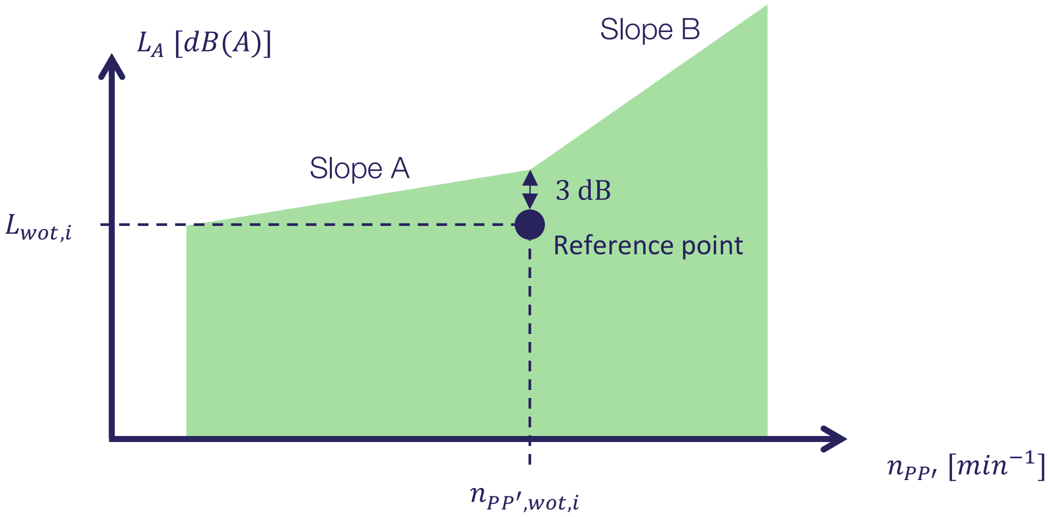


Figure 2-3: Exemplary ASEP testing range, modified from [17]

The measurement equipment, acoustic environment, meteorological conditions, background noise classification, microphone positioning, and vehicle conditions must comply with the same technical specifications as outlined in Annex 3 and therefore Chapter 2.1.1 of this deliverable. This ensures consistency in testing methodology while extending the operating envelope to capture additional noise behaviours under representative use cases.
Operational restrictions and conditions for the RD-ASEP procedure are more specifically defined to target engine operating points relevant for dynamic, real-world acceleration:

- The vehicle speed at line AA' ($v_{AA'}$) shall be at least $10\frac{\text{km}}{\text{h}}$.
- The vehicle speed at line BB' ($v_{BB'}$) shall not exceed $80\frac{\text{km}}{\text{h}}$ for vehicles with $PMR \leq 150$, and not exceed $100\frac{\text{km}}{\text{h}}$ for vehicles with $PMR > 150$.
- The engine speed at line AA' ($n_{AA'}$) must be at least

$$0.1 * (n_{rated} - n_{idle}) + n_{idle} \quad \text{Eq. 2-7}$$

  - ensuring that the engine is operating under moderate load conditions from the start of the test.
- The engine speed at line BB' ($n_{BB'}$) must not exceed $0.8 * n_{rated}$, effectively capping the test within a sub-maximum operating regime to reflect typical acceleration scenarios.

The test procedure itself mirrors that of Annex 3: the vehicle approaches line AA' at a steady speed. As the front of the vehicle reaches AA', the accelerator is fully opened (Wide Open Throttle – WOT), and this position is held until the rear of the vehicle passes line BB'. At this point, the accelerator is quickly released to return the engine to idle. This acceleration mimics typical real-world driving behaviour, such as overtaking or merging, in which vehicles emit higher levels of sound. Specifically for RD-ASEP however, the TA Authority may define a throttle position for a reference test. This means, partial throttle position of maintaining a throttle position when passing AA' is also possible when defined by the TA Authority.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

For the selection of test gears, a reference engine speed at line BB' ($n_{BB',ref}$) is calculated. Gear selection must comply with constraints based on achieving this reference while remaining within the defined limits for $n_{AA'}$ and $n_{BB'}$. This allows gear choice to reflect realistic, yet challenging operating points that could potentially lead to excessive sound emissions if not properly controlled by vehicle design or calibration.

Two RD-ASEP test procedures are generally defined based on the resulting engine speed ranges, intended to capture variability in engine loading and acceleration response across the powertrain's operational envelope. The ASEP noise limits are not fixed values but are instead calculated depending on engine speed and gear-specific conditions, taking into account variations in noise characteristics across the rpm range.

The inclusion of RD-ASEP within Regulation No. 41 underscores the regulatory intent to mitigate excessive noise emissions in everyday traffic scenarios, not just under idealized or narrowly defined test conditions. It aims to close potential loopholes and to ensure that vehicles demonstrating compliance in Annex 3 remain acoustically controlled throughout their normal range of operation.

2.2 UN Regulation No. 9

UN Regulation No. 9 applies to category L_2, L_4, and L_5 vehicles (trikes and quads) [2]. This regulation is designed to ensure that these vehicles comply with specific noise limits, both in motion and stationery, in accordance with defined measurement standards, close to the ones defined in Chapter 2.1. If the vehicle in question has multiple modes of operation, all modes must be compliant with the noise limits specified under this regulation. For hybrid vehicles, it is required to conduct two distinct measurement campaigns: one with the battery fully charged and the other with the battery fully discharged. This requirement ensures that the noise emissions are evaluated under both operating conditions, as hybrid vehicles can exhibit different acoustic behaviours depending on the charge level of the battery.

Again, Annex 3 defines the TA procedure with vehicle-in-motion as well as stationary tests. Stationary noise tests under this regulation provide a reference value for authorities, which may use this method to check vehicles in use. These tests are crucial for ensuring that vehicles on the road meet noise standards and do not contribute excessively to urban noise pollution. Annex 4 – comparable to Annex 6 in Chapter 2.1.2 – specifies the noise limits that vehicles must adhere to for in-motion tests. These limits are established based on vehicle category and PMR, ensuring that noise emissions remain within permissible thresholds. Annex 6 outlines the Additional Sound Emission Provisions (ASEP). These provisions require that, in cases where multiple driving modes are available, the worst-case scenario for sound emissions must be tested to ensure that the vehicle does not exceed the noise limits during typical use.

Furthermore, any modifications made to the vehicle type, exhaust system, or silencing system must be reported to the TA Authority. The TA Authority will assess whether these modifications have a negligible effect on noise emissions or if further testing is required to confirm compliance with the established limits.

The Conformity of Production (COP) requirements ensure that all vehicles produced under the Type Approval do not exceed the noise levels measured during the initial acceptance tests. Specifically, the following limits must be adhered to:

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

- The noise level measured on acceptance must not exceed 3 dB(A) above the values obtained in Annex 3 measurements.
- The noise level must not exceed 1 dB(A) beyond the underlying limits specified in Annex 4.
- The noise level should not exceed 1 dB(A) above the limits set forth in Annex 6 for the ASEP provisions.

These stringent requirements ensure that mass-produced vehicles maintain consistent compliance with noise standards throughout their production run, preventing significant deviations from the originally tested values.

2.2.1 Annex 3: Methods for measuring the emitted sound

Annex 3 of UN Regulation No. 9 defines the procedures for in-motion and stationary noise testing of L_2, L_4, and L_5 vehicles. In many respects, the structure and methodology align with the test procedures described in UN Regulation No. 41 Annex 3, as outlined in Chapter2.1.1, though adjusted for the specific characteristics of three- and four-wheeled vehicles and their respective drivetrains.

The acoustic instrumentation must comply with the requirements for class 1 microphones, applying time weighting “F” and frequency weighting “A”. Engine speed and vehicle speed are to be measured with high precision, and meteorological conditions must be recorded, including ambient temperature, barometric pressure, wind speed (not exceeding 5 m/s), and relative humidity. Background noise is to be classified and must remain sufficiently low to avoid influencing the results. The tests are to be conducted on a dry ISO 10844 surface, visible in Figure 2-1.

Prior to testing, the vehicle is brought to its normal operating condition, including engine and drivetrain temperatures and a fuel tank filled to at least 90%. The test mass m_{test} includes the vehicle in ready-to-drive state plus driver and equipment, with the latter two weighing between 70 and 90 kg. Tyre pressures are set according to the manufacturer's recommendation.

During wide-open-throttle (WOT) testing, the vehicle must approach the measurement zone between lines AA’ and BB’ at a constant speed. Upon reaching AA’, the accelerator is opened fully and held until the rear of the vehicle crosses BB’. Gear selection and the speed at the entry of the test zone depend on the drivetrain configuration. For vehicles without a gearbox and for those with locked gears, the lowest $v_{AA'}$ is selected between the following conditions regarding the entry condition

- $n_{AA'} < 0.75 * n_{rated}$
- $n_{AA'} < 0.75 * n_{max}$
- $v_{AA'} = 50\frac{km}{h}$

For vehicles with non-locked gears, the limitation refers only

- $n_{AA'} < 0.75 * n_{max}$
- $v_{AA'} = 50\frac{km}{h}$

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101056777

These criteria mirror the approach taken in UN Regulation No. 41, although some parameters differ slightly. At least two valid measurements must be taken on each side of the vehicle, with only minor deviations permitted between them.

For the stationary noise test, the engine is tested in neutral. If this is not possible, the vehicle is placed on a roller bench. The microphone is positioned at a distance of 0.5 ± 0.01 m from the reference point of the exhaust outlet, at a 45 ± 5° angle to the vertical plane containing the exhaust axis, and at the height of the reference point but not less than 0.2 m above the ground. The engine is smoothly accelerated from idle to the target speed and held there for at least one second within a tolerance band of ±5%. The throttle is then released rapidly, and the maximum A-weighted sound level is recorded. The target speed depends on the rated engine speed:

- $n_{rated} \leq 5000\text{min}^{-1}$ 75% of n_{rated}
- $n_{rated} > 5000\text{min}^{-1}$ 50% of n_{rated}

Three consecutive measurements within a 2 dB(A) range are required. Vehicles with multiple modes must be tested in each available mode.

For TA and future compliance checks, the tested gear (if applicable), vehicle speed at AA' $v_{AA'}$, and the final averaged result of four valid WOT measurements L_{wot} are recorded. There are also requirements concerning the use of absorbent fibrous materials in the exhaust system, similar to those found in UN Regulation No. 63.

Overall, the technical execution and structure of Annex 3 in UN Regulation No. 9 follow the same principles established in UN Regulation No. 41, while adapting individual parameters and test logic to suit the specific requirements of L_2, L_4 and L_5 vehicle categories.

2.2.2 Annex 4: Noise Limits

Annex 4 of UN Regulation No. 9 defines the maximum permissible sound level values for L_2, L_4, and L_5 vehicle categories. The structure and intention of this annex are closely aligned with those described in Annex 6 of UN Regulation No. 41, as presented in Chapter 2.1.2, where noise limits are categorized based on the vehicle's power-to-mass ratio (PMR). In contrast, UN Regulation No. 9 applies fixed noise limits directly to the vehicle category, without further subdivision, as shown in Table 2-4.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Table 2-4: Maximum sound levels for UN Regulation R9 (Annex 4)

Vehicle category	Maximum sound level values in dB(A)
L_2	76
L_4	80
L_5	80

These values apply to the average result of the in-motion wide-open-throttle (WOT) tests as defined in Annex 3 of the regulation. Unlike UN Regulation No. 41, which differentiates noise limits based on PMR bands, UN Regulation No. 9 applies a simpler category-based threshold approach. This reflects both the structural differences in vehicle configurations and the anticipated use cases of L_2, L_4, and L_5 vehicles, where classification-based grouping may provide a more practical framework for noise regulation.
Overall, while the measurement method and acceptance criteria remain consistent with those in UN Regulation No. 41 (in terms of averaging and rounding procedures), the use of fixed thresholds in UN Regulation No. 9 results in a more straightforward, albeit less nuanced, regulatory approach to setting noise limits

2.2.3 Annex 6: ASEP

Annex 6 of UN Regulation No. 9 defines the Additional Sound Emission Provisions (ASEP), which are applicable only to L_4 and L_5 category vehicles with a $\text{PMR} > 50$. The general purpose and structure of the ASEP provisions are consistent with those found in UN Regulation No. 41, as discussed in Chapter 2.1.3, aiming to ensure that vehicles remain compliant with noise limits under real-world driving conditions, outside of the narrow conditions of the TA test.
The procedural and technical requirements for ASEP measurements fully correspond to the specifications laid out in Annex 3. In terms of test execution, the vehicle must approach line AA' at a steady speed; once the front of the vehicle crosses AA', the accelerator is fully opened and kept at wide-open throttle until the rear crosses BB', at which point the throttle is released to idle as quickly as possible. This procedure is identical to the WOT acceleration described for the TA in-motion test in Chapter 2.2.1.
Specific restrictions are imposed on vehicle and engine speeds during the test:

- The vehicle speed at line AA' ($v_{AA'}$) shall be at least $20\,\frac{\text{km}}{\text{h}}$
- The vehicle speed at line BB' ($v_{BB'}$) shall not exceed $80\,\frac{\text{km}}{\text{h}}$
- The engine speed at line AA' ($n_{AA'}$) must be at least according to Eq. 2-7

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

- The engine speed at line BB' ($n_{BB'}$) must not exceed $n_{BB',max}$, which is derived from a function of idling and rated engine speed and the PMR.

These conditions ensure that ASEP captures a realistic and challenging portion of the vehicle's operating range without being overly restrictive.
As in UN Regulation No. 41, gear selection is a critical factor, and the correct test gear must be determined based on the reference engine speed at BB'. Two test procedures are defined within the ASEP framework, depending on engine speed. This adds complexity but allows more representative coverage of real-world conditions. The ASEP limits themselves are also dynamically calculated, depending on the engine speed during the test run, rather than applying a fixed threshold. This aligns conceptually with the approach used in UN Regulation No. 41, though the underlying calculation may differ slightly in detail and parameter sensitivity.
In summary, the ASEP requirements under UN Regulation No. 9 maintain close procedural consistency with those under UN Regulation No. 41 while reflecting the specific vehicle classes and operating characteristics of L_4 and L_5 vehicles. By focusing on high-PMR configurations and dynamically adapting test conditions and limiting values to vehicle behaviour, Annex 6 ensures that sound emissions are kept in check under a broad range of typical driving scenarios.

2.3 UN Regulation No. 63

UN Regulation No. 63 [4] applies to L_1-vehicles and outlines the procedures and requirements to ensure that these vehicles comply with defined noise limits during both stationary and in-motion operation. In the case of vehicles with multiple operating modes, compliance must be demonstrated for all modes. Similar to UN Regulations No. 41 and No. 9, the regulation is structured around a series of annexes, with Annex 3 detailing the technical test procedures and Annex 4 setting the applicable noise limits. As with the other regulations, stationary noise testing serves as a reference method that national authorities can use for verifying the compliance of vehicles already in use.
Any modification affecting the vehicle type, exhaust system, or silencing system must be reported to the Type Approval Authority, which will determine whether the change is minor or if further testing is required. This mirrors the approach found in UN Regulation No. 41 (Chapter 2.1) and UN Regulation No. 9 (Chapter 2.2). In terms of Conformity of Production, the same stringent tolerances apply: the measured noise level during production must not exceed the type-approved value (as determined in Annex 3 tests) by more than 3 dB(A), nor may it exceed the noise limit defined in Annex 4 by more than 1 dB(A). These provisions ensure a consistent noise performance of L_1 vehicles throughout their production lifecycle and reinforce the reliability of the type approval process.

2.3.1 Annex 3: Methods for measuring the emitted sound

The test procedures described in Annex 3 of UN Regulation No. 63 for L_1-vehicles follow a structure that is broadly aligned with the test methodologies established under UN Regulation No. 41 (Chapter 2.1.1) and UN Regulation No. 9 (Chapter 2.2.1). As in those regulations, Annex 3 of UN Regulation No. 63 requires the use of class 1 microphones with time weighting "F" and frequency weighting "A", high-precision measurements of engine and vehicle speed, and detailed meteorological

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

condition logging, including air temperature, wind speed (which must remain below $5\frac{\mathrm{m}}{\mathrm{s}}$), barometric pressure, and relative humidity. The acoustic environment must also be classified, and all measurements are to be conducted on a dry ISO 10844 surface.

Prior to testing, the vehicle must be brought to its normal operating condition with respect to temperature, drivetrain behaviour, and fuel level. The definition of test mass again corresponds with UN Regulation No. 41 and R9, calculated as the sum of the reference mass (vehicle ready for operation, with at least 90% fuel) and the combined weight of the driver and equipment, which must lie between 70 and 90 kg. Tyre pressure must comply with the manufacturer's recommendation.

For in-motion wide-open throttle (WOT) testing, the vehicle must approach the AA' line at a constant speed and, as soon as the front crosses AA', the accelerator must be fully and rapidly opened and held until the rear of the vehicle reaches BB'. Unlike UN Regulation No. 41 and R9, however, where gear selection and $v_{AA'}$ vary depending on gearbox configuration and engine speed parameters, UN Regulation No. 63 simplifies this process: the vehicle must enter the test zone at $30\frac{\mathrm{km}}{\mathrm{h}}$ if the vehicle's maximum speed exceeds that value, or at the maximum speed otherwise. The highest gear that allows the engine speed at AA' to be at or above 50% of the rated engine speed n_{rated} is to be used, a criterion that mirrors the spirit of ensuring a representative load condition but is less complex than the multi-tiered gear selection logic found in UN Regulation No. 63 and R9. At least two valid measurements must be recorded from each side of the vehicle.

For stationary noise testing, the vehicle must be in neutral; if neutral is not possible, it should be placed on its stand. The microphone is positioned in the same manner as in the other regulations: 0.5 ± 0.01 m from the exhaust outlet reference point at a 45 ± 5° angle to the vertical plane through the pipe's axis, with the microphone height equal to that of the reference point, but no lower than 0.2 m from the ground. The target engine speed is defined by the same thresholds as in UN Regulation No. 63 and R9:

- $n_{rated} \leq 5000\mathrm{min}^{-1}$ 75% of n_{rated}
- $n_{rated} > 5000\mathrm{min}^{-1}$ 50% of n_{rated}

The engine must be gradually increased from idle to the target, held within ±5%, then rapidly released. The maximum A-weighted sound level during at least 1 second of steady engine speed is used as the test value. Three measurements must be made within a tolerance of 2 dB(A). All modes must be tested if the vehicle has multiple operational modes.

Compliance reference data include the selected gear, the approach speed $v_{AA'}$, and the final test result, which is the average of the four measured values rounded to the nearest whole dB(A). Furthermore, Annex 3 of UN Regulation No. 63 also requires documentation and compliance of any fibrous absorbent materials used in the exhaust system, again echoing the standards found in UN Regulation No. 63 and Regulation No. 9.

Overall, while the procedural backbone of Annex 3 in UN Regulation No. 63 remains consistent with the methodology in UN Regulation No. 63 and R9, the simplification in gear and speed criteria, tailored specifically for lower-powered L_1 vehicles, marks a practical divergence suited to the vehicle class's performance characteristics.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

2.3.2 Annex 4: Noise Limits

Annex 4 of UN Regulation No. 63 outlines the applicable noise limits for vehicles falling under L_1, as tested in accordance with the procedures detailed in Annex 3. These noise thresholds are defined based on the maximum design speed of the vehicle and the nature of its propulsion system, providing a clear framework for evaluating compliance. The following table summarizes the maximum permitted A-weighted sound pressure levels:

Table 2-5: Maximum sound levels for UN Regulation No. 63 (Annex 4)

Maximum design speed in $\frac{km}{h}$	Maximum sound level values in dB(A)
<=25	66
> 25	71
Cycles designed to pedal equipped with an auxiliary propulsion, other than electrical, with the primary aim to air pedalling and output of auxiliary propulsion is cut off at a vehicle speed $\leq 25 \frac{km}{h}$	63

These values reflect the regulation's intent to maintain low noise emissions, particularly for vehicles primarily used in urban or low-speed environments. Compared to the limits specified in UN Regulation No. 41 (Chapter 2.1.2) and UN Regulation No. 9 (Chapter 2.2.2), the thresholds in UN Regulation No. 63 are generally lower, reflecting the reduced power output and usage patterns of L_1-vehicles. While UN Regulation No. 41 and Regulation No. 9 define noise limits by vehicle category and power-to-mass ratio (PMR), UN Regulation No. 63 instead uses maximum design speed and functional vehicle configuration as the primary criteria for determining the applicable noise limits.

2.4 Comparative Analysis of TA Procedures for LVs

A cross-regulation comparison of UN Regulation No. 41, UN Regulation No. 9, and UN Regulation No. 63 from Chapter 2.1, Chapter 2.2 and Chapter 2.3 respectively, reveals several structural similarities in terms of the testing framework and measurement conditions, yet distinct procedural differences exist, especially in the implementation of dynamic test procedures, the evaluation scope, and classification thresholds for noise limits. These differences reflect the intended application range of the regulations, each addressing specific LV classes with varying technical profiles and operational characteristics.

All three regulations share fundamental test design principles, such as the use of class 1 microphones with "F" time weighting and "A" frequency weighting, meteorological thresholds including wind speed

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

below 5 m/s, a dry ISO 10844 surface, and requirements for vehicle preconditioning, tyre pressure alignment with manufacturer specifications, and the documentation of specific compliance data including gear used, $v_{AA'}$, and the final test result. Similarly, stationary noise tests follow a harmonized concept across all regulations, measuring sound pressure during a controlled engine speed sequence, using a defined microphone position relative to the exhaust outlet, and applying a target engine speed based on the rated engine speed n_{rated}. One notable divergence within this common testing framework lies in the definition of the test mass. While all vehicles must be in their normal operating condition, the specific mass attributed to the driver and any additional equipment differs slightly: Regulation 41 specifies this combined mass as $75\,\mathrm{kg} \pm 5\,\mathrm{kg}$, whereas both Regulation 9 and Regulation 63 permit a broader range of $70\,\mathrm{kg}$ to $90\,\mathrm{kg}$. This subtle difference reflects a variation in how test mass is standardized across the vehicle classes covered by each regulation.
However, considerable differences arise in the execution of dynamic (in-motion) testing. In UN Regulation No. 41 and Regulation No. 9, the vehicle must conduct full-load wide open throttle (WOT) tests. UN Regulation No. 41 also includes constant speed (CRS) tests, whereas UN Regulation No. 63 prescribes WOT tests only. The selection and number of test runs also vary: for example, the target speed: The target speed regulated varies between the regulations in the target value as well as the position in the testing field where this speed shall be reached. Under UN Regulation No. 41, the defined v_{test} is located at PP' and values $40\,\frac{\mathrm{km}}{\mathrm{h}}$ for vehicles with a $\mathrm{PMR} \leq 25$ and $50\,\frac{\mathrm{km}}{\mathrm{h}}$ for those with $\mathrm{PMR} > 50$. UN Regulation No. 9 sets $v_{AA;}$ as the target speed which is then defined as the lowest speed among a multiple criteria evaluation with a cap at $50\,\frac{\mathrm{km}}{\mathrm{h}}$. The target speed for Regulation 9 therefore is vehicle-dependent and not a fixed value for all measurements conducted according to Regulation 9. Regulation 63 simplifies this by prescribing $v_{AA;}$ as $30\,\frac{\mathrm{km}}{\mathrm{h}}$ for vehicles capable of exceeding this speed, or the maximum vehicle speed otherwise. This means, different LVs can have target speeds ranging from below $30\,\frac{\mathrm{km}}{\mathrm{h}}$ at the entry lane AA' up to $50\,\frac{\mathrm{km}}{\mathrm{h}}$ at the entry lane AA' for WOT tests and therefore a high variety of engine speeds – which is a higher indicator for noisy events than the actual vehicle speed – occur during the measurements.
Significant procedural differences emerge in dynamic (in-motion) noise testing. Both UN Regulation No. 41 and R9 require full-load Wide Open Throttle (WOT) tests, with UN Regulation No. 63 additionally mandating Constant Speed (CRS) tests under certain conditions. In contrast, UN Regulation No. 63 only calls for WOT testing.
The length of the measurement zone also diverges across the regulations. In UN Regulation No. 41, the measurement continues for 20 meters beyond BB', accommodating what happens after full acceleration is released at BB' for the more powerful L_3 vehicles. In contrast, UN Regulation No. 63 limits measurement to the BB' line, consistent with the reduced speed and output characteristics of L_1 vehicles. Regulation No. 9 adheres to the BB' line as well, aligning more with UN Regulation No. 63 in this regard.
Noise limit classification also follows different rationales. UN Regulation No. 41 and Regulation No. 9 establish limits based on PMR, providing tiered thresholds that escalate with increasing vehicle performance capability. UN Regulation No. 63, conversely, uses maximum design speed and vehicle configuration (e.g., auxiliary pedalling systems) to determine applicable noise limits. This reflects the differing vehicle types covered: performance-oriented L_3, L_4, L_5 in UN Regulation No. 63 and Regulation No. 9, and low-powered or assisted vehicles in UN Regulation No. 63.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Gear selection procedures represent another area of marked regulatory divergence. UN Regulation No. 41 presents a complex decision tree, especially for locked gear systems, requiring gear-dependent reference acceleration matching and fallback procedures using adjacent gears. Non-locked gears are required to run in fully automatic mode with limited upshifting. R9 introduces similar but slightly simplified selection logic, especially considering that L through L_5 vehicles may be equipped with automatic or continuously variable transmissions. UN Regulation No. 63, on the other hand, applies a straightforward gear selection rule: use the highest gear that allows entering the measurement zone at or above 50% of n_{rated}, highlighting the generally lower powertrain complexity of L_1 vehicles.
The implementation of additional test procedures such as ASEP or RD-ASEP further distinguishes the three regulations. UN Regulation No. 41 mandates RD-ASEP testing for L_3 vehicles with $\mathrm{PMR} > 50$, involving expanded test zones and engine speed-dependent ASEP limit curves. UN Regulation No. 9 includes ASEP (not RD-ASEP) for L_4 and L_5 vehicles with $\mathrm{PMR} > 50$, also applying engine-speed-based evaluation but with different speed thresholds. UN Regulation No. 63 does not prescribe any additional ASEP testing, again reflecting the regulation's focus on simpler vehicle types with limited noise dynamics.
In conclusion, while the regulations converge on general measurement methodology, instrumentation, and environmental prerequisites, they diverge significantly in terms of test execution, classification criteria, gear use strategies, and post-processing scope. These distinctions are guided by the varying technical architectures and use cases of the vehicle classes addressed by each regulation, ensuring both regulatory proportionality and technical relevance across the L-category spectrum.

2.5 UN Regulation No. 92 – Approval of Non-Original Replacement Exhaust Silencing Systems

UN Regulation No. 92 [11] establishes uniform provisions concerning the approval of non-original replacement exhaust silencing systems (NORESS) for vehicles of categories L_1, L_2, L_3, L_4, and L_5, with respect to their sound emissions. This regulation, which was recently amended in 2024 [18], primarily targets the aftermarket sector and thereby exerts significant influence on the existing fleet of LVs.

- The noise reduction effectiveness of the NORESS are verified in accordance with the methods set out in UN Regulations Nos 9, 41 or 63. The sound level values for the vehicle stationary test and in motion test shall not exceed the values for the same vehicle when fitted with the original silencing system, as in points (I) and (II) below.
- NORESS have the following features compared to original silencers:
    a. Their components bear different trade names or marks to the original,
    b. The characteristics of the materials constituting a component are different or the components differ in shape or size; a modification in respect to coating (zinc coating, aluminium coating, etc.) is not considered a change of type,
    c. The operating principles of at least one component are different,
    d. Their components are combined differently.
- Any NORESS or components of it other than that used in the vehicle type approval are included. An approval of the noise performance of NORESS requires the following:

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

I. If the vehicle is of the type for which approval has been issued pursuant to the requirements of each of UN Regulations Nos 9, 41 or 63:
    a. The sound level during the test in motion shall not exceed the limit specified in the appropriate UN Regulation by more than 1 dB(A).
    b. The sound level during the stationary test shall not exceed by more than 3 dB(A), the level determined during the approval and indicated on the manufacturer's plate.
II. If the vehicle is not of the type for which approval has been issued pursuant to the requirements of the appropriate UN Regulation, the sound level shall not exceed by more than 1 dB(A) the limit applicable at the time when it was first put on the road.

- In addition to the acoustic performance requirements, the regulation includes several provisions to prevent circumvention of noise limits and ensure long-term compliance:
- NORESS components must be designed in a way that prevents the easy removal of key elements such as baffles or expansion chambers. If such parts must be used, they should be attached in a non-removable or destructively attached manner to prevent tampering or replacement.
- Systems that include multiple user-selectable modes – either mechanical or electronically controlled – must comply with all regulatory requirements in all modes of operation. The reported sound emission levels must reflect the loudest mode.
- The regulation prohibits the incorporation of any device or mechanism designed solely to comply with test procedures, but which would be inactive or bypassed during regular vehicle operation. Any such manipulation is explicitly forbidden.

Additionally, all NORESS systems must also comply with the Additional Sound Emission Provisions (ASEP), ensuring that sound emissions remain within legal limits across a wide range of real-world driving conditions.

In the most recent revision [19], several important amendments were introduced, notably clarifying definitions around exhaust components and tampering, further strengthening the framework for anti-tampering measures. These updates aim to close existing loopholes and reinforce the durability of compliance over the service life of the vehicle. UN Regulation No. 92 thus plays a crucial role in maintaining acoustic performance standards across the lifecycle of LVs, especially after the replacement of original exhaust systems. It ensures that vehicle owners and aftermarket suppliers remain aligned with the EU's objectives for environmental noise control and regulatory consistency.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

3 Overview of the noise measurements conducted within the project

This chapter provides an overview of the various measurement campaigns carried out within the LENS project as part of Work Packages 3 and 4. It begins with a presentation of the on-road measurements, including illustrative the RW driving profile from one representative vehicle extracted from Deliverable D.3.5 [8]. Subsequently, Chapter 3.2 focuses on the RW driving cycles, which are controlled test track measurements, as documented in D3.5 [8]. Selected example results are also presented to support the discussion and provide insights into the testing methodologies applied. The objective of this chapter is to highlight the different measurement environments and to evaluate how the RW driving cycles, which are partly derived from the RW driving profile, compare to those on standardized test tracks. These insights serve as a foundation for refining noise assessment procedures under real-world conditions for LVs.

3.1 On-road measurements (RW driving profiles)

Within the LENS project, an on-board sensor system for capturing noise data in real traffic conditions, RW driving profiles, was developed [20]. This sensor unit is equipped with a microphone and a GPS module. The primary function of the system is the simultaneous recording of sound pressure levels and vehicle location data. This enables the correlation of vehicle movement with noise emissions, allowing the identification of acoustically relevant driving scenarios and therefore deriving those RW driving profiles. The system is designed to be portable and adaptable to various LVs [21]. At its core, a microcontroller serves as the control unit, featuring serial peripheral interfaces. The MEMS microphone converts sound pressure into electrical signals, while the GPS module records the location data. Both noise and position data are stored on a micro-SD card. For user-friendly operation, the device includes only a single switch to start and stop data recording. Due to the low power consumption of its components, the system is particularly well suited for battery-powered operation.
The sensor system was distributed to several project partners for testing and integration on different LVs. The objective is to use the recorded data to develop a methodology capable of detecting acoustically significant driving situations to derive RW driving profiles. However, conducting such on-board measurements in real traffic presents several practical challenges. Key difficulties include ensuring a secure and vibration-free fixation of the sensor to avoid rattling and isolating the vehicle's own noise from ambient background noise, which includes variable wind noise and sound from other traffic. Despite these challenges, the on-board measurement approach holds significant potential and further evaluation is recommended, as it could be a cost-effective option to minimize the need for new or extensive test track campaigns. For example, the data would allow for a simple and practical test determining the differential between the vehicle's loudest and quietest driving conditions. Furthermore, additional development could enable the system to automatically identify relevant noise-critical conditions from the time signal, significantly streamlining the analysis process. As a first step, the

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

optimal mounting position of the sensor on the vehicle was evaluated. To this end, the sensor was installed in various positions on multiple vehicles, and equivalent measurements were performed [22]. The measurement microphones showed similar temporal patterns, indicating that the identification of acoustically relevant driving scenarios is not significantly affected by microphone position. Based on the results, the recommended mounting location for the system is centrally at the rear of the vehicle.
In the following, the data evaluation of on-road measurements is discussed using one representative vehicle from the L3e-A1 equipped with manual transmissions [23]. In Figure 3-1, the events with the highest A-weighted sound pressure levels exceeding the 90th percentile were identified and analysed individually. The 90th percentile threshold is marked to highlight the relevant noise events.
Each identified condition in the dataset is assigned a number to represent the corresponding driving scenario. Driving conditions associated with elevated noise levels above the 90th percentile include short acceleration phases during driving (Figure 3-1, No. 1), acceleration from near standstill (Figure 3-1, No. 3), and steady-state driving (Figure 3-1, No. 5), as illustrated in Figure 3-1. Specifically, scenario No. 1 represents a short acceleration event, while No. 2 refers to acceleration from a near standstill. Scenario No. 3 involves acceleration from a standstill including gear shifts. No. 4 corresponds to acceleration during driving, also with gear shifts, and No. 5 denotes a phase of nearly constant driving. These events often involve dynamic engine behaviour such as throttle application, gear changes, and typically end with deceleration phases due to throttle release and decreasing engine speed.

Figure 3-1: On board sound pressure level vs. time for an on-road measurement of an L3e-A1 vehicle [23]

Regarding the frequency of these scenarios within the evaluated data sample: scenario No. 1 occurred once, No. 2 did not appear in the observed time segment, No. 3 occurred five times, No. 4 occurred

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

twice, and No. 5—representing the longest durations—appeared five times. It should be noted that only events exceeding the 90th percentile threshold of the A-weighted sound pressure level are shown in this analysis. As a result, some typical driving conditions are not visible in this excerpt.

Figure 3-2 provides a detailed visual analysis of the sound pressure levels (SPL) measured for a RW driving profile. The left-hand plots display the SPL in dB(A) as a function of engine speed and vehicle speed, visualized using a colour scale. The right-hand plots present the engine speed over the vehicle speed, again color-coded by the corresponding SPL in dB(A). These plots offer insights into how various operating conditions—such as throttle application, gear selection, and speed—affect noise emissions, with a focus on their alignment with existing regulatory frameworks.

The left-hand plot in Figure 3-2 shows that high throttle application—approaching full throttle—typically results in elevated sound pressure levels, with values reaching approximately 90 dB(A). This trend highlights that substantial acoustic output is linked to especially engine speed, but also engine load and throttle demand. A generally linear relationship is observed between engine speed and SPL, suggesting that noise emissions increase proportionally with rising engine speed. This finding supports previous observations reported in [24], underlining the consistency of this behaviour across similar LVs.

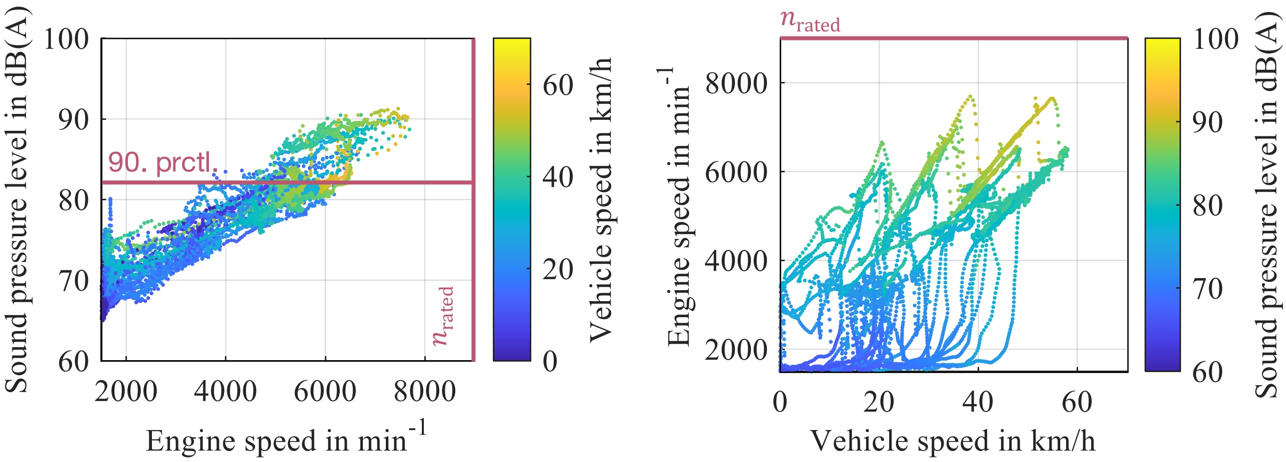


Figure 3-2: SPL vs. engine speed vs. vehicle speed for an L3e-A1 vehicle [23]

The right-hand plot of Figure 3-2 reveals further detail by illustrating SPL across combinations of vehicle speed and engine speed within specific gear ranges. The data suggest that certain gear selections—especially in combination with moderate to high vehicle speeds—are associated with peak SPL values. The relationship is not strictly linear, indicating the influence of additional factors such as gear shifts, transient throttle input, and engine load. An important regulatory consideration arises when these measurements are compared with the provisions of UN Regulation No. 41, which applies to L3 vehicles with a PMR greater than 50. According to this regulation, the RD-ASEP require that the engine speed at the moment the rear of the vehicle passes the designated line BB' of the test area (nBB′) must not exceed 80% of the rated engine speed. For this specific vehicle, with a rated engine speed of 9000 min^{-1}, the upper limit for the RD-ASEP control range is thus 7200 min^{-1}. The right-hand side of Figure 3-2 demonstrates that, under certain driving conditions, some engine speed data points exceed this 80% threshold—despite occurring at relatively low vehicle speeds. This observation raises

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

the question of whether the current RD-ASEP boundary conditions accurately reflect real-world conditions. In practice, it may be necessary to reassess the RD-ASEP upper control limit for engine speed to ensure that all relevant and noise-critical scenarios are adequately covered by the regulation. Real-world driving patterns can generate high noise emissions in conditions not currently covered by the regulation, such as low-speed but high-throttle scenarios or high-speed driving in lower gears. A more comprehensive regulatory framework could help ensure that noise emissions are adequately managed across the full spectrum of driving conditions. Based on those measurements and surveys, critical driving patterns are analysed in Deliverable D 3.5 [8] which will be only referenced here in Chapter 3.2.2.

3.2 Measurements on a test track

This chapter presents a detailed proposal for real-world driving patterns, which serve as a foundation for large-scale measurement campaigns. The proposed methodology is designed to focus on driving patterns causing high noise. It outlines a structured sequence of tests, starting with stationary and transfer function measurements, followed by dynamic RW driving patterns. The procedures integrate both roadside and on-board data acquisition systems and are aligned with existing regulatory frameworks, including UN Regulations [2; 25; 4] and ISO standards [12].
Furthermore, this chapter defines the technical requirements for measurement equipment, vehicle instrumentation, and test environments. It includes specific guidance on test track characteristics, permissible environmental conditions, and microphone placement. Through these efforts, the LENS project contributes to the development of more accurate and context-sensitive approaches for evaluating vehicle noise emissions, ultimately supporting more effective regulation and urban noise management.

3.2.1 Measurement setup

The setup and equipment are based on the UN Regulations from Chapter 0. Figure 3-3 below shows the microphone positions. Line AA' describes the entrance of the relevant measurement area perpendicular to the driving direction, line BB' the exit of the area. Line CC' corresponds to the centre of the vehicle/the vehicles driving path. In case of public road measurements, line CC' corresponds to the centre of the vehicle driving lane. The line PP' is the position of the microphone 7.5m perpendicularly to the reference line CC' and 1.2m height.
For the real-world driving pattern measurements, only one road-side microphone is mandatory. However, it is recommended to use the setup according to Figure 3-3 as described in the following. In addition to the microphones at PP', which is also visible at Figure 2-1, three additional microphones and one artificial head/ binaural headset should be placed if possible. The purpose of the artificial head is to capture binaural recordings that allow for a detailed psychoacoustic analysis, providing insights into the perceived character and annoyance of the noise beyond standard level measurements. Two of the additional microphones shall be placed on BB' where the vehicle is leaving the measurement zone. The placement of the remaining additional microphone and the artificial head/binaural headset is dependent on the specific vehicle under test; they shall always be positioned on the side where the main exhaust outlet is located. Figure 3-3 illustrates this setup for a vehicle with its exhaust on the

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

side corresponding to the top of the diagram. The vehicle shall be equipped with at least one microphone in the back of the rear. It should be ensured that the data can be synchronized.
For roadside measurement equipment, a data acquisition system with a sampling frequency of at least 16384 Hz is required. At least one microphone of accuracy class 1 must be used. A system for synchronization, such as GPS or light barriers, is also necessary. For the on-board system (required for test 1 if not using roadside equipment and for test 2), it includes one microphone and a system for synchronization (e.g., GPS, light barriers).

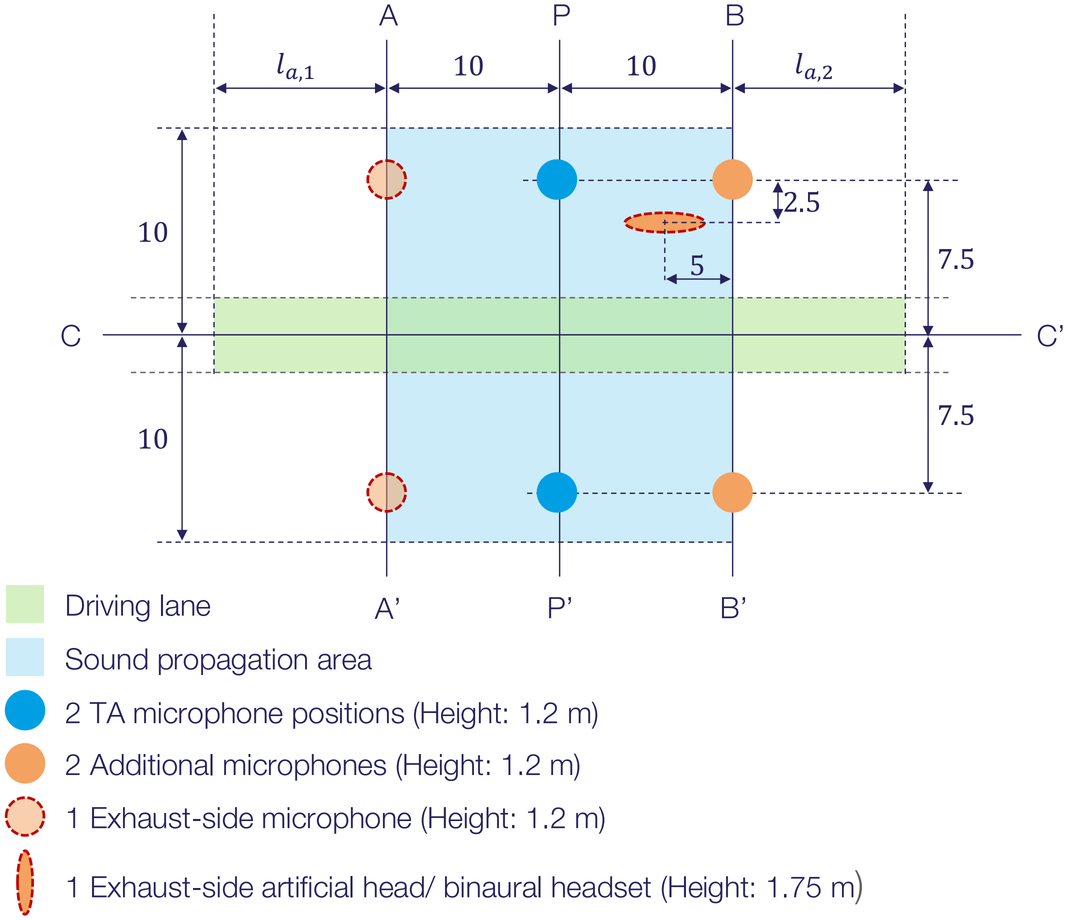


Figure 3-3: Measurement setup for the real-world driving patterns (distances are measured in meters)

Further possible measurement equipment, which is not mandatory, includes additional roadside microphones for checks related to symmetry and directivity. If feasible, an additional on-board data acquisition system can be used for engine speed measurements. If both on-board and roadside data systems are used, their data must be synchronized and matched, so that the on board noise level can be easily converted to a roadside level at 7,5m. On-Board equipment, if an engine speed measurement system is used, should be mounted in a way that prevents significant influence on the acoustic measurements.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

3.2.2 RW driving patterns

Partly based on studies conducted in the Netherlands between 2021 and 2022 [26–28], the driving patterns listed in Table 3-1 were recommended within the LENS project. In the following sections, these conditions are evaluated with respect to their suitability for use in TA procedures. Key criteria include the reproducibility of the conditions—not only within repeated tests carried out by a single organization, but also across different organizations. This is essential, as type approval procedures must be consistently applied by various approval authorities, vehicle manufacturers, and technical services.

Table 3-1: Recommended driving conditions from LENS-Deliverable D6.1 [16]

No.	Condition	Vehicle operation	Short name	Already in TA?
(1)	Cold start	Engine start	'coldstart'	✗
(2)	rpm burst	Stationary, short activation and release of accelerator	'rpmburst'	✗
(3)	Acceleration from standstill	Acceleration, late gear change	'rpmlongacc'	✗
(4)	Max rpm pass by	Constant speed with max rpm	'rpmconthi'	✗
(5)	Transition from constant speed/ acceleration to deceleration phase	Deceleration	'rpmdropoff'	✗
(6)	"Max" acceleration from standstill	Acceleration	'rpmshortacc'	✗
(7)	Acceleration from $50\frac{\mathrm{km}}{\mathrm{h}}$ to $100\frac{\mathrm{km}}{\mathrm{h}}$	Acceleration may be varied	'rpmidspeedacc'	R41 ✓ R9 & R 63 ✗

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

(8)	rpm fluctuation	Variable speed	'rpmfluct'	✗
(9)	Backfire	Multiple gear changing or manual operation	'bang'	R41 ✓ R9 & R 63 ✗

Another important factor is the complexity and feasibility of each condition. Since time and resources are limited, the inclusion of more complex testing conditions can significantly increase costs. Therefore, a cost-benefit analysis is necessary to assess the practicality of implementation. This also raises questions regarding the execution of these procedures on various test tracks, especially those with differing lengths. ISO 10844 does not define a minimum track length, and many existing test tracks have been designed to accommodate current TA procedures. Introducing test conditions that require significantly higher speeds could render some of these tracks unusable. Given the high technical and maintenance requirements of ISO 10844-compliant tracks, this would represent a major impact. Constructing a new test track - potentially at a different location to meet the increased length requirements - could lead to substantial additional costs for different parties involved. A detailed explanation of the three defined measurement campaigns—including the correlation of stationary, transfer function, and real-world driving patterns—is provided in [8], along with a comparison between vehicles with manual transmissions and continuously variable transmissions (CVTs). For clarity, only the overview table for manual transmissions is shown here (Table 3-2), as it fully encompasses all relevant patterns, including those applicable to CVT vehicles.
In summary, the comprehensive testing procedure consists of three campaigns:

1. Preliminary stationary measurements aim to link engine speed and emitted noise under static conditions. If engine speed can be reliably recorded during Campaign 3, this step can be skipped.
2. Transfer function measurements are conducted at constant speeds (e.g., $30\frac{\mathrm{km}}{\mathrm{h}}$ and $50\frac{\mathrm{km}}{\mathrm{h}}$) to establish a relationship between on-board and roadside microphones. This enables later noise estimation without full on-board instrumentation.
3. Real-world driving patterns involve 16 dynamic patterns that reflect common or acoustically significant driving conditions (e.g., cold start, aggressive acceleration, deceleration). These are performed primarily with roadside microphones, unless full equipment is used for improved accuracy.

Table 3-2: Overview of real-world driving patterns defined in the LENS-Deliverable 3.5 [8]

No.	Pattern	Description
1	Cold start / engine start	Stationary engine start

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

2	Throttle control	Shortly activating and releasing throttle control, stationary
3	Aggressive acc. from standstill	Aggressive acceleration from standstill, first gear
4	Moderate acc. from standstill	Moderate acceleration from standstill, first gear
5	Gear shift, first to second, from standstill	Short acceleration in first gear from standstill, shift into second gear, aggressive acceleration
6	Aggressive acc. from const. speed, first gear	Aggressive acceleration from constant speed ($<10\frac{\mathrm{km}}{\mathrm{h}}$), first gear
7	Gear shift, first to second, const. speed	Short acceleration in first gear from constant speed ($<10\frac{\mathrm{km}}{\mathrm{h}}$), shift into second gear, aggressive acc.
8	Full/Max. throttle acc., gear i	Full throttle acceleration from constant speed, gear i
9	Gear shift i to i + 1, from const. speed	Short acceleration in gear i from constant speed, shift into gear i + 1, aggressive acceleration
10	Constant speed, gear i, high/max. engine speed	Constant speed in gear i with high/max. engine speed
11	Gear shift, i to i - 1, from const. speed	Constant speed in gear i and downshift to gear i - 1, aggressive acceleration
12	Gear shift, i to i - 2, from const. speed	Constant speed in gear i and downshift to gear i - 2, aggressive acceleration
13	Intermittent throttle control, gear i	Constant speed in gear i, intermittent throttle control, fluctuating engine speed
14	Deceleration, gear i	Constant speed in gear i, releasing throttle control, deceleration

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

15	Backfire	Vehicle dependent
16	Flap exhaust	Vehicle dependent

The methodology enables a standardized and efficient approach to vehicle noise assessment. Detailed procedures, pattern definitions, and CVT adaptations are available in source [8].

3.2.3 Exemplary Results

In the following Chapter, three different parameters for each pattern from Table 3-2 are examined. In Deliverable 3.5 [8], the distinction between manual transmission and CVT-transmission is additionally made due to this distinction in the legislative regulations regarding TA. For the analysis in this chapter, three key parameters were selected to provide a comprehensive assessment of the noise emissions. This specific choice is intended for this study to gain deeper insights into the nature of LV noise, although the findings also inform the discussion on potential future options for TA. The selected parameters are:

- A-weighted sound pressure level (in dB(A)): This is the standard metric used for regulatory conformity in all current TA procedures, as detailed in Chapter 0. It serves as the primary benchmark for legal compliance.
- Loudness (in sone): This psychoacoustic parameter was chosen because it correlates strongly with the human perception of sound intensity. It provides a more accurate measure of how "loud" a sound is subjectively perceived to be, which can differ from the simple energy-based dB(A) measurement.
- Roughness (in asper): This parameter quantifies the rapid temporal modulation of sound, which is a key characteristic of the "aggressive" or "raspy" sound often associated with LV noise. High roughness can significantly increase annoyance, even if the overall dB(A) level is not excessive.

The inclusion of loudness and roughness alongside the standard dB(A) level allows for a more nuanced evaluation of the noise character and its potential for annoyance, which is a key objective of this investigation. The usage of several psychoacoustic parameters have been proven useful in the literature [29–31] The results are shown as violin plots. The width of the violin is a normalized representation of the data distribution always reaching its maximum at the peak of the distribution. Therefore, the absolute width has no direct meaning; instead, it shows the relative density of the measured values. This visualization helps to quickly see whether the results for a given motorcycle category are concentrated around a specific value or more evenly spread across a wider range. Since the width is scaled, it's not a direct count of data points, but it does indicate how values are distributed relative to each other. When combined with a scatter plot of individual measurements, as shown below, the violin plot also makes it easier to spot outliers. In total, 92 vehicles are shown in the analysis, distributed as the following

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

- 10 L1e-B vehicles
- 23 L3e-A1 vehicles
- 21 L3e-A3 vehicles
- 28 L3e-A3 vehicles
- 5 L5e vehicles
- 1 L6e-BP vehicle
- 3 L7e-B1 vehicles
- 3 L7e-B2 vehicles

Each measurement and therefore each driving pattern was generally performed twice. The value shown in the analysis corresponds to the maximum of those two measurements. This means, each dot in the following analysis represents one bike.

Figure 3-4 shows the above explained analysis for the first driving pattern, the cold start, for all measured vehicles. In Deliverable 6.1 [16], this pattern is also defined as a noisy condition and therefore condition (1) in Table 3-1 as 'coldstart'. This condition can be found in living areas when riders turn on their bikes or on parking lots. The A-weighted sound pressure level, top graph in Figure 3-4, shows a clear dependency on the vehicle (sub-)category. The subcategory L3e-A3 exhibits the highest median sound pressure levels during a cold start with approx. 72 dB(A), followed by L1e-B and L3e-A1 with a median value of approx. 65 dB(A), and L3e-A2 with a median value of approx. 63 dB(A). It is noteworthy that in this driving pattern, the maximum sound pressure level within the L3e-A1 class occurs with a value of up to 81 dB(A). The loudness values, shown in the middle in Figure 3-4, correlate strongly with the dB(A) levels. Here too, L3e-A3 shows the highest median values with approximately 25 sone, which confirms that more powerful vehicles are not only objectively loud during the starting process but are also perceived as subjectively significantly more intense. The roughness, Figure 3-4 bottom graph, shows similar median values for L1e-B and L3e-A3, each in the range of approximately 0.5 asper. This indicates that the starting process for L1e-B, despite lower power, can be perceived acoustically as equally "rough" as for more powerful vehicles. The highest roughness is reached in the L3e-A3 class with up to 1.2 asper.

Driving pattern 2, which is the throttle control, is shown in Figure 3-5. This is also a Deliverable D. 6.1 condition and can be found as No. (2) in Table 3-1 as 'rpmburst'. This definition is because this pattern can occur at a traffic light or a crossing. Regarding the A-weighted sound pressure level, Figure 3-5 top graph, it is visually apparent that the L3e-A3 subcategory exhibits the highest median values. Within the L3e categories, a clear trend towards higher levels with increasing nominal performance class (A1 is the lowest performance class in L3e and A3 the highest) can be observed. Furthermore, the wide range of measurement data in subcategory L3e-A2 indicates a considerable dispersion of the measurement values, which suggests potentially very varied throttle bursts. Comparing the top graphs of Figure 3-4 and Figure 3-5, a general increase in the sound pressure level can be seen when moving from Figure 3-4 to Figure 3-5. This is expected as the engine speed is raised between the two patterns.

The pattern of the loudness values, Figure 3-5 mid graph, seems to follow that of the sound pressure levels from the top graph. The L3e-A3 subcategory also shows the highest median loudness values here, suggesting that its throttle bursts are subjectively perceived as the loudest. When comparing the loudness from Figure 3-4 and Figure 3-5, the same analysis as to the sound pressure level can be made. The comparable high increase for the L5e vehicles for the sound pressure level as well as for

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

the loudness is pointed out here. The roughness, Figure 3-5 bottom graph, appears to be nearly the same for all categories in this driving cycle. This observation is also rather similar to the ones made for Figure 3-4.

The next Figure, Figure 3-6, shows the aggressive acceleration from standstill. In Table 3-1, this is pattern (3) and named shortly ‘rpmlongacc’. In real traffic, this pattern can take place when the vehicle came to a stop, e.g. when a red traffic light is turning green, and the driver tries to accelerate as fast as possible. For the measurement procedure in the test track, this means, the vehicle starts at line AA’, a full-throttle acceleration is performed until the rear of the vehicle reaches the line BB’ from Figure 2-1. For this driving pattern, the feasibility is an important factor. Especially for high performance vehicles, a full-throttle acceleration from standstill is not feasible for the track length of 20m. Therefore, the acceleration should be as high as possible but is highly vehicle- and driver-dependent. However, during this pattern, the L3e-A3 subcategory produces the highest sound pressure levels, Figure 3-6 top graph. These are followed by the L3e-A2 and L5e-A categories. Again, a clear gradation of noise emissions within the L3e categories (A1 < A2 < A3) can be observed. Vehicles in the L1e-B and L6e-BP classes exhibit the lowest sound pressure levels under these conditions. The loudness values, Figure 3-6 mid graph, reflect these high sound pressure levels and reach extremely high values for L3e-A3, indicating a very intense subjective perception of loudness. Roughness, Figure 3-6 bottom graph, is significantly increased for all categories during this aggressive acceleration manoeuvre. The combination of very high level, very high loudness, and simultaneously high roughness makes this pattern acoustically particularly prominent and potentially highly disturbing.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101056777

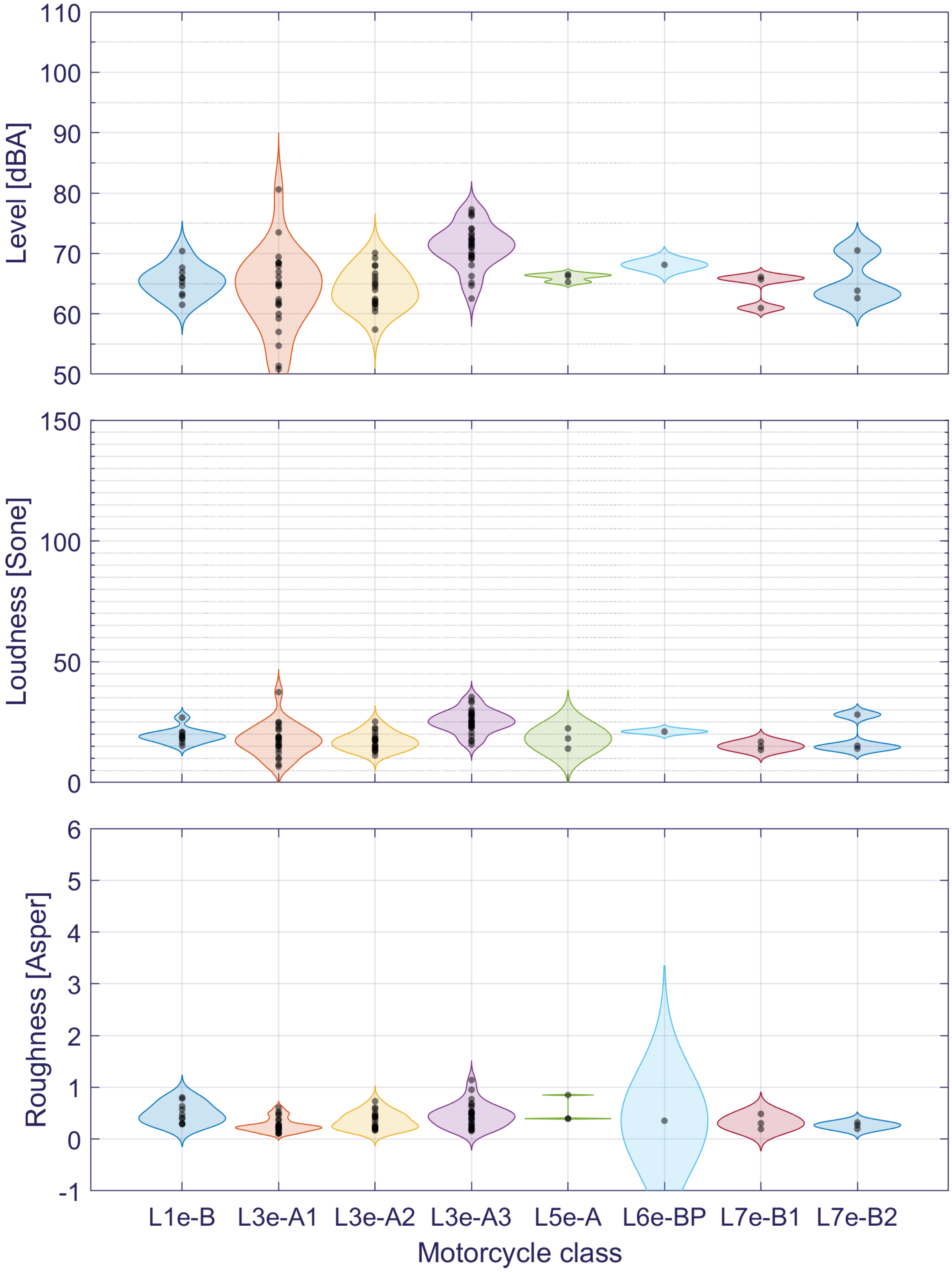


Figure 3-4: Acoustic parameters vs. subcategory for driving pattern 1 (cold start / engine start)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

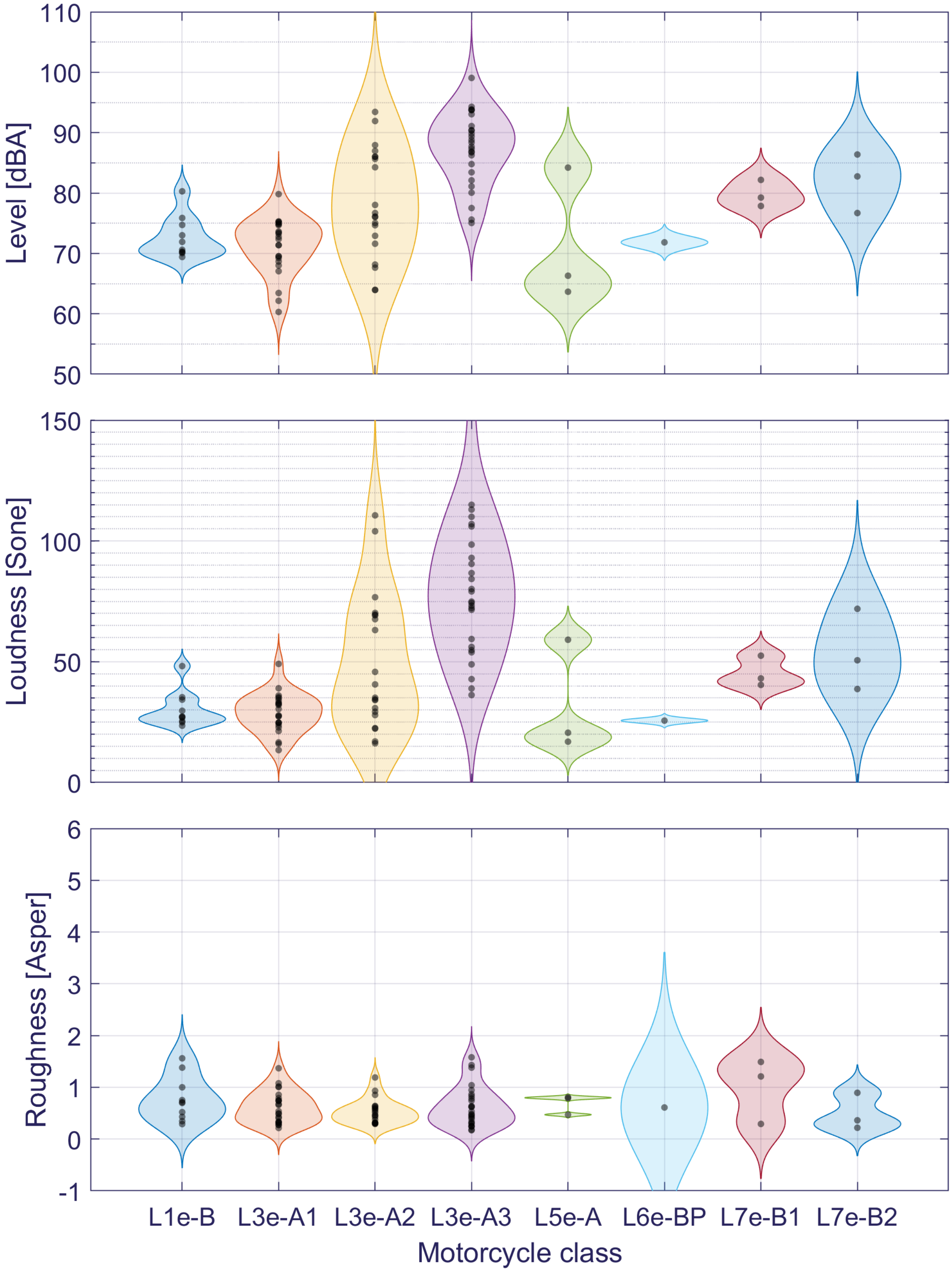


Figure 3-5: Acoustic parameters vs. subcategory for driving pattern 2 (throttle control)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

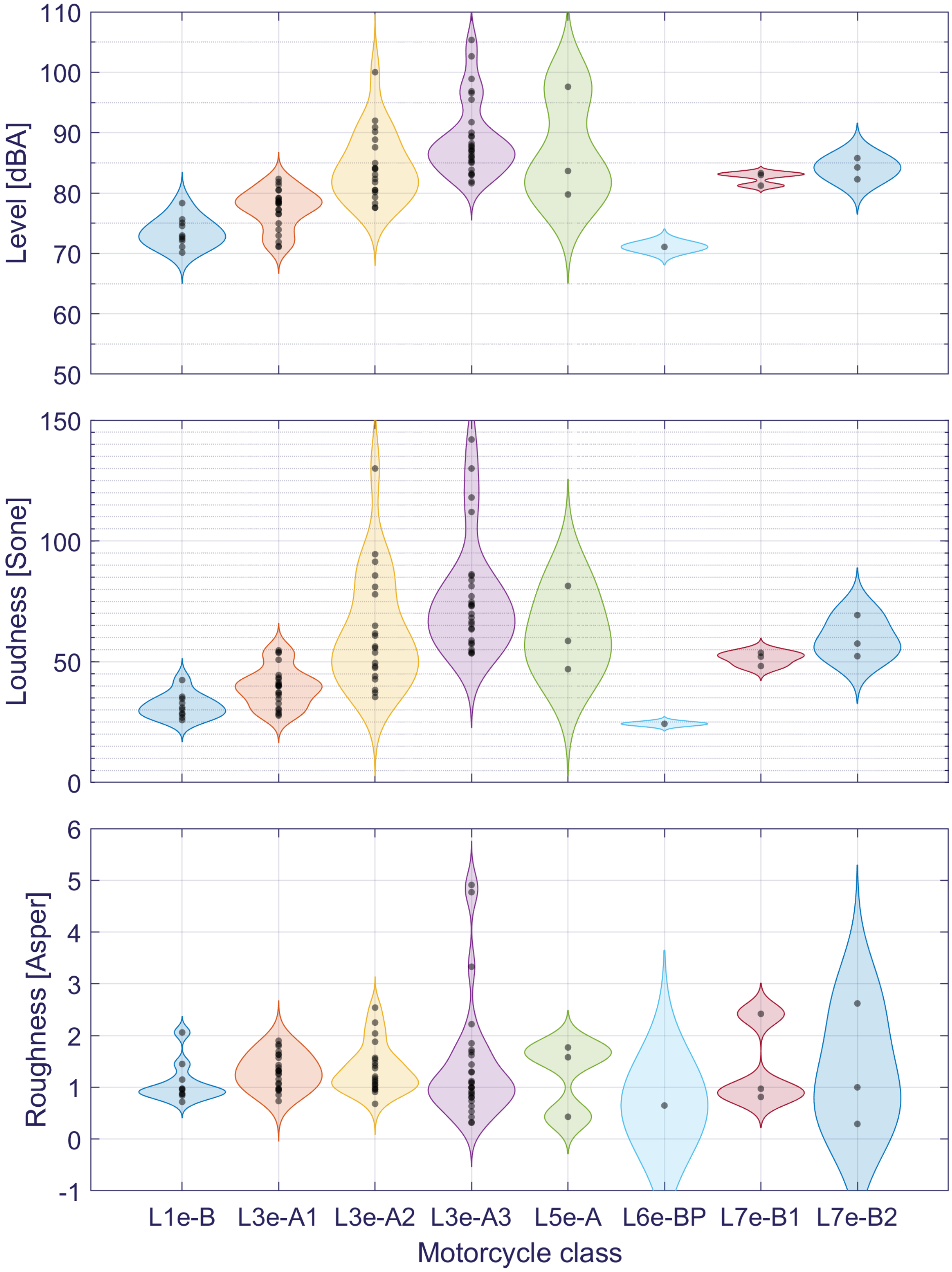


Figure 3-6: Acoustic parameters vs. subcategory for driving pattern 3 (aggressive acceleration from standstill)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

The fourth driving pattern is shown in Figure 3-7 and is a moderate acceleration from standstill. This means, the procedure is rather similar to pattern 3, shown in Figure 3-6, but the acceleration is not as high. This means, in real traffic the driving patterns 3 and 4 can be found in the same situations and the pattern is still highly driver dependent. In direct visual comparison to aggressive acceleration from Figure 3-6, the median sound pressure level from the moderate acceleration in Figure 3-7 are visibly lower. However, the ranking of the categories regarding their noise emissions appears to remain tendentially similar. The dispersion of the measurement values also appears to be lower than aggressive acceleration. The loudness values, Figure 3-7 mid graph, follow this trend of the sound pressure levels and are also significantly reduced compared to Driving Pattern 3. The roughness values, Figure 3-7 bottom graph, are also lower for all categories during moderate acceleration than aggressive acceleration from Figure 3-6. The sound character can thus be classified as "smoother" and less aggressive. These observations lead to the conclusion of a significant reduction in noise emissions with a moderate driving style. The direct comparison between driving pattern 3 and driving pattern 4 impressively demonstrates the massive influence of driver behaviour on noise emissions.

For vehicles with possible gear shifts, the results from the driving pattern 5 are shown in Figure 3-8. This pattern is also a short acceleration from standstill, but within the measurement, a gear shift into the second gear is performed. This pattern can also occur in real traffic at a red light turning green or at a cross walk, depending on the driver behaviour. As shown in Figure 3-8, this pattern could be done for the L3e-categories and therefore concerning the Regulation No. 41 from 2.1. In this combined gear shift and acceleration manoeuvre, the L3e-A3 subcategory is the loudest with a median level of approx. 83 dB(A), followed by L3e-A2 with approx. 79 dB(A) and L3e-A1 with approx. 75 dB(A), all visible in Figure 3-8, top graph. Generally, the levels are lower than aggressive acceleration from standstill in first gear (Figure 3-6) but higher than for the moderate acceleration in Figure 3-7. The loudness values, Figure 3-8 mid graph, follow the trend of the sound pressure levels, with L3e-A3 exhibiting the highest median subjective loudness of approx. 55 sone. Regarding roughness, Figure 3-8 bottom graph, this pattern shows more moderate peak values than aggressive acceleration in first gear (Figure 3-6 bottom graph).

The driving pattern 6 is defined as an aggressive acceleration from low constant speeds (below 10 km/h) in the first gear. In real traffic, this is a pattern happening when, e.g. the driver does not have to come to a full stop at a traffic light or pedestrian crossing when being able to continue driving. The results for this are shown in Figure 3-9. The sound pressure level distributions from Figure 3-9, top graph, for this pattern strongly resemble those of driving pattern 3 (aggressive acceleration from standstill, Figure 3-6). The L3e-A3 subcategory tends to show the highest median sound pressure level values and a wide scatter of measurement data. Vehicles in the L1e-B and L6e-BP categories, on the other hand, appear to exhibit the lowest levels. The emission values are generally to be classified as very high. The pattern of loudness values, Figure 3-9 mid graph, appears to follow that of the sound pressure level values, with L3e-A3 also showing the highest loudness values. The roughness values, Figure 3-9 bottom graph, also appear to be high, especially for the more powerful L3e categories and the L7e-B2 subcategory, similar to the observations for driving pattern 3. These observations indicate that the noise emissions during this pattern are similarly high to those during aggressive acceleration from standstill. This suggests that the difference between "standstill" and "very slow speed" is of minor acoustic importance for this type of pattern. However, regarding a possible type approval suggestion, the definition of the initial speed is clearer for pattern 3 (0 km/h) as it is for pattern 6 (below 10 km/h).

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

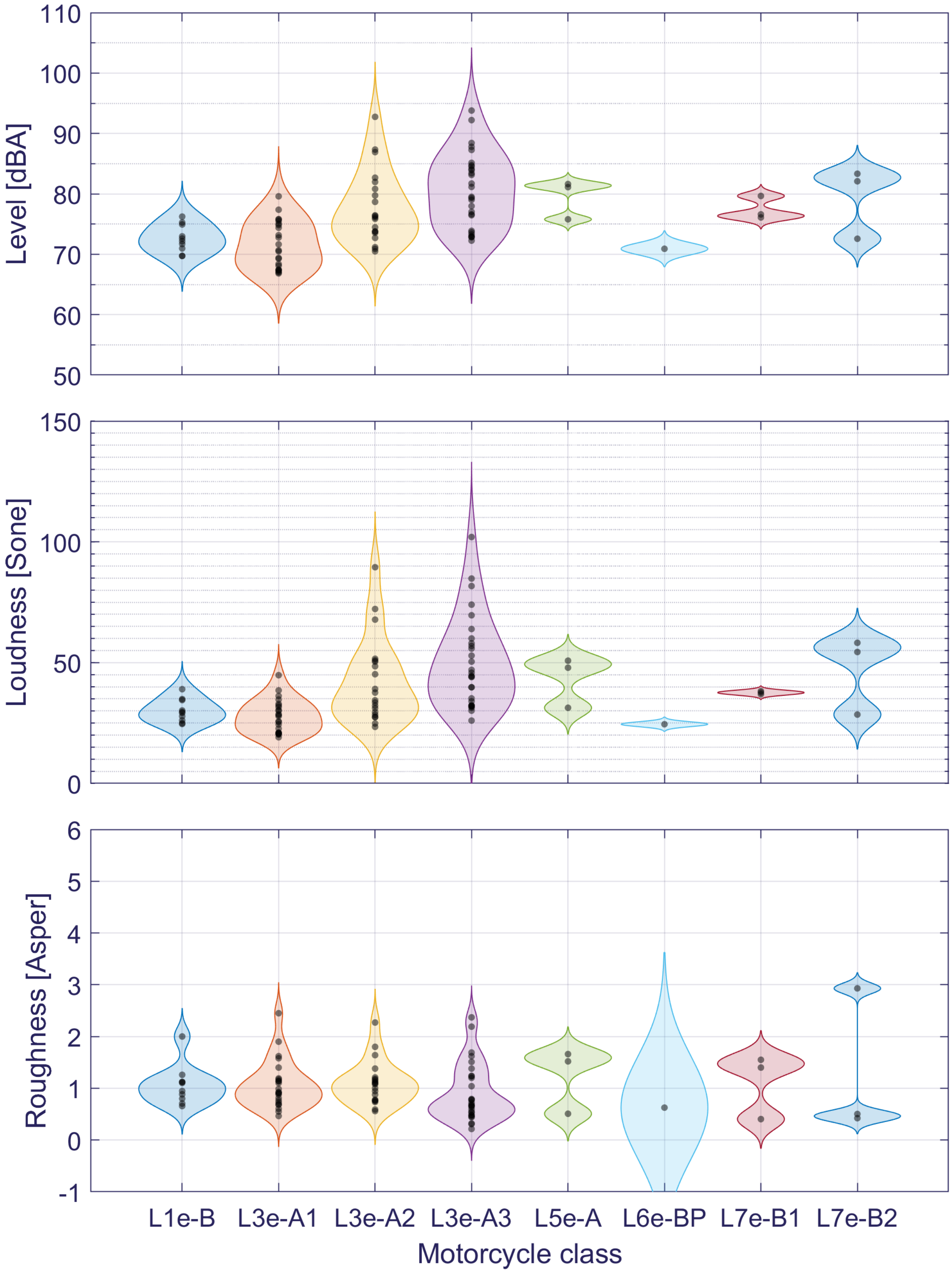


Figure 3-7: Acoustic parameters vs. subcategory for driving pattern 4 (moderate acc. from standstill)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

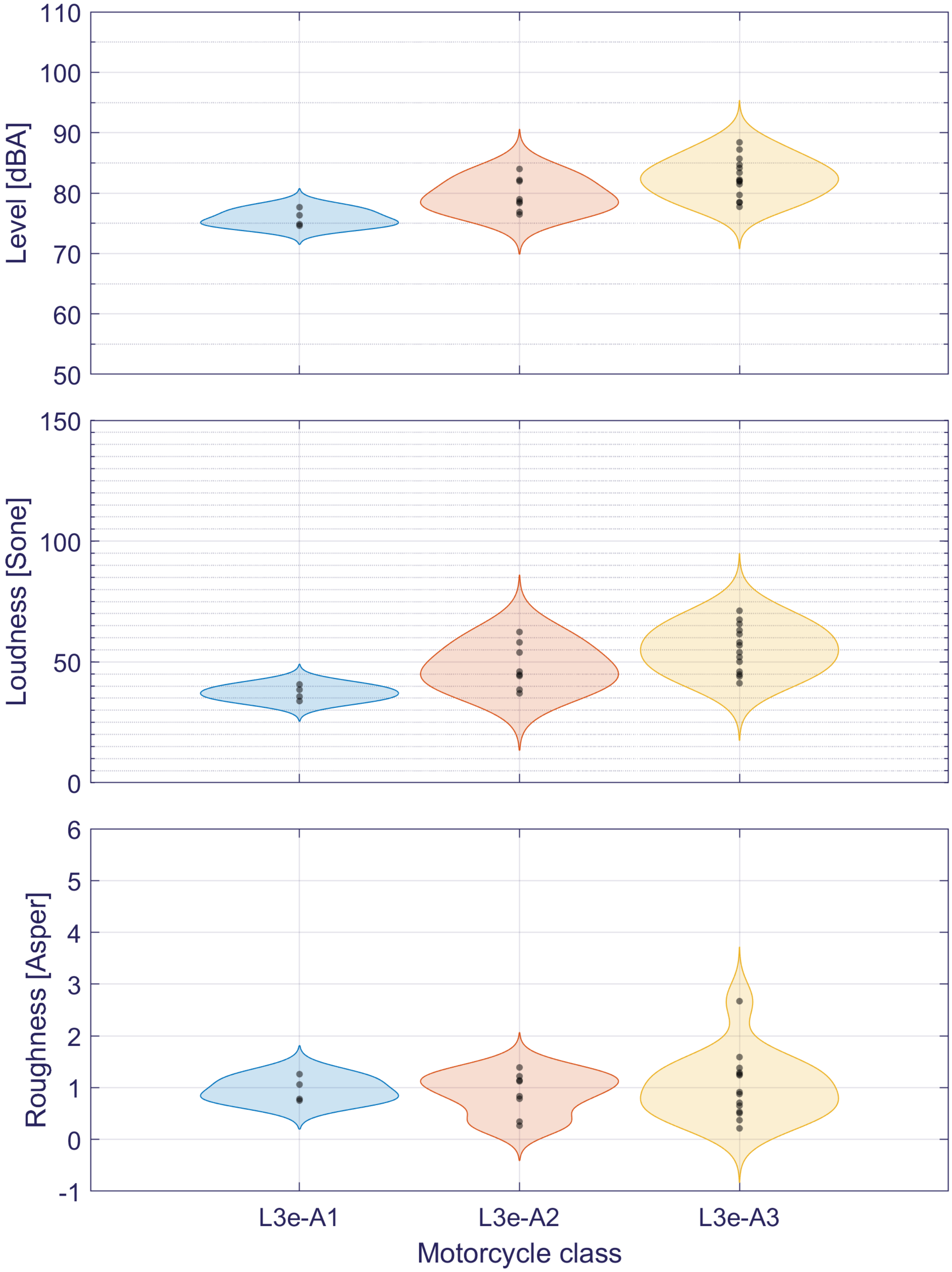


Figure 3-8: Acoustic parameters vs. subcategory for driving pattern 5 (gear shift, first to second, from standstill)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

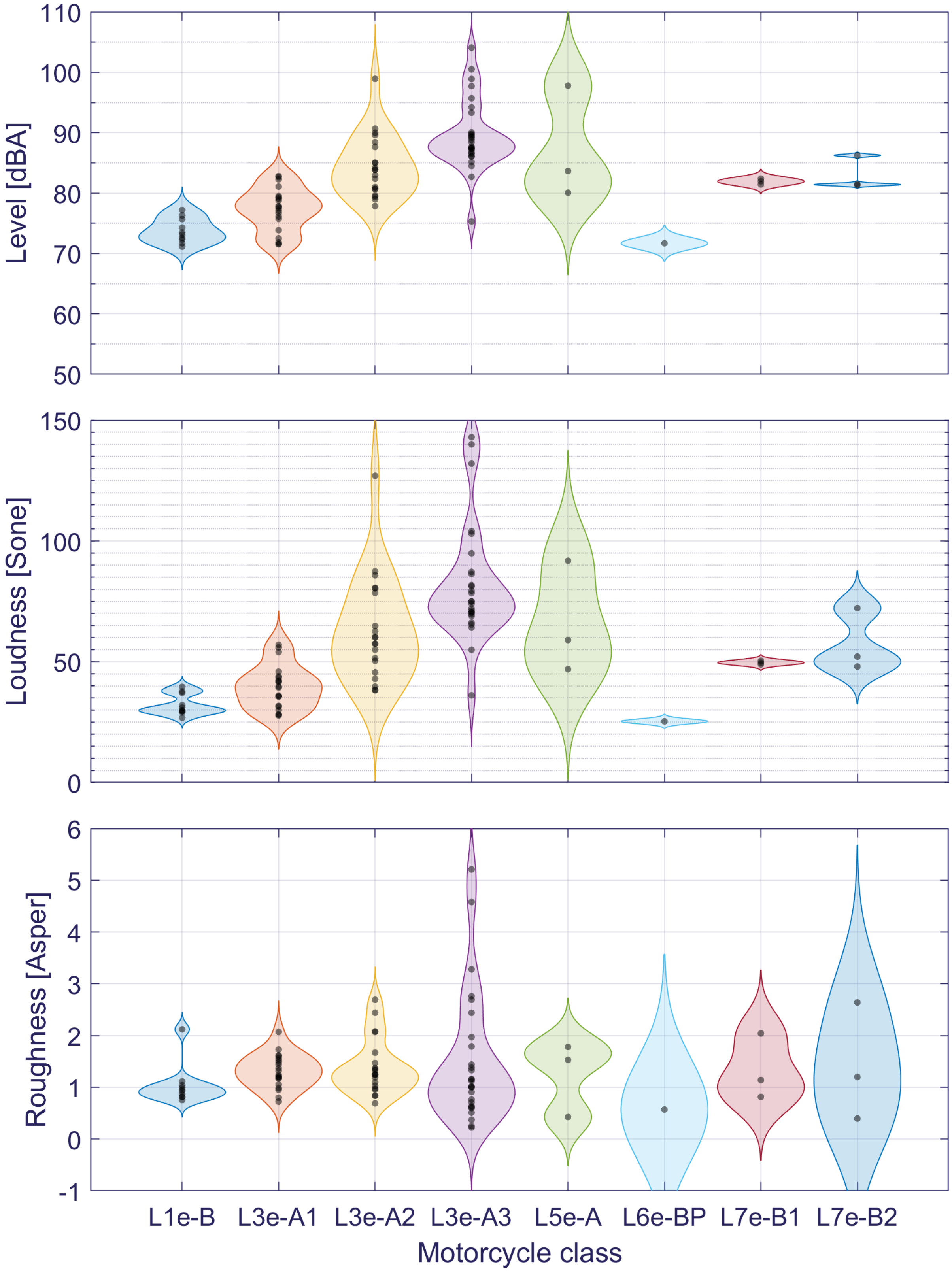


Figure 3-9: Acoustic parameters vs. subcategory for driving pattern 6 (aggressive acc. from const. speed, below 10 km/h)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Driving Pattern 7, depicted in Figure 3-10, involves a short acceleration in first gear from a constant, slow speed (<10 km/h), followed by an upshift to second gear and subsequent aggressive acceleration. This pattern is therefore relevant only for vehicles equipped with more than one gear, which in this context are the L3e subcategories. Within the L3e categories, the most powerful class, L3e-A3, exhibits the highest sound pressure levels, Figure 3-10 top graph, with a median of approximately 84 dB(A), followed by L3e-A2 and L3e-A1. The Loudness, Figure 3-10 mid graph, correlate strongly with the dB(A) levels. The loudness relationship A1 < A2 < A3 is also clearly evident here. The Roughness, Figure 3-10 bottom graph, also demonstrates an increase with the power of the vehicles. A comparison with gear shift 1-2 from standstill (Driving Pattern 5, Figure 3-8) indicates that Driving Pattern 7 tends to be louder and rougher.

Figure 3-11 presents the results of full throttle acceleration from a constant speed in second gear. For CVTs, a comparable pattern involving full throttle acceleration from a constant speed of 30 km/h was conducted; these results were included to allow for broader comparability, as CVTs by definition do not have a fixed second gear. In this pattern, the L3e-A3 subcategory attains the highest Sound Pressure Level, Figure 3-11 top graph, with a median level of approximately 86 dB(A), closely followed by the L7e-B2 subcategory at about 85 dB(A). Vehicles in the L7e categories demonstrate acoustic behaviour similar to powerful motorcycles during this pattern, indicating that these four-wheeled vehicles can also be significant noise sources under full load conditions. Within the L3e categories, a clear trend towards higher levels with increasing nominal power class (A1 < A2 < A3) is observed. The quietest vehicles in this pattern are L1e-B and L6e-BP, each with a median level of around 72 dB(A). The loudness, Figure 3-11 mid graph, and roughness, Figure 3-11 bottom graph, correlate with the dB(A) levels, with L3e-A3 and L7e-B2 exhibiting the highest values. These results demonstrate that significant noise emissions also occur during full throttle accelerations in second gear, particularly for powerful L3e and L7e vehicles.

Figures 3-12 (third gear) and 3-13 (fourth gear) continue the analysis of Driving Pattern 8, focusing on full throttle acceleration from a constant speed in higher gears. Across both third and fourth gears, a consistent trend of higher noise levels with increasing nominal power class of the L3e vehicles (A1 < A2 < A3) is maintained. The L5e-A subcategory shows sound pressure level, top graph of figures, comparable to L3e-A2 and L7e-B2 (in 3rd gear) comparable to L3e-A3. The loudness values, mid graph of figures, closely mirror the sound pressure level trends, with the L3e-A3 subcategory showing the highest loudness in both gears. L7e-B2 (in 3rd gear) and L5e-A also demonstrate significant loudness values. This indicates a persistently high subjective perception of noise intensity during full acceleration in these gears. Roughness, bottom graph of figures, remains most pronounced for the L3e-A3 subcategory in both gears. This signifies a continuously rough and potentially aggressive sound character under these conditions. The L7e-B2 subcategory also showed elevated roughness in 3rd gear (Figure 3-12). Full throttle acceleration in third and fourth gears results in persistently high sound pressure levels and perceived loudness. The sound character also maintains a significant degree of roughness. These findings are significant as these gears are typically used at higher speeds, including urban and extra-urban cruising and overtaking, indicating that substantial noise emissions can occur under common, dynamic driving conditions.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

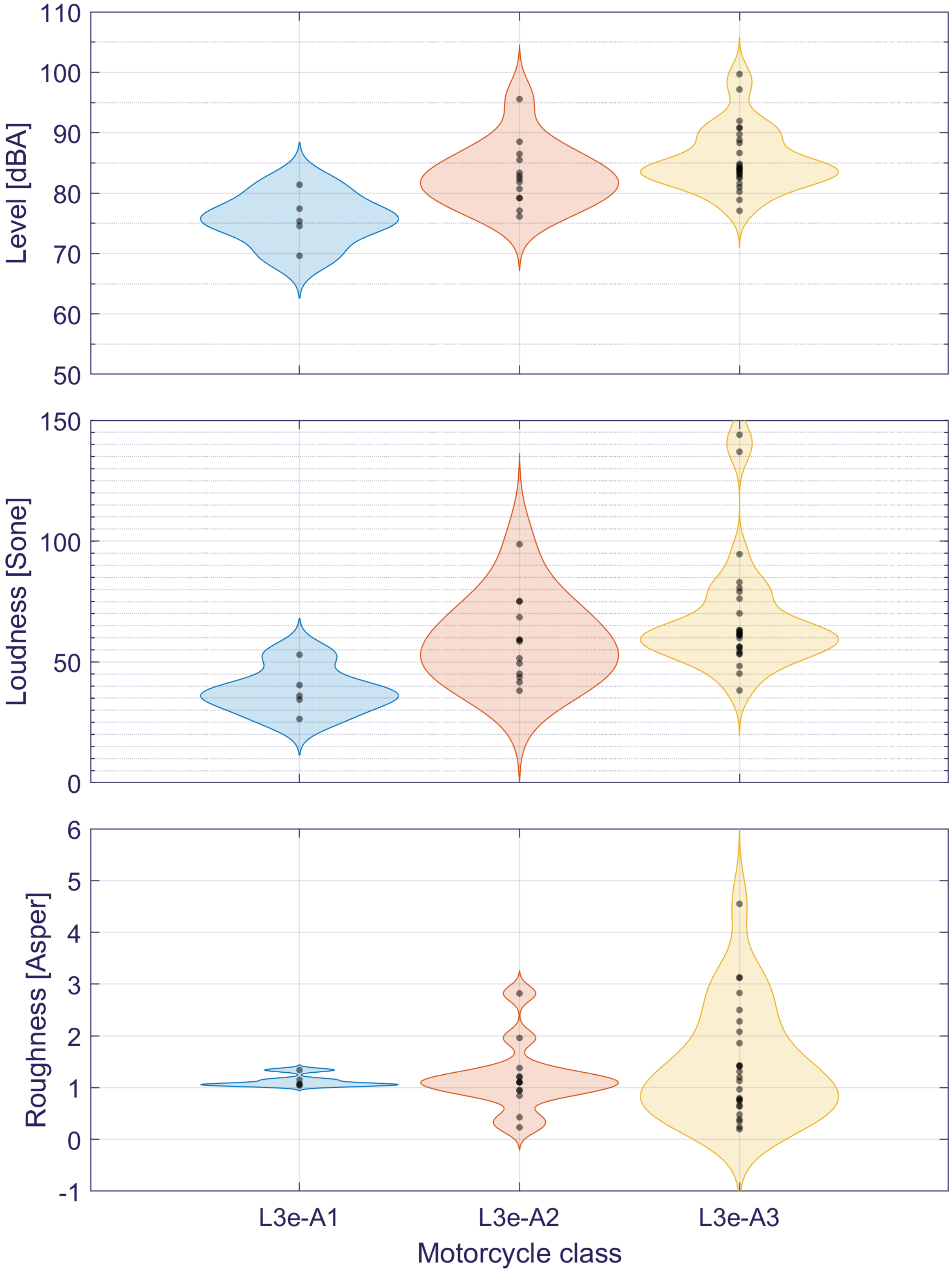


Figure 3-10: Acoustic parameters vs. subcategory for driving pattern 7 (gear shift, first to second, const. speed)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

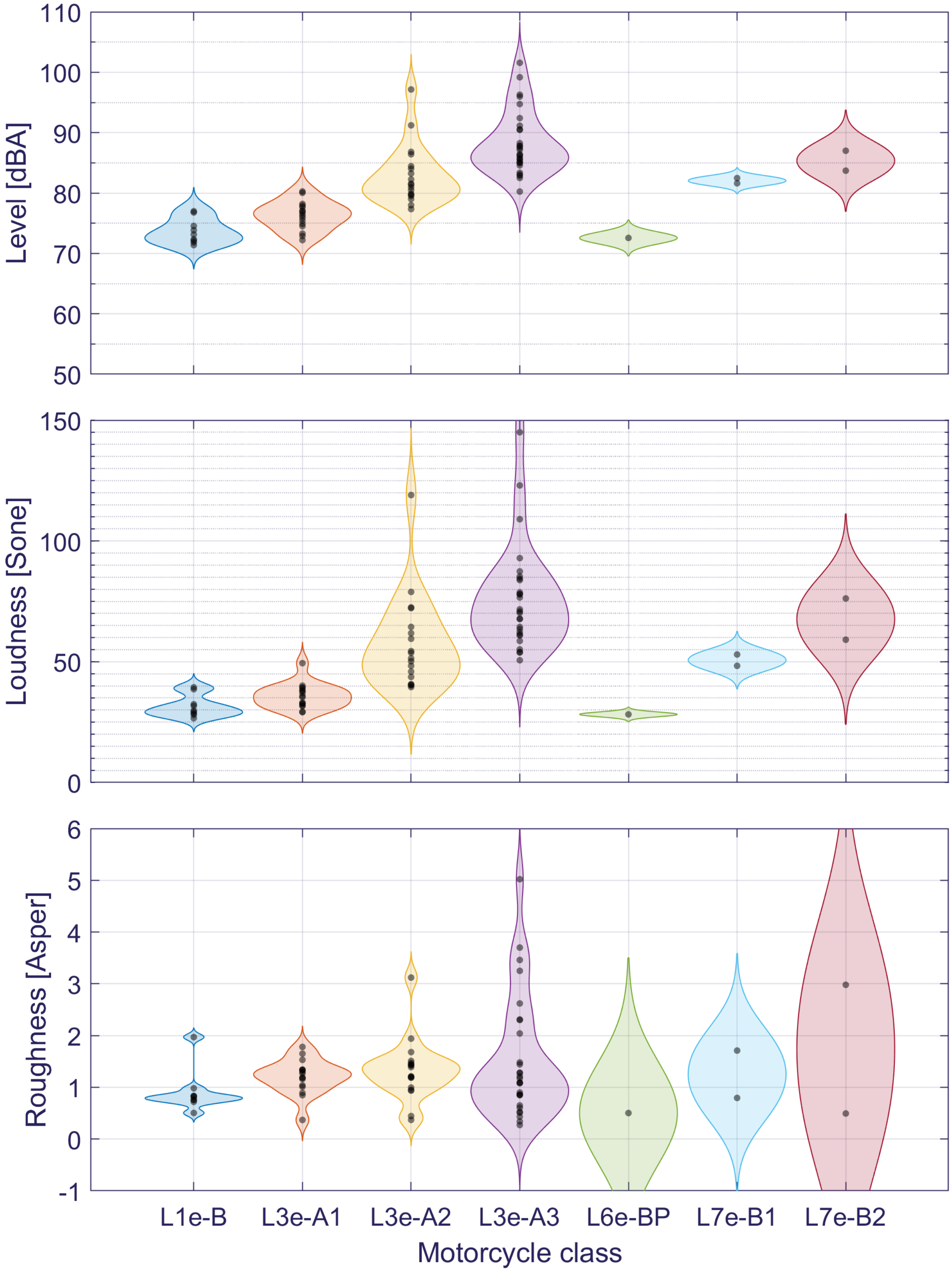


Figure 3-11: Acoustic parameters vs. subcategory for driving pattern 8 (full/ max. throttle acc., gear 2/30 km/h)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

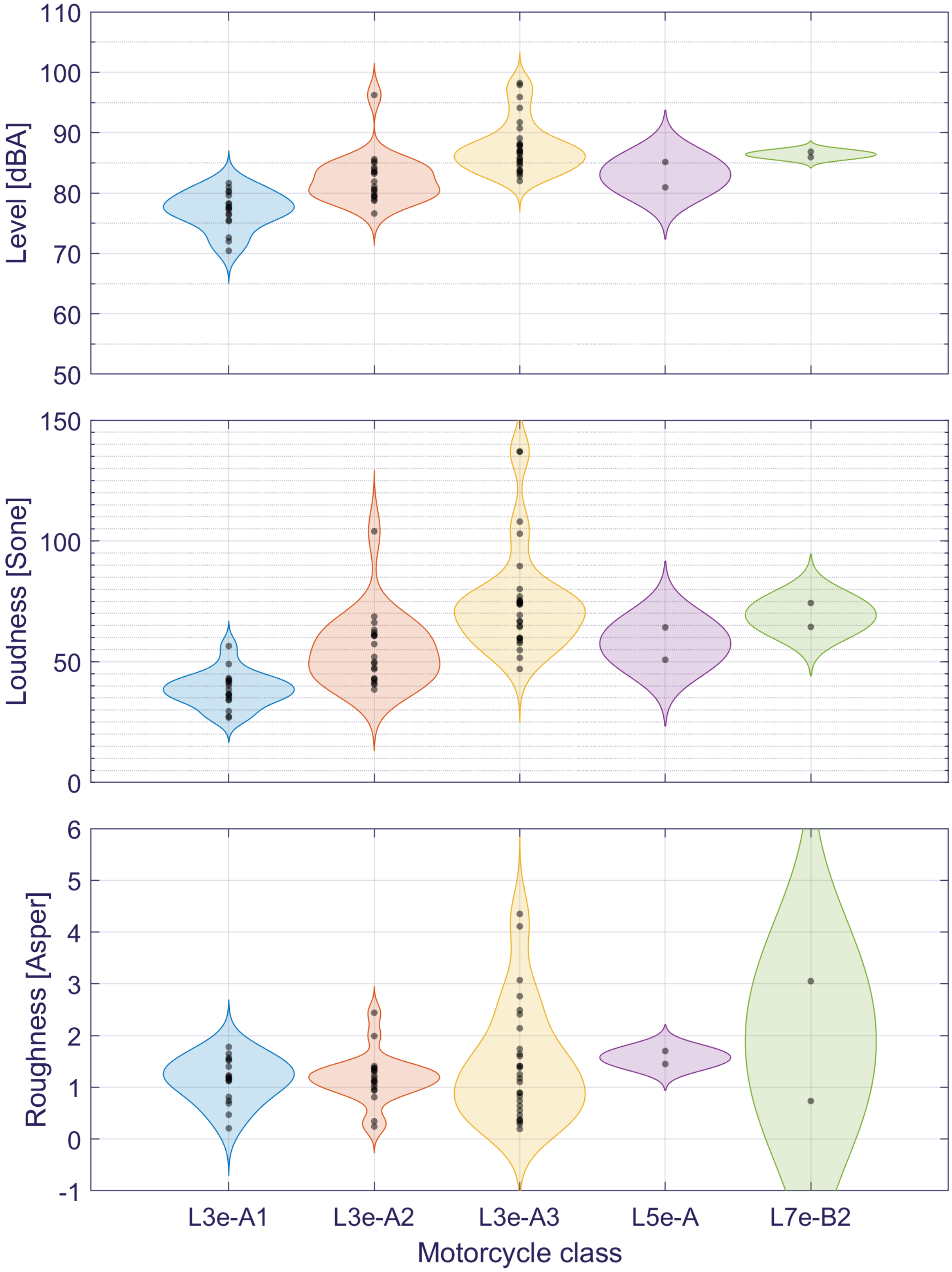


Figure 3-12: Acoustic parameters vs. subcategory for driving pattern 8 (full/ max. throttle acc., gear 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

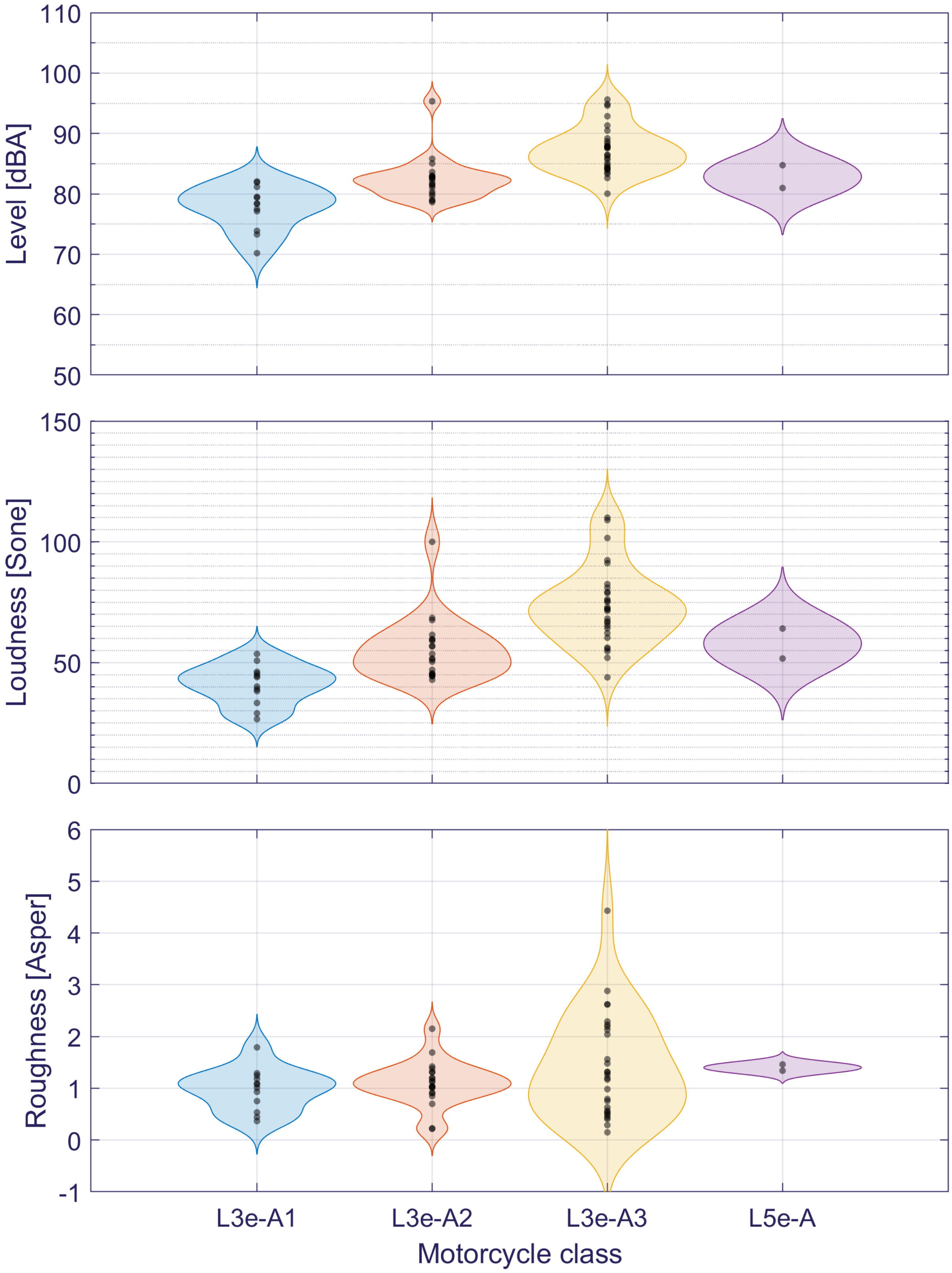


Figure 3-13: Acoustic parameters vs. subcategory for driving pattern 8 (full/ max. throttle acc., gear 4)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figures 3-14 (gear shift 2 to 3), 3-15 (gear shift 3 to 4), and 3-16 (gear shift 4 to 5) provide an analysis of Driving Pattern 9. This pattern involves a short acceleration in the current gear from a constant speed, followed by an upshift to the next higher gear and subsequent aggressive acceleration. The L3e categories A1, A2, and A3 are depicted in each of these figures. For all investigated upshift patterns (gearshit from 2 to 3, 3 to 4 and 4 to 5), the acoustic values for level, loudness, and roughness consistently demonstrate a clear gradation corresponding to the L3e vehicle power class (A1 < A2 < A3). The L3e-A3 subcategory exhibits the highest values across all three parameters, indicating a very dynamic and potentially disturbing sound character during the combined shifting and acceleration phase. Gear shifts themselves can be sources of significant noise emissions and abrupt sound changes. This is particularly significant with regard to extra-urban driving or journeys on highways, where such gear shifts occur frequently. The results suggest that the dynamic aspects of driving, including gear shifts, can make a substantial contribution to the overall noise pollution from LVs.
Figure 3-17 illustrates Driving Pattern 10, which consists of driving at a constant speed in first gear with high engine speed. For CVTs, this pattern was executed at a constant speed of 30 km/h to ensure comparability. L3e categories (especially L3e-A2 and L3e-A3) as well as the L7e-B2 subcategory demonstrate very high median dB(A) values, Figure 3-6 top graph, during this pattern. These levels appear to be potentially comparable or even lower than those recorded during aggressive acceleration from a standstill (compare with Figure 3-6). Vehicles in the L1e-B and L6e-BP categories exhibit the lowest levels in this scenario. The pattern of loudness values, Figure 3-6 mid graph, follows that of the dB(A) levels, with very high values for the high-performance categories, especially L3e-A3, which exceeds 150 sone. This indicates an exceptionally high level of subjective noise annoyance. The roughness values, Figure 3-6 bottom graph, appear moderate for most categories, with median values typically ranging between 0.5 and 1 asper. Driving at high engine speeds in a low gear represents an extreme noise scenario. In this state, the engine operates in an inefficient range that is also acoustically very loud, leading to significant environmental noise impact.
Figure 3-18 continues the investigation of Driving Pattern 10, this time focusing on constant speed driving in second gear with high engine speed. For CVTs, this pattern was executed at a constant speed of 50 km/h. Even when driving at high engine speed in second gear, a clear dependency of noise emissions on the vehicle (sub-)category remains evident. L3e-A3 is the most acoustically prominent subcategory. Categories L1e-B and L6e-BP are the least conspicuous. The L7e-B2 and L5e-A categories fall into the mid-range of observed noise levels. In comparison to driving at high engine speeds in first gear (as shown in Figure 3-17), the level, loudness, and roughness values in second gear for the high-performance categories (especially L3e-A3) tend to be slightly lower, but still at a high level. The high roughness recorded for L3e-A3 continues to indicate a very prominent and potentially disturbing sound character. The persistently high values, particularly for the L3e-A3 subcategory, underscore the fact that driving at high engine speeds, irrespective of the specific gear selected among the lower gears, leads to considerable noise emissions and a potentially annoying sound quality due to roughness.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

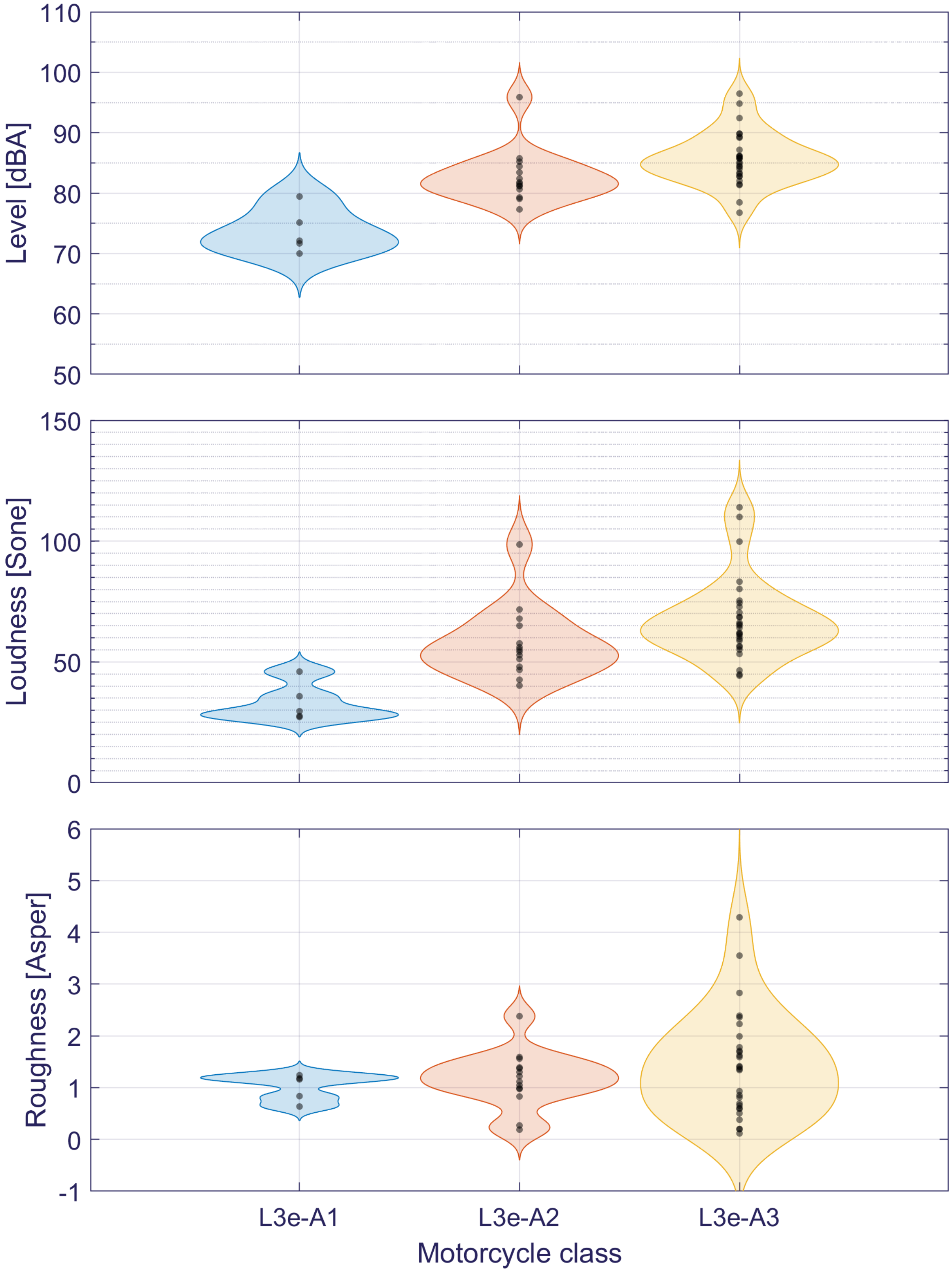


Figure 3-14: Acoustic parameters vs. subcategory for driving pattern 9 (gear shift, from const. speed, gear 2 to 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

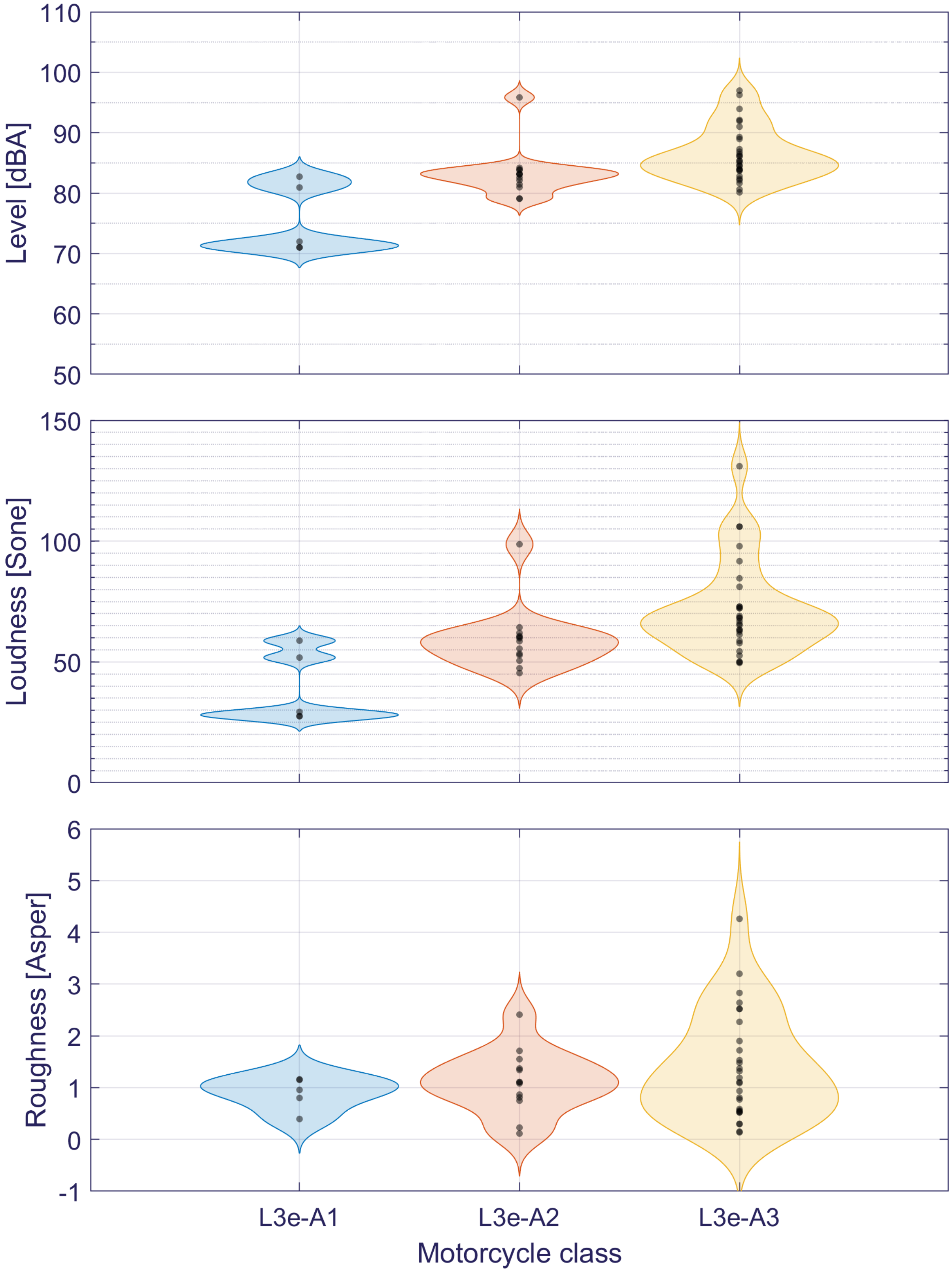


Figure 3-15: Acoustic parameters vs. subcategory for driving pattern 9 (gear shift, from const. speed, gear 3 to 4)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

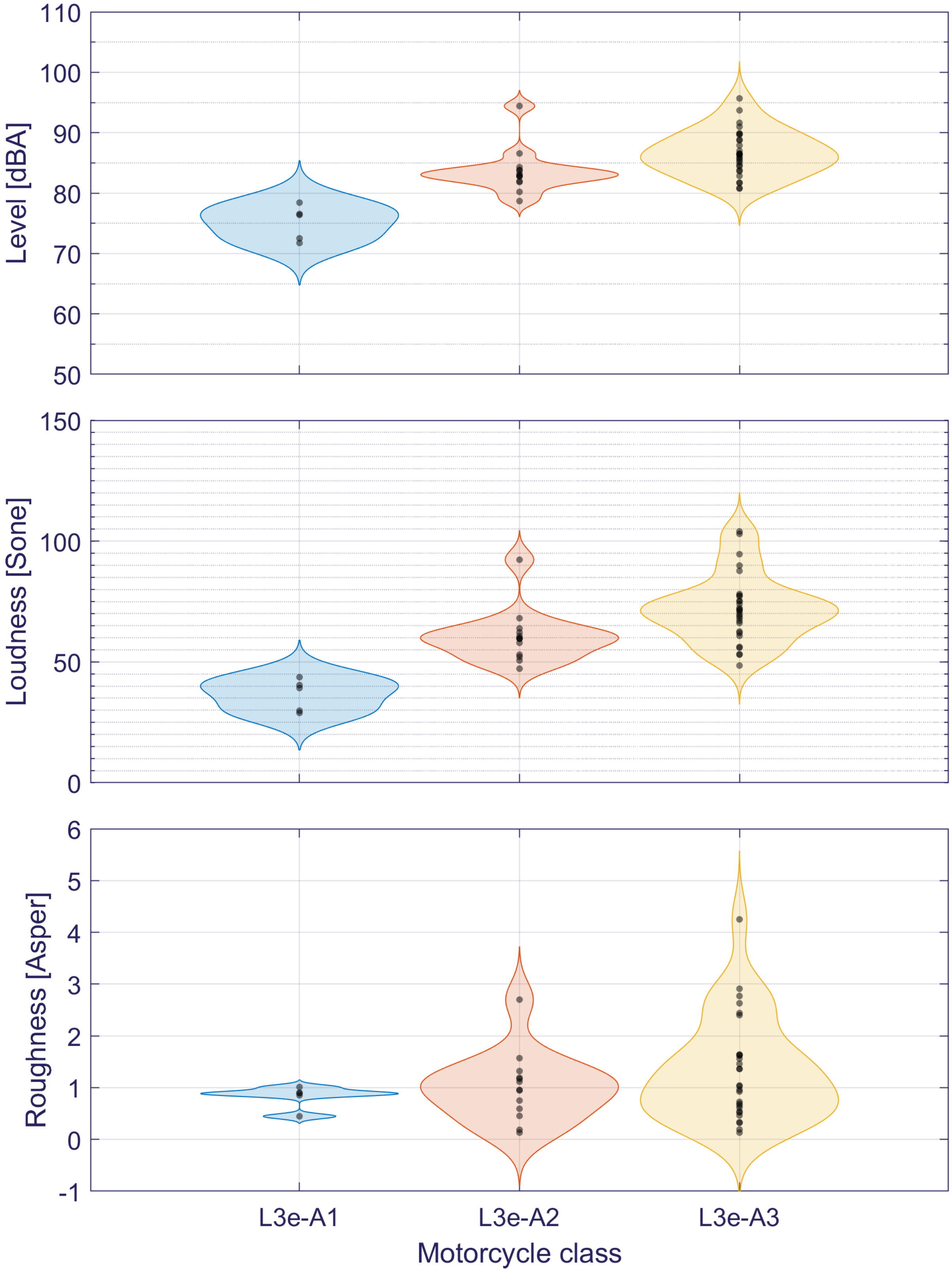


Figure 3-16: Acoustic parameters vs. subcategory for driving pattern 9 (gear shift, from const. speed, gear 4 to 5)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

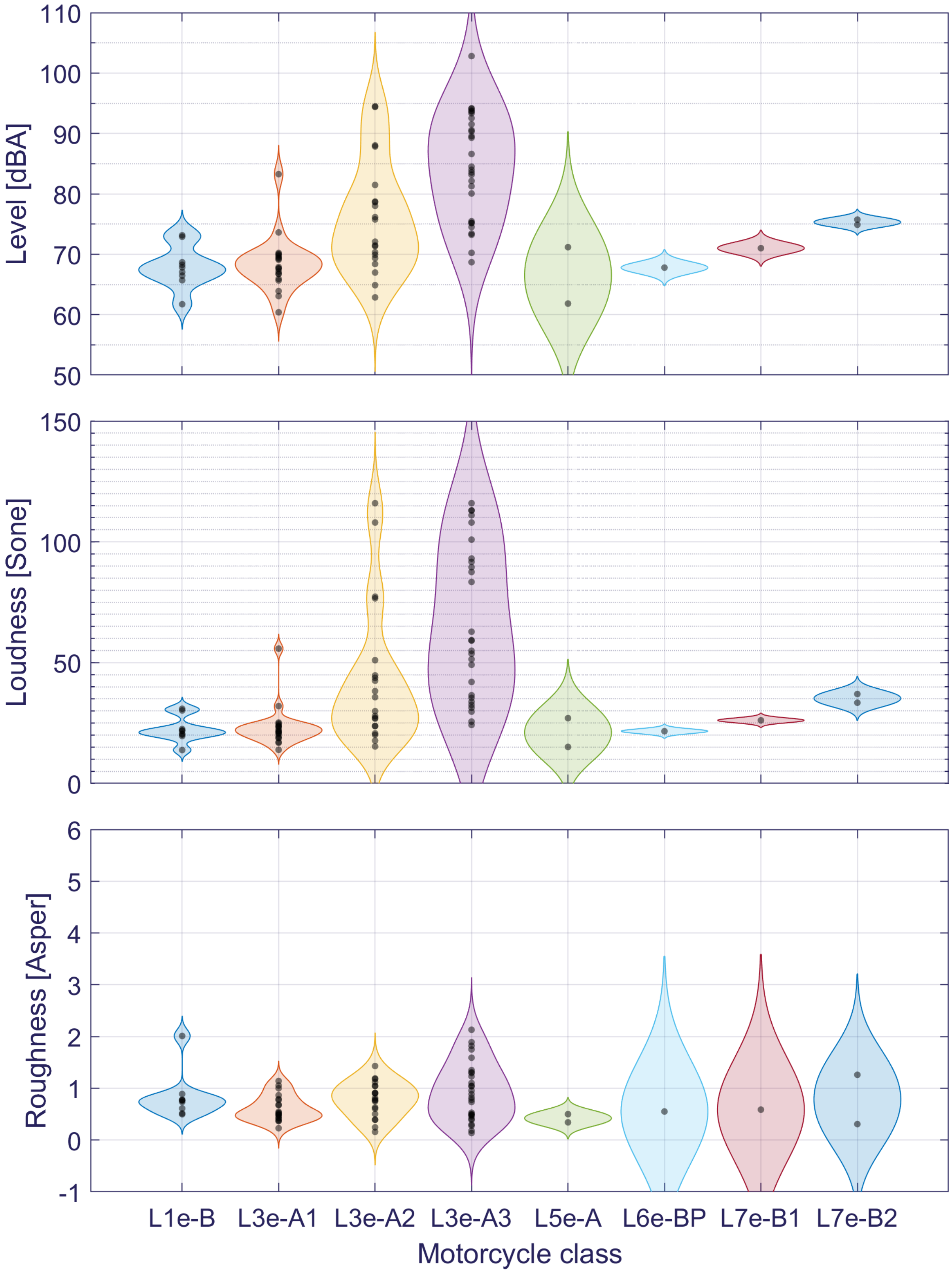


Figure 3-17: Acoustic parameters vs. subcategory for driving pattern 10 (const. speed, high/ max. engine speed, gear 1/ 30 km/h)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

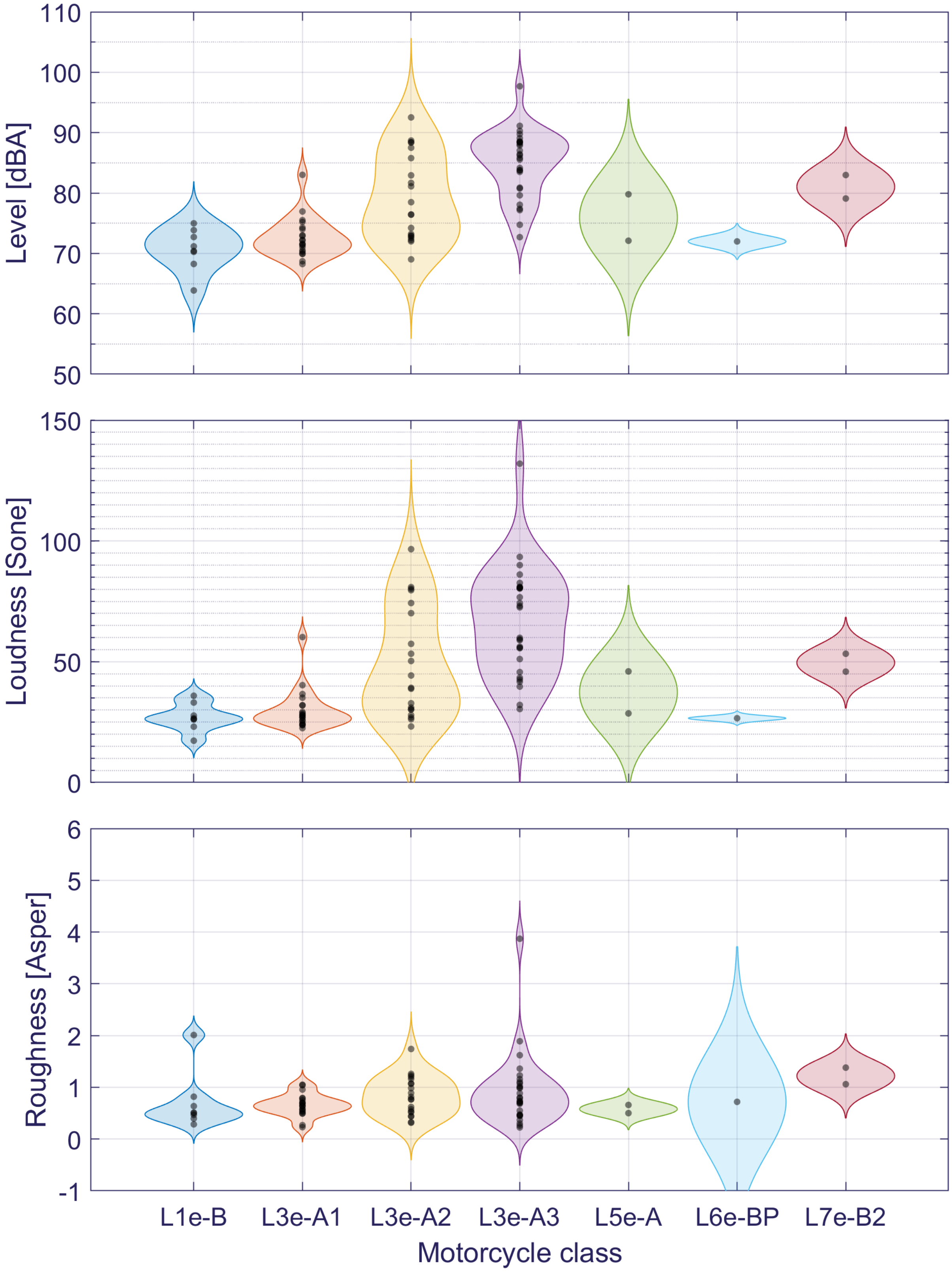


Figure 3-18: Acoustic parameters vs. subcategory for driving pattern 10 (const. speed, high/ max. engine speed, gear 2/ 50 km/h)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

The analysis of Driving Pattern 10 is extended in Figure 3-19 to constant speed driving in third gear with high engine speed. The sound pressure levels, Figure 3-6 top graph, and loudness, Figure 3-6 mid graph, for the L3e categories appear to remain high when driving at high engine speed in third gear. L3e-A3 tends to exhibit the highest values identified as the loudest subcategory in this specific gear and operating conditions. The L7e-B2 subcategory shows values that are comparable to those of L3e-A3. Compared to second gear (Figure 3-18), the values for L3e-A3 might be slightly reduced, but still significant. A particularly noteworthy aspect is the roughness, Figure 3-6 bottom graph. For the L3e-A3 subcategory, roughness in third gear at high engine speed appears to be lower than in first or second gear under comparable conditions (Figure 3-17 and 3-18). The observed reduction in roughness, despite potentially still high sound pressure levels and loudness, is an interesting phenomenon. It suggests that although the engine remains loud at this operating point, it may be running more smoothly and producing fewer strongly noise components compared to its operation in lower gears at high engine speed.

Figure 3-20 concludes the examination of Driving Pattern 10, focusing on constant speed driving in fourth gear with high engine speed. When driving at this pattern, the sound pressure level values for the L3e-A3 subcategory, Figure 3-6 top graph, tend to be lower compared to those observed in the lower gears (1 to 3) for this specific driving pattern. L3e-A3 still represents a significant noise source, but it is no longer at the extreme levels seen in lower gears. In contrast, the values for the other categories increase slightly. Correspondingly, the pattern of loudness values, Figure 3-6 mid graph, follows that of dB(A) levels. The roughness, Figure 3-6 bottom graph, for all categories is fairly consistent with the observation for third gear. L5e-A shows the highest roughness values of about 1 asper. These results show that the noise emissions from driving at high engine speed are strongly dependent on the selected gear. While high engine speeds in low gears can lead to extreme noise peaks, the emissions in higher gears at the same or similar high engine speed are often more moderate, though still significant for powerful vehicles. This has implications for defining critical driving conditions in test procedures, as it highlights that not only the absolute engine speed but also the selected gear and the resulting vehicle speed must be carefully considered.

Figures 3-21 (gear 2 to 1), 3-22 (gear 3 to 2), 3-23 (gear 4 to 3), and 3-24 (gear 5 to 4) investigate Driving Pattern 11. This pattern consists of driving at a constant speed in the current gear, followed by a downshift to the next lower gear and subsequent aggressive acceleration. The L3e categories A1, A2 and A3 are shown in each of these figures to illustrate the acoustic effects of this dynamic behaviour. The sound pressure levels, top graph of figures, and loudness values, mid graph of figures, for the L3e categories during this Driving Pattern appear to consistently show the known performance-based gradation. L3e-A3 tends to exhibit the highest values, followed by L3e-A2, and then L3e-A1. The roughness values, bottom graph of figures, appear to be moderate for all three L3e categories during these patterns. L3e-A3 tends to show slightly higher roughness values, but overall, the sound is not characterized by extreme roughness despite the aggressive acceleration component. Such downshifting and subsequent aggressive acceleration manoeuvres are typical of sporty driving styles or overtaking situations.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

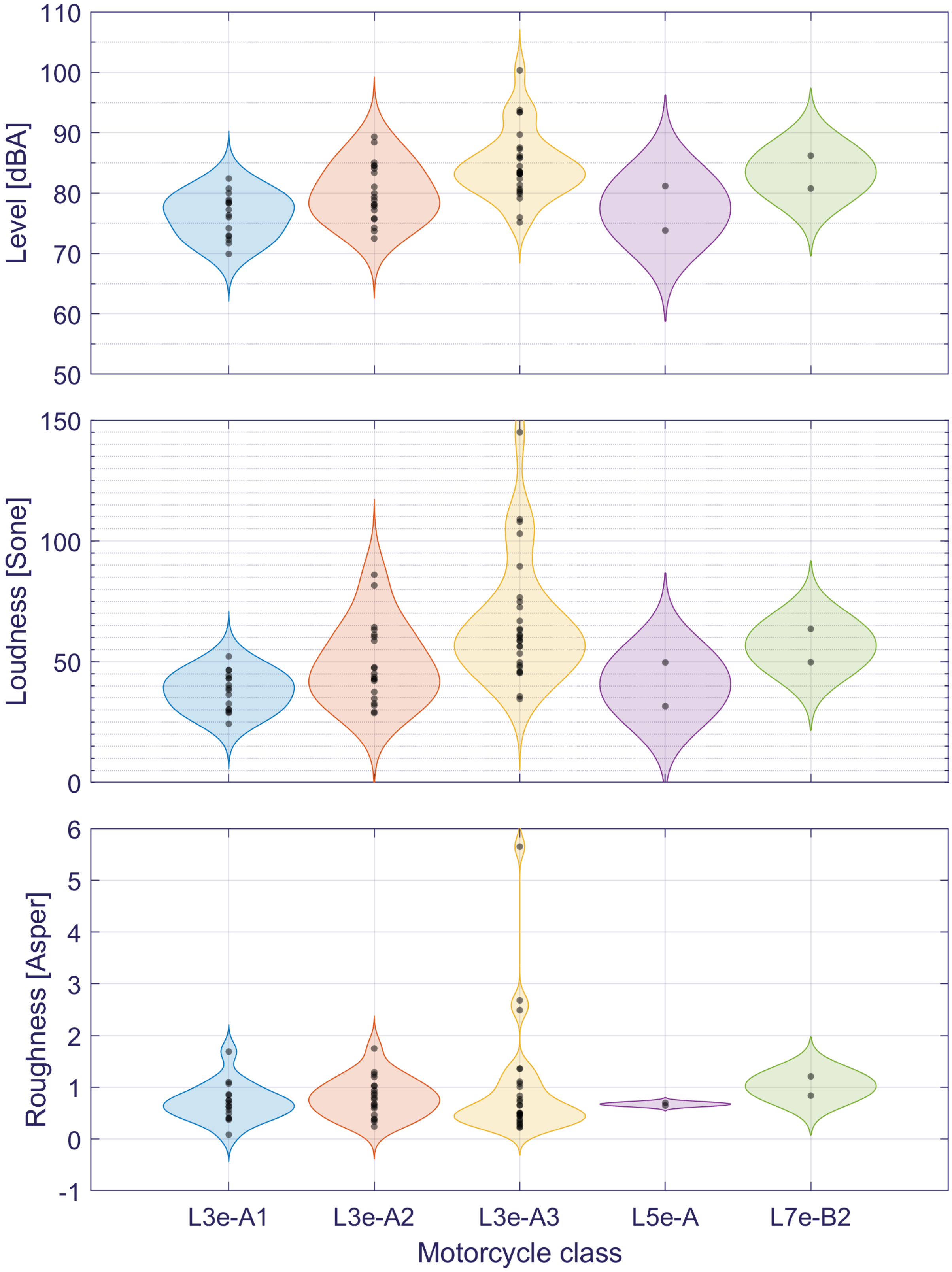


Figure 3-19: Acoustic parameters vs. subcategory for driving pattern 10 (const. speed, high/ max. engine speed, gear 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

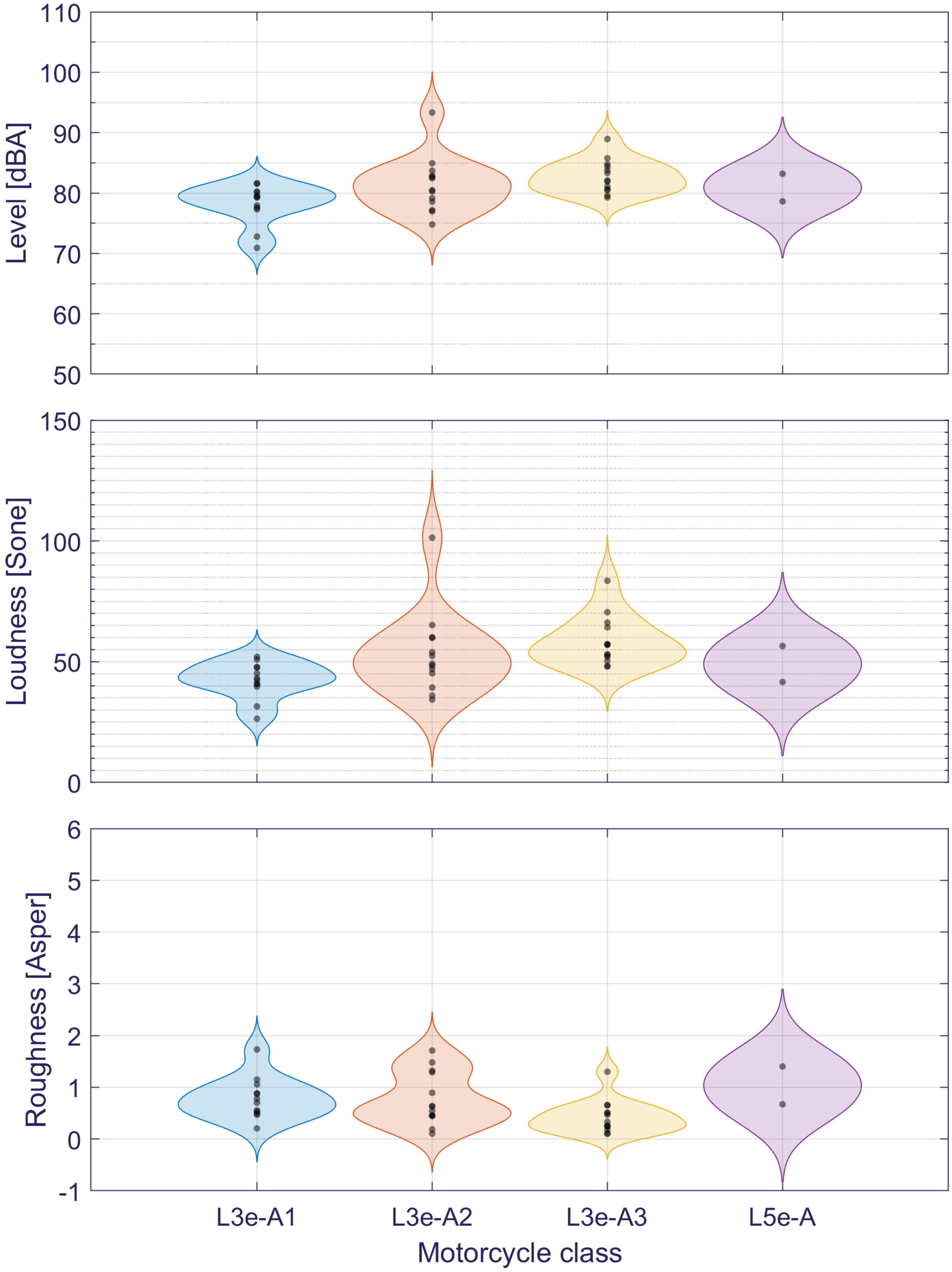


Figure 3-20: Acoustic parameters vs. subcategory for driving pattern 10 (const. speed, high/ max. engine speed, gear 4)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure 3-21: Acoustic parameters vs. subcategory for driving pattern 11 (gear shift, from const. speed, gear 2 to 1)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

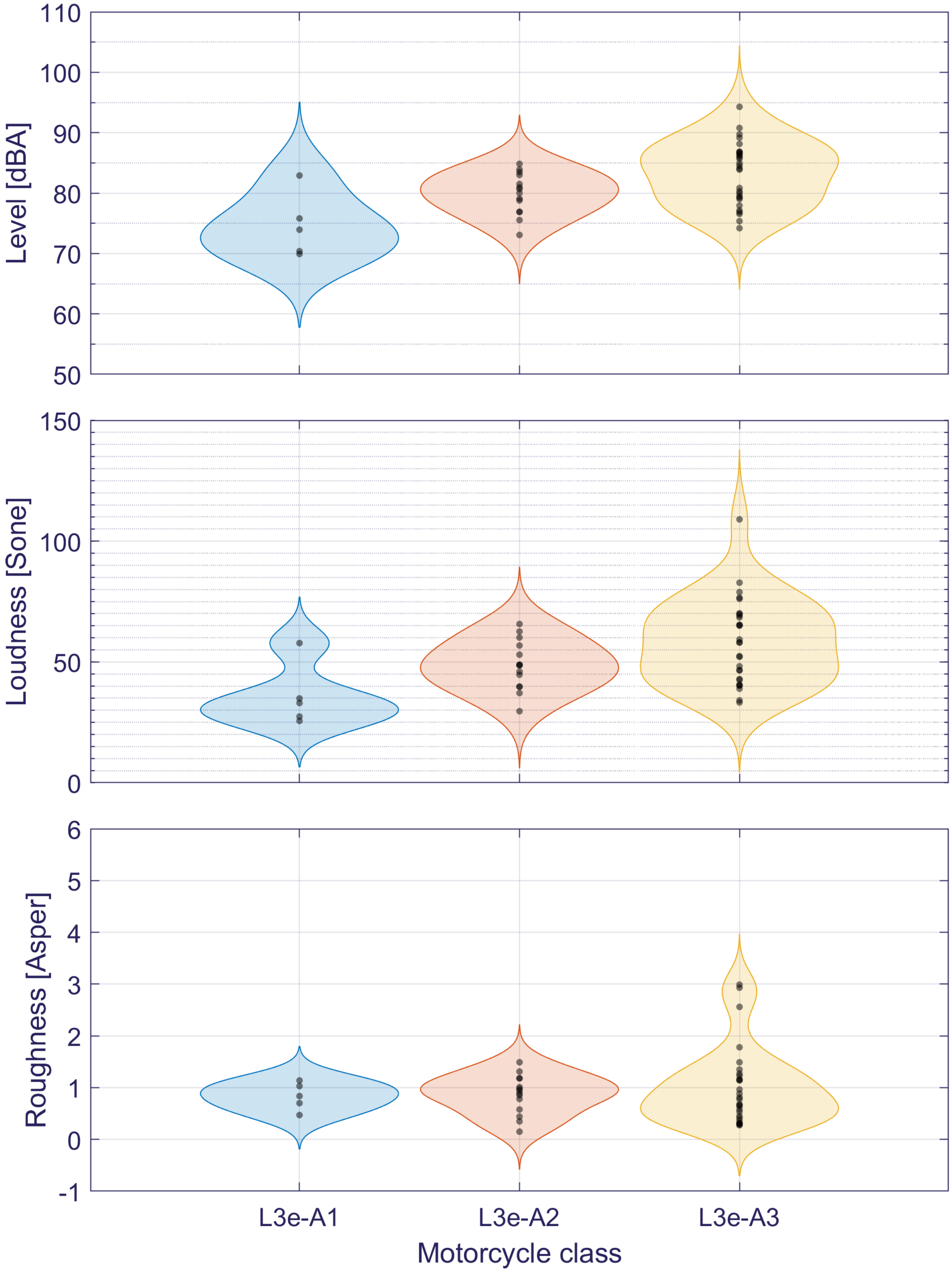


Figure 3-22: Acoustic parameters vs. subcategory for driving pattern 11 (gear shift, from const. speed, gear 3 to 2)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

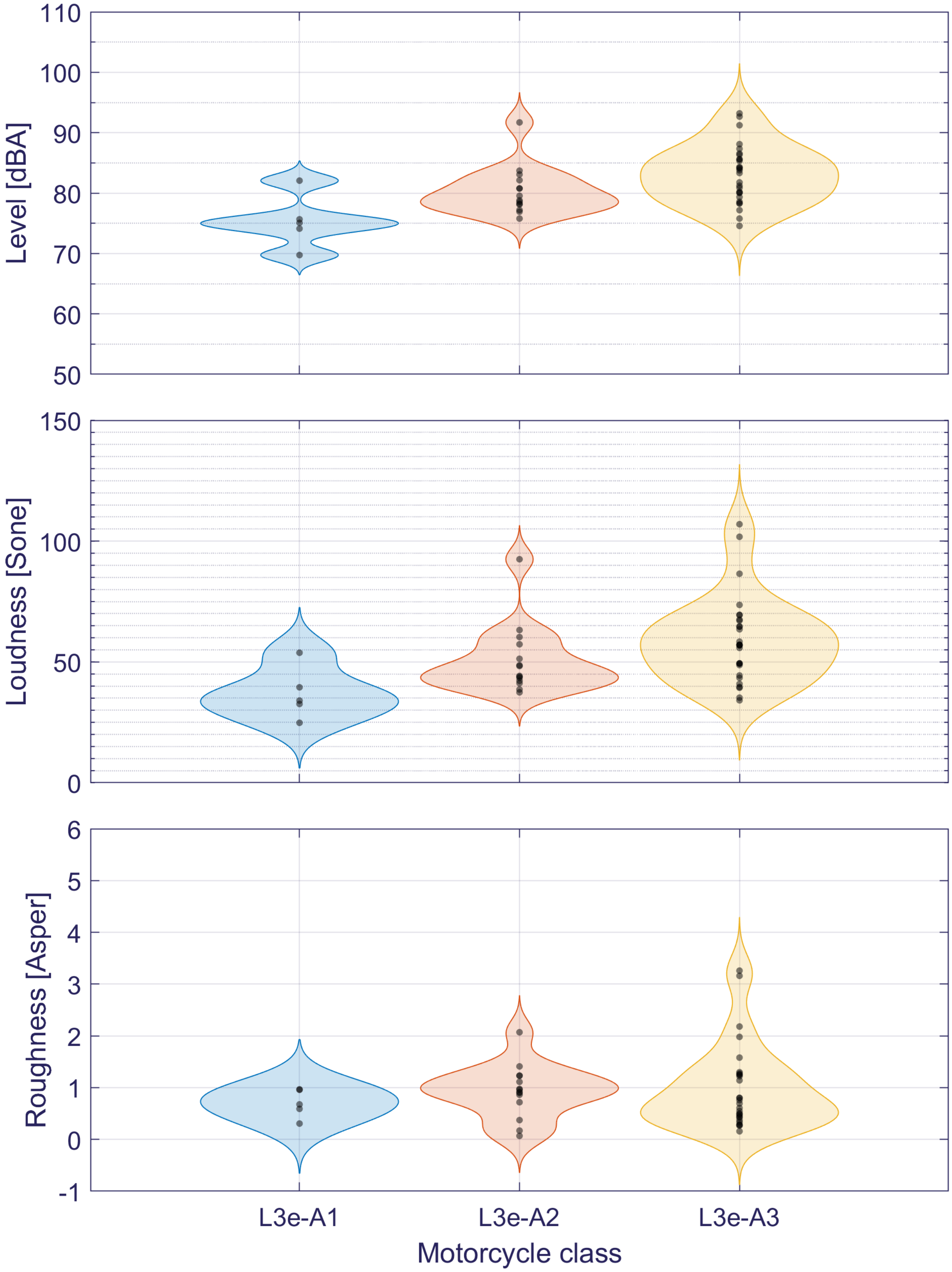


Figure 3-23: Acoustic parameters vs. subcategory for driving pattern 11 (gear shift, from const. speed, gear 4 to 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

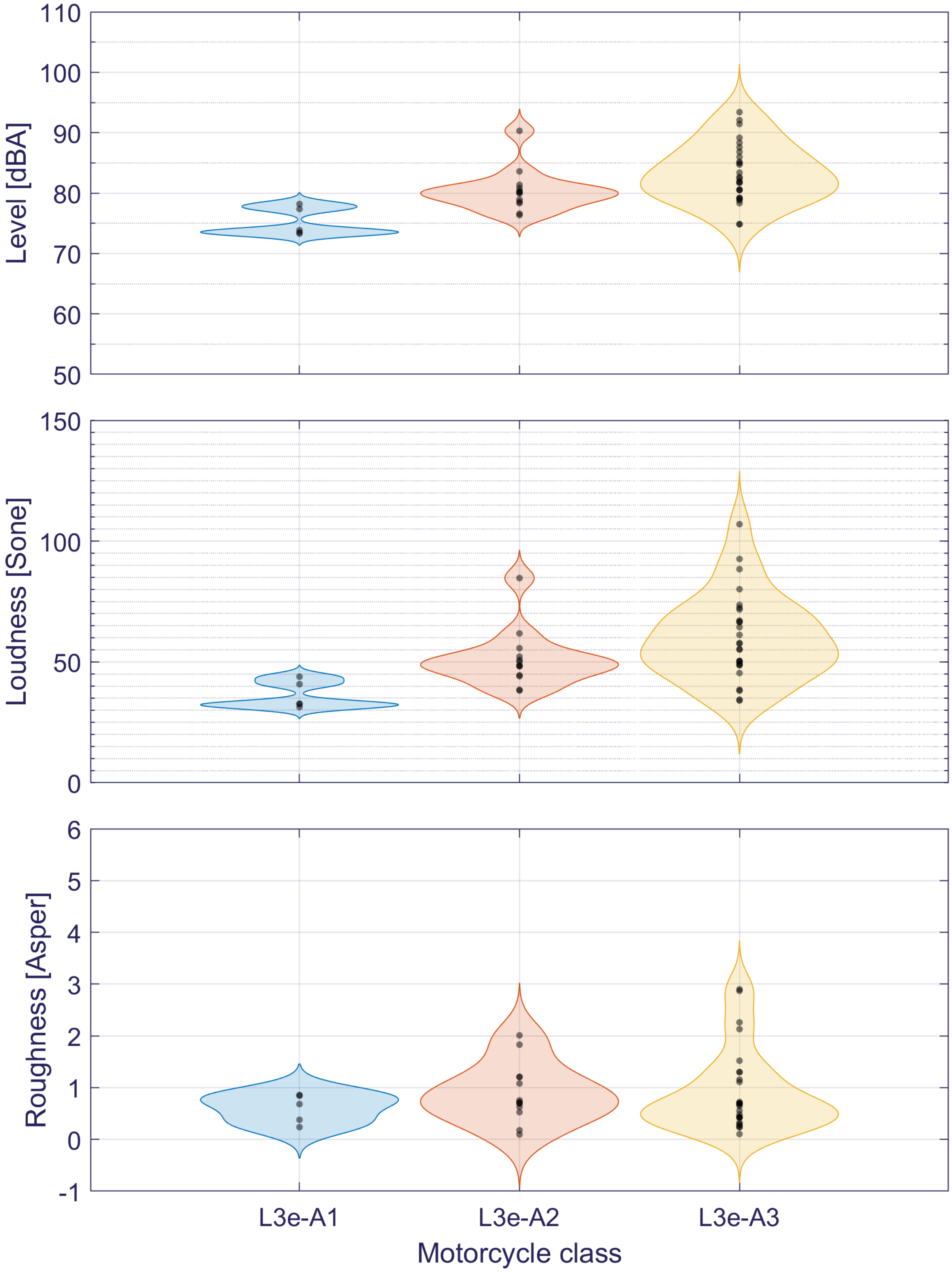


Figure 3-24: Acoustic parameters vs. subcategory for driving pattern 11 (gear shift, from const. speed, gear 5 to 4)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figures 3-25 (first gear), 3-26 (second gear), and 3-27 (third gear) investigate Driving Pattern 13. This pattern consists of intermittent operation of the throttle while maintaining a constant speed. Across all three investigated gears (1, 2, and 3), intermittent throttle operation consistently shows a clear gradation of sound pressure levels, top graph of figures, and loudness, mid graph of figures, according to the power class of the L3e vehicles (A1 < A2 < A3). The L3e-A3 subcategory achieves very high median loudness values in all three gears, indicating a strong subjective noise perception. Dispersion of measurement values, particularly for L3e-A3, is considerable in all gears, underscoring the high variability of this driver-influenced pattern. In contrast to the level and loudness values, the roughness values, bottom graph of figures, for the individual throttle applications show a moderate level and a tendency to converge across all three gears and all three L3e classes. This suggests that while the individual bursts of throttle are loud, they do not possess an extremely "rough" or heavily modulated sound character. This driving behaviour can occur in reality due to various driving styles or situations and has the potential to create very conspicuous and annoying noise patterns. The results emphasize the need to consider such non-stationary and heavily driver-influenced patterns when assessing the real-world noise emissions of LVs.

Figure 3-28 shows the acoustic parameters for Driving Pattern 14, which represents deceleration after releasing the throttle control in first gear. For CVTs, this pattern was executed by reaching the AA' line at the motorcycle's top speed and then releasing the throttle to allow the motorcycle to decelerate until the rear of the vehicle reached the BB' line from Figure 2-1. The sound pressure levels, Figure 3-6 top graph, during this pattern are generally low to moderate. Loudness, Figure 3-6 mid graph, and Roughness, Figure 3-6 bottom graph, are correspondingly low, which indicates a significantly lower subjective perception of the noise intensity and a smooth sound character compared to driving conditions under load (such as acceleration or constant speed driving). These results clearly show significantly lower noise emissions for this pattern, which can therefore be classified as acoustically non-critical.

Figures 3-29 (second gear), 3-30 (third gear), 3-31 (fourth gear), and 3-32 (fifth gear) continue the analysis of Driving Pattern 14 (deceleration after throttle release), extending the examination to higher gears for the L3e categories. During deceleration in these higher gears (2nd through 5th), the median values of the acoustic parameters (sound pressure level, loudness, and roughness) are generally moderate and show a trend of convergence across all L3e subcategories (A1, A2, A3). This convergence suggests that vehicle-specific powertrain noises, which are dominant under load, recede into the background during deceleration. Consequently, other noise sources, such as tyre-road interaction noise and wind noise, which are less dependent on engine performance class and more influenced by vehicle speed and design, likely become more influential in the overall sound signature. Generally, the median values observed during deceleration in these higher gears are slightly higher than those observed in first gear (Figure 3-28). This might be attributed to higher initial coasting speeds associated with deceleration in higher gears, leading to a potentially stronger contribution from these speed-dependent, non-powertrain noise sources.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

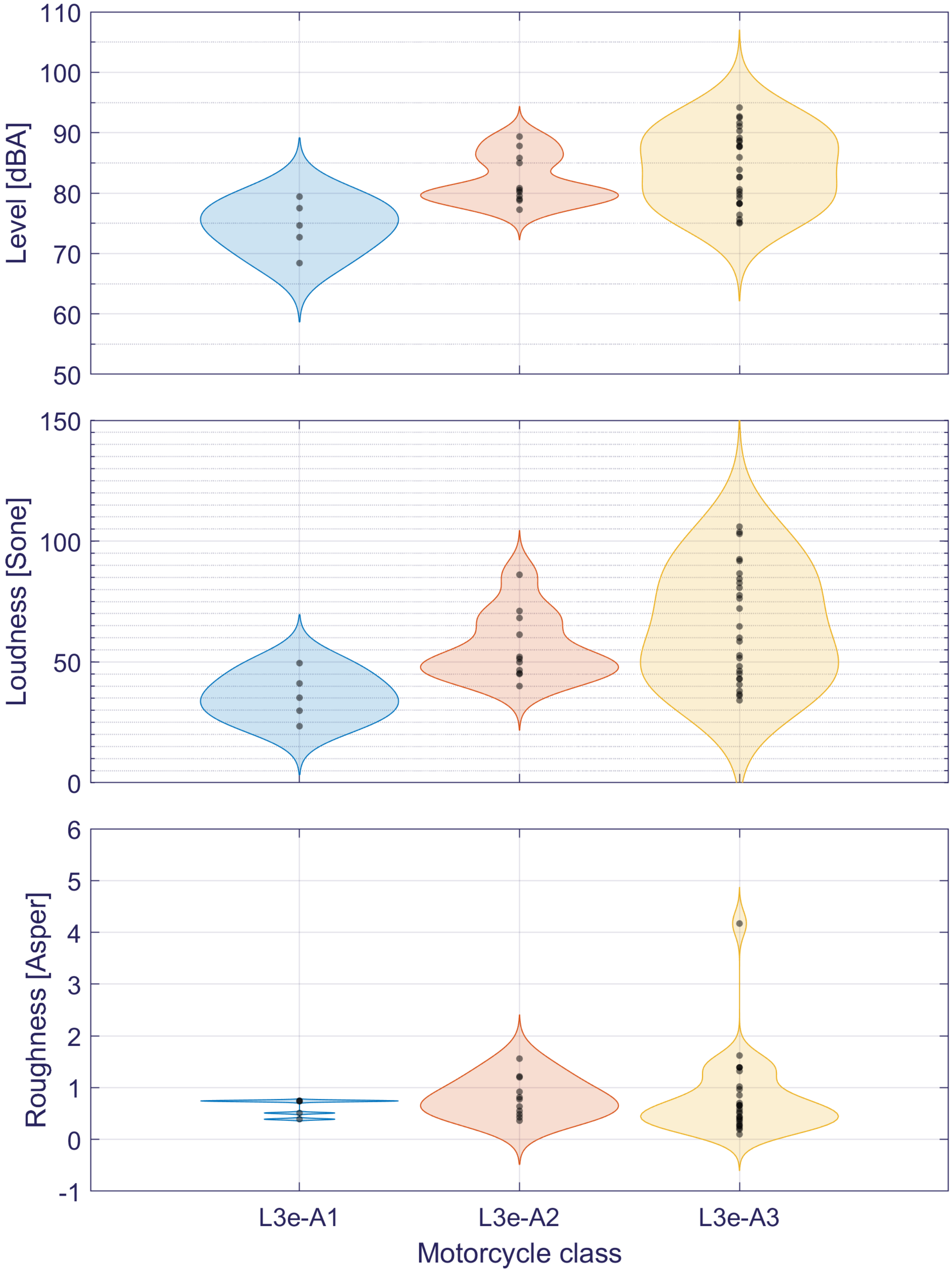


Figure 3-25: Acoustic parameters vs. subcategory for driving pattern 13 (intermittent throttle control, gear 1)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

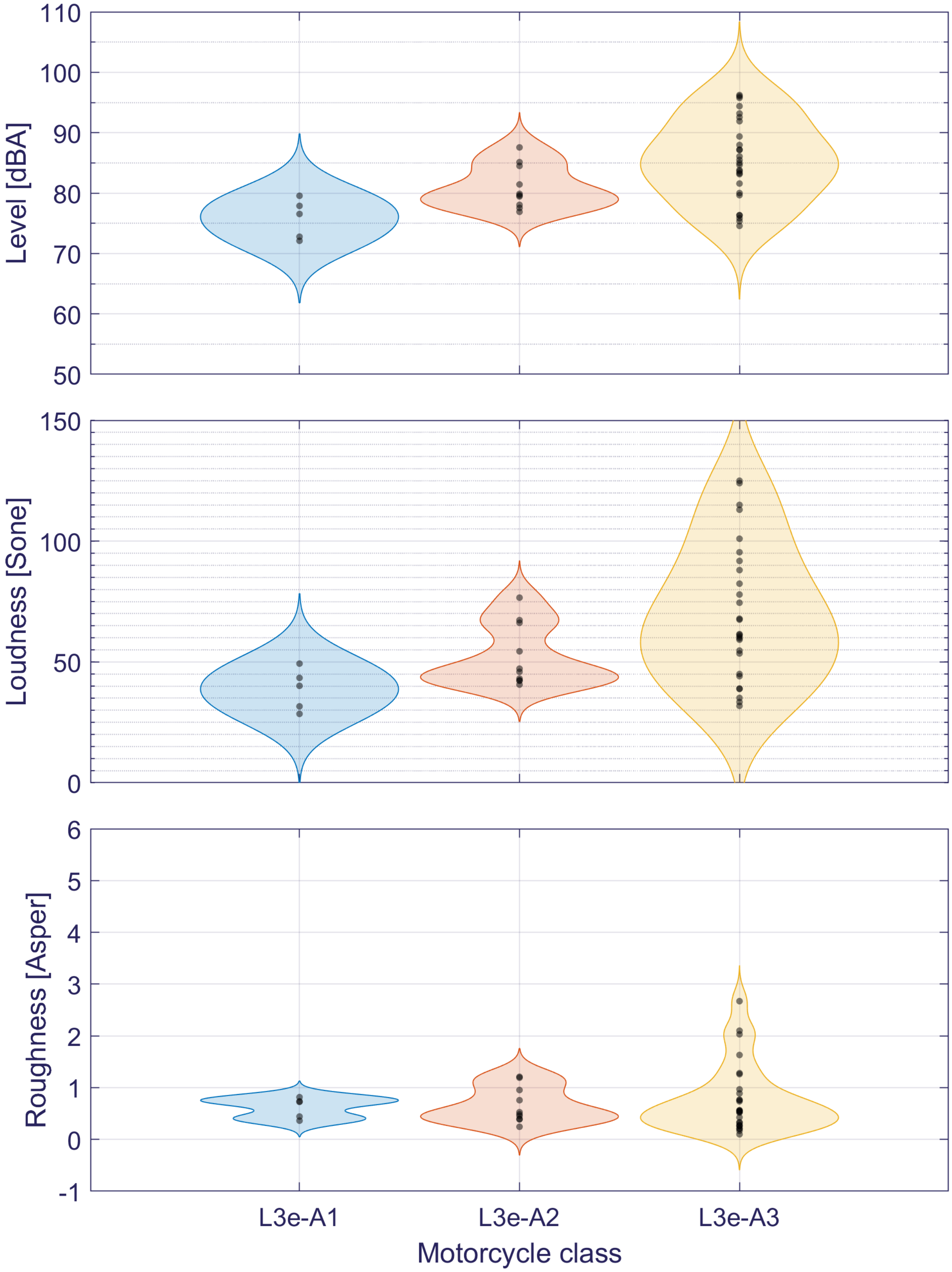


Figure 3-26: Acoustic parameters vs. subcategory for driving pattern 13 (intermittent throttle control, gear 2)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

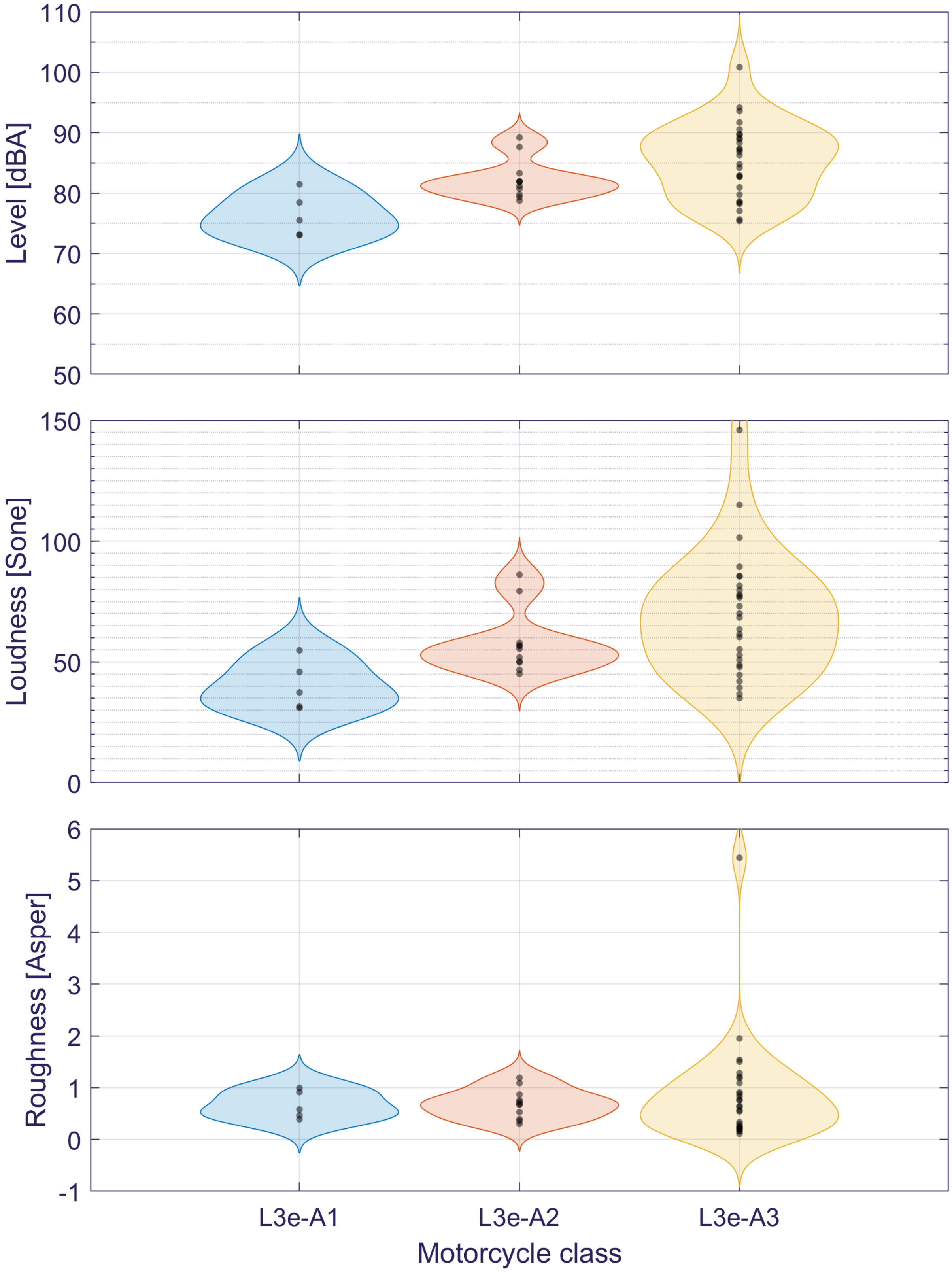


Figure 3-27: Acoustic parameters vs. subcategory for driving pattern 13 (intermittent throttle control, gear 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

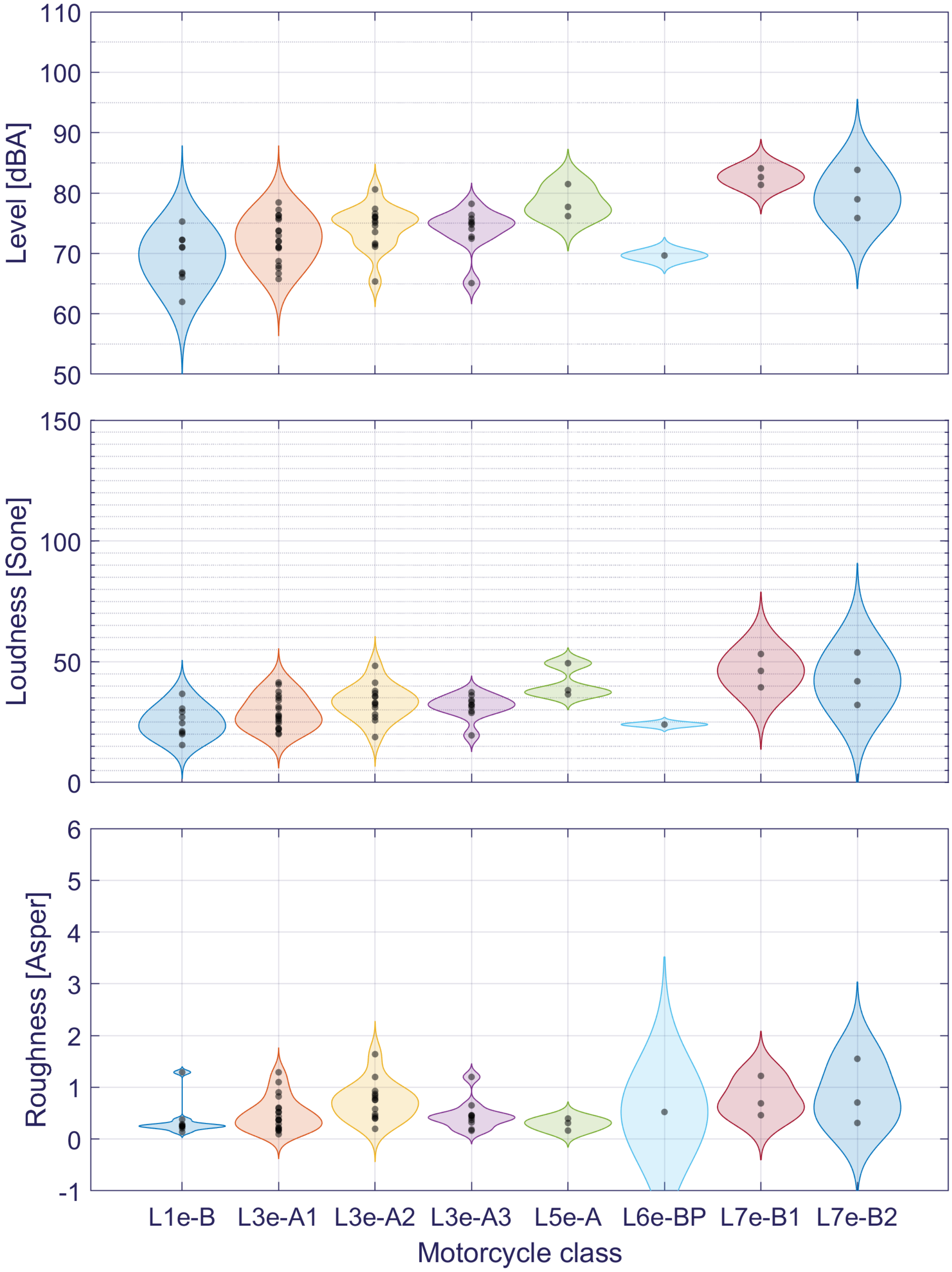


Figure 3-28: Acoustic parameters vs. subcategory for driving pattern 14 (deceleration, gear 1/ max. speed)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

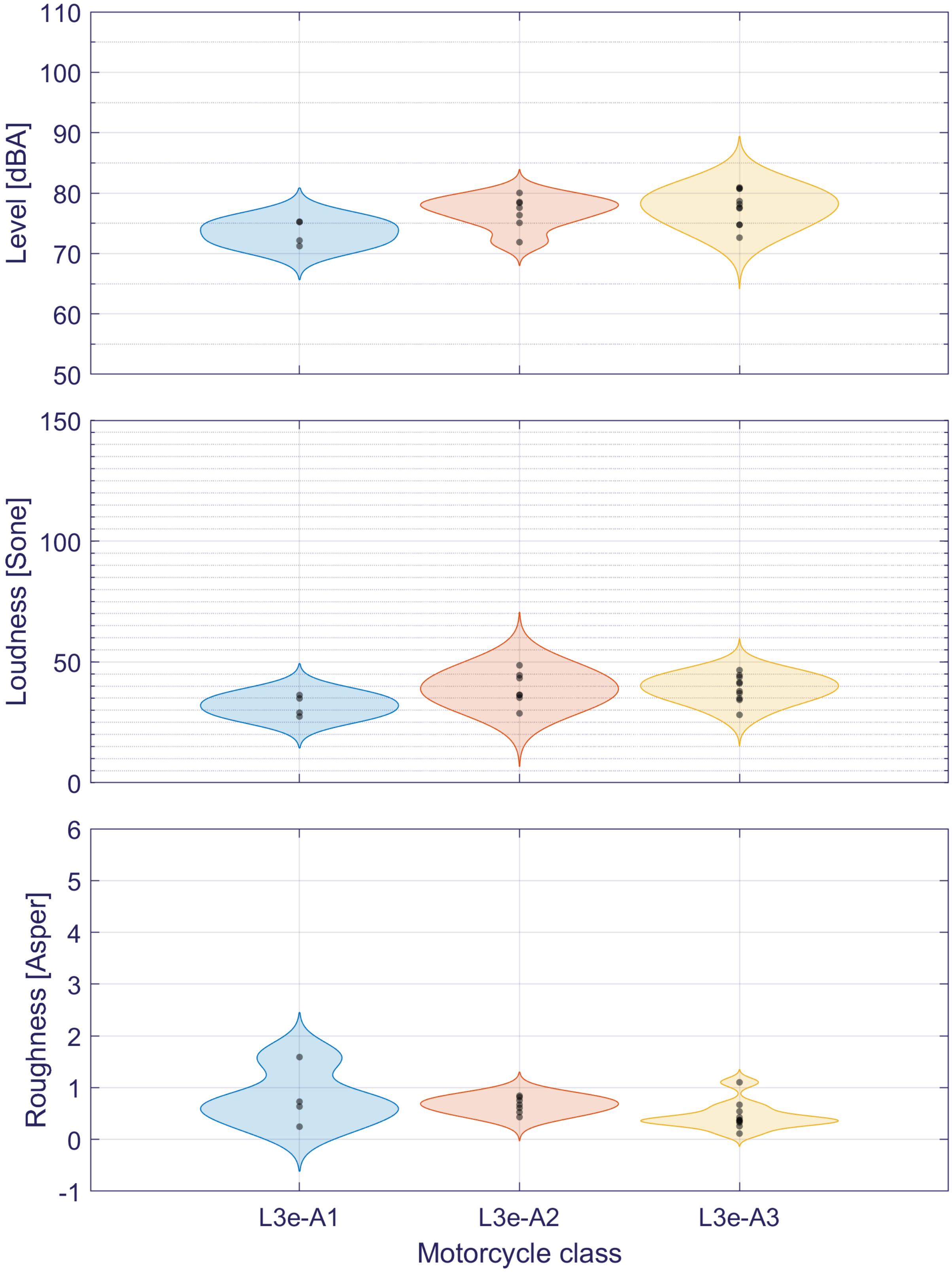


Figure 3-29: Acoustic parameters vs. subcategory for driving pattern 14 (deceleration, gear 2)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

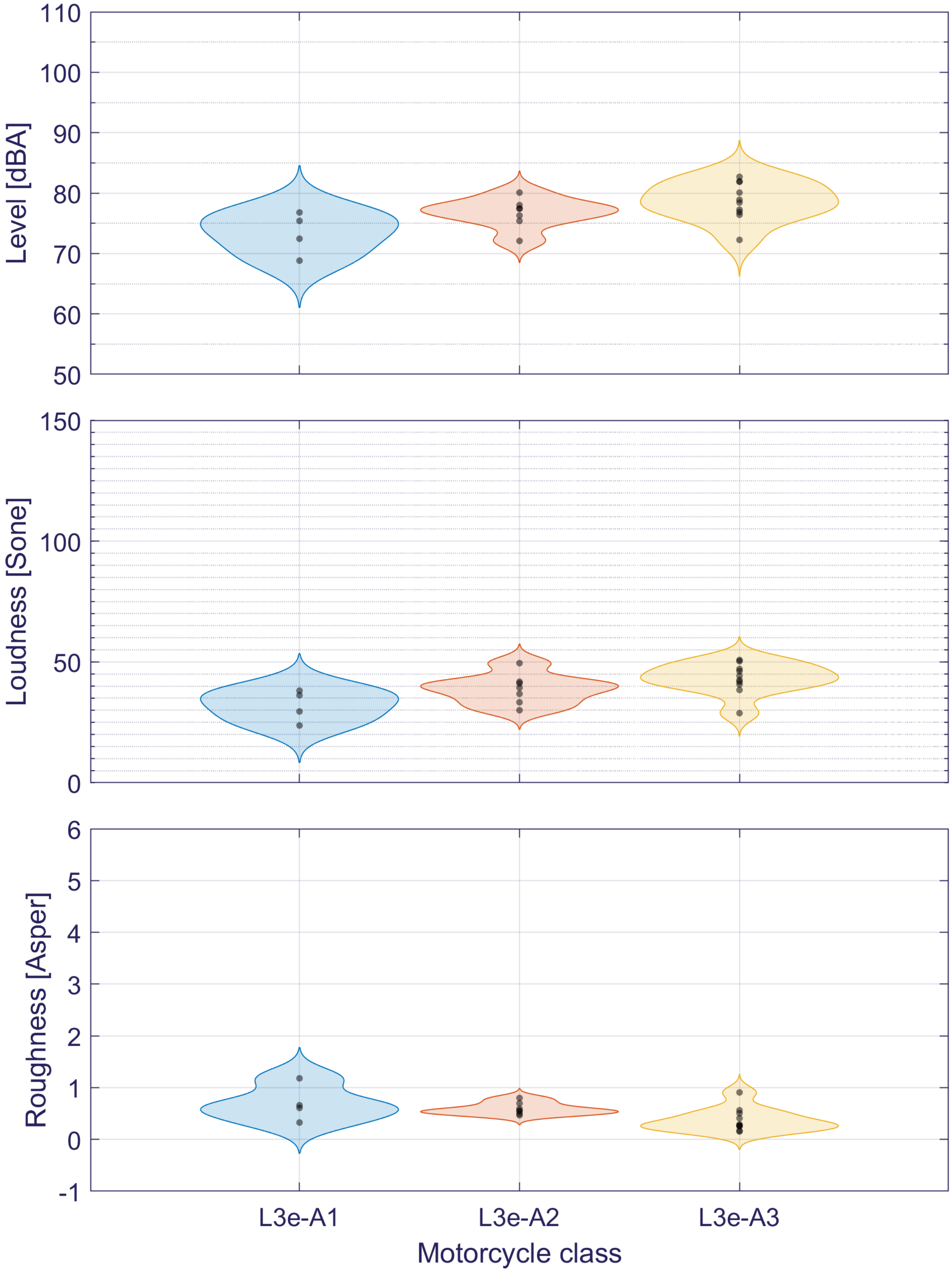


Figure 3-30: Acoustic parameters vs. subcategory for driving pattern 14 (deceleration, gear 3)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

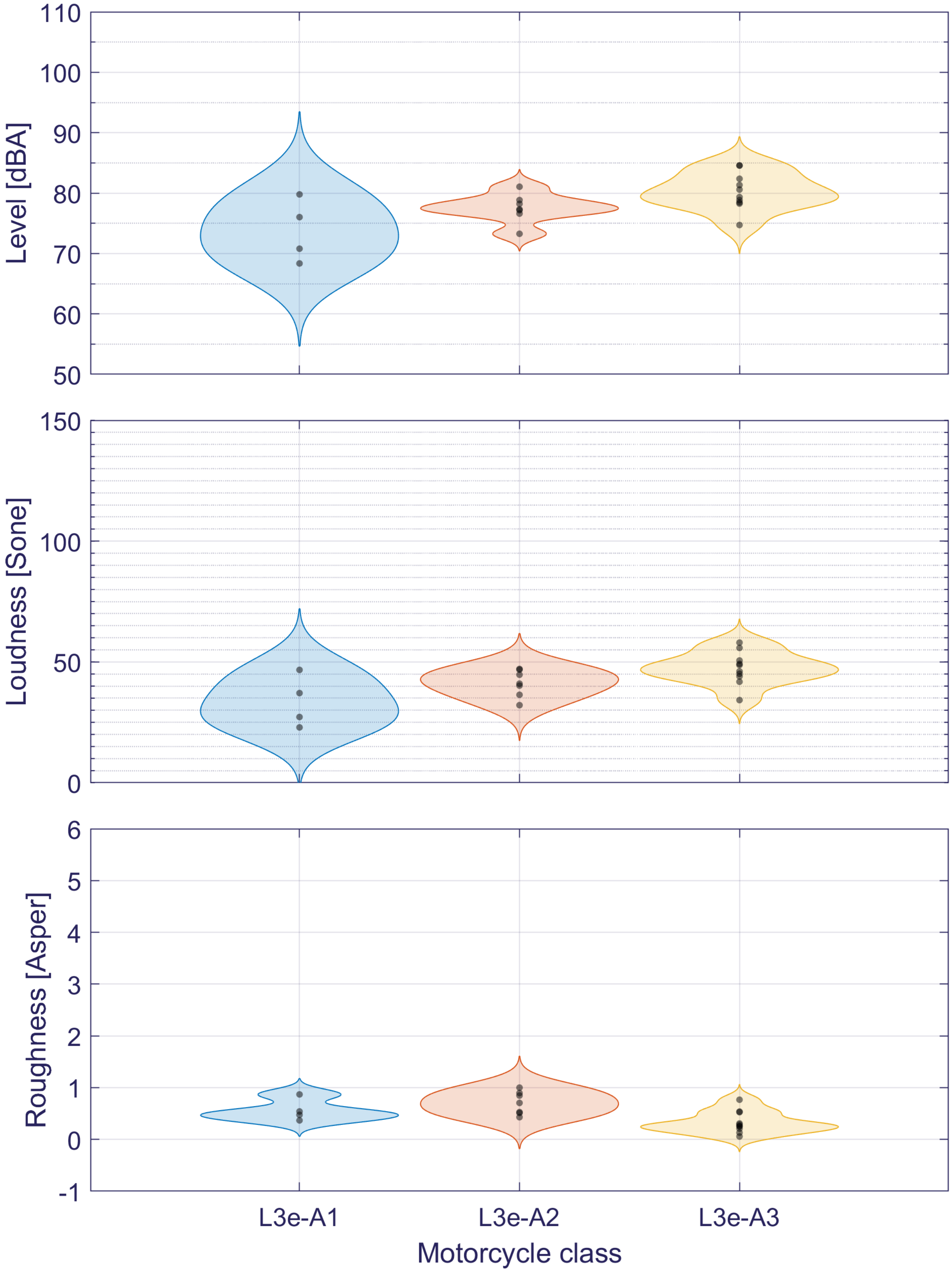


Figure 3-31: Acoustic parameters vs. subcategory for driving pattern 1 (deceleration, gear 4)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

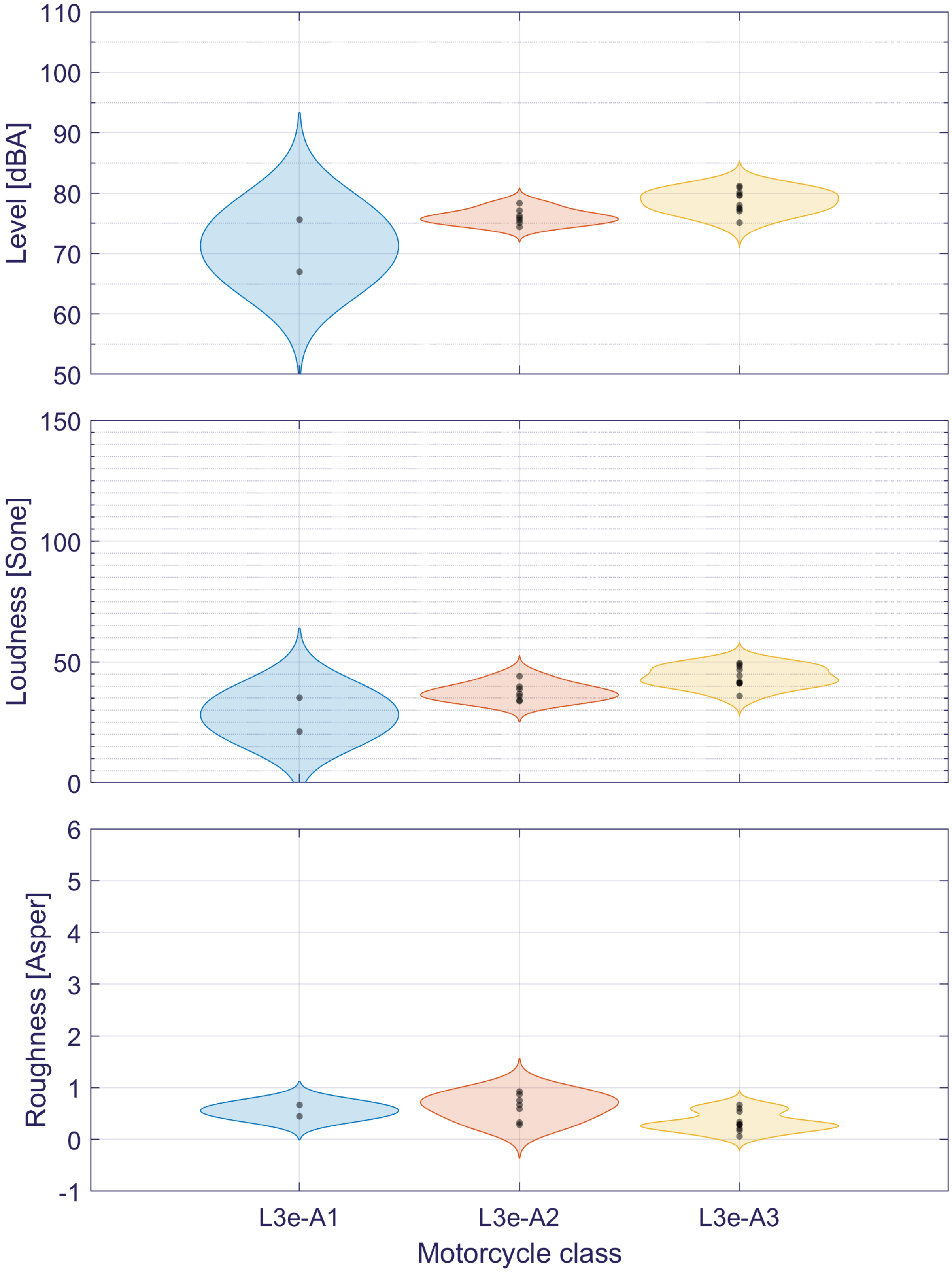


Figure 3-32: Acoustic parameters vs. subcategory for driving pattern 1 (deceleration, gear 5)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

4 Suggested Revisions

This chapter outlines proposed revisions to current noise emission assessment procedures for LVs. While a straightforward and often-discussed measure to reduce vehicle noise is the tightening of existing noise limits, this alone would not sufficiently address the complexity of real-world acoustic emissions. Particularly for motorcycles and other LVs, high noise levels often result not only from peak sound pressure levels (as defined in the TA regulations), but also from specific operating conditions that are not adequately covered under current TA procedures. This means, even a vehicle that complies with regulatory noise limits under test conditions may still produce highly disturbing noise in actual road traffic. This can even be worsened for tampered, modified or aging vehicles. In the Appendix A, a noise masking study is included in this deliverable. This shows that the main contribution to the overall level of the tested motorcycles – which are L3e and L5e – results from the powertrain. This means, that reducing the powertrain noise would be most effective with respect to reducing the overall sound emitted by motorcycles from the study.

Fundamentally, the relationship between speed and noise is significant – higher vehicle and engine speeds typically result in elevated noise levels, which is also shown in Chapter 3.2. This poses a particular challenge when trying to evaluate and regulate noise emissions based on real-world driving behaviour. A testing procedure that captures limited speed ranges or skips common high-load situations, such as strong accelerations or decelerations, is unlikely to reflect the true acoustic impact of a vehicle on the environment. The same holds for the stationary roadside enforcement test, which, while relevant for the existing fleet, only captures a single, unloaded operating condition and therefore also provides a very limited view of the vehicle's overall noise profile.

In order to address these limitations, this chapter is structured into three subchapters, each focusing on a different aspect of the regulatory framework:

- Harmonizing type approval procedures
- Boundary conditions
- Operating conditions

The first section examines existing discrepancies between the different regulations regarding noise TA of LVs as pointed out in Chap 2.4. It proposes steps towards harmonization to ensure that assessment procedures are both comprehensive and universally applicable. Differences in how test methods vary between different subcategories may lead to inconsistent outcomes, undermining efforts to reduce environmental noise at the European level. The aim is to identify overlapping elements and consolidate them into unified, more robust frameworks.

The second part “boundary condition” addresses the technical framework under which noise measurements are conducted, including both the measurement setup and the criteria used for evaluation.

Finally, the last section focuses on the actual driving conditions under which vehicles are tested. It evaluates current procedures and proposes revisions that reflect more noise-relevant situations. Special attention is given to manoeuvres involving rapid acceleration, deceleration, and fluctuating engine speeds, as those conditions are frequently encountered in real traffic but often underrepresented in approval tests. References are made to existing regulatory frameworks such as

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101056777

the Additional Sound Emission Provisions (ASEP) and their extended version, the Real Driving Additional Sound Emission Provisions (RD-ASEP), as both attempt to close the gap between the classical TA procedure and real-world noise behaviour.

4.1 Harmonizing Type Approval Procedures

Based on the comparative analysis of UN Regulations No. 41, 9, and 63, several recommendations emerge for refining and harmonizing the TA procedures across LVs. An overview can be found in Table 4-1. A first point of consideration concerns the definition of the test mass. While all regulations require the vehicle to be in normal operating condition, the specification for driver and equipment mass differs slightly: Regulation No. 41 requires 75 ± 5 kg, whereas Regulations No. 9 and 63 allow a broader range between 70 and 90 kg. Harmonizing this requirement across all three regulations would simplify vehicle preparation and increase consistency between tests.

Differences are also apparent in the types of dynamic driving tests required. Regulation No. 41 mandates both full-load wide open throttle (WOT) and constant speed (CRS) tests, whereas Regulation No. 9 requires WOT only, and Regulation No. 63 also limits the procedure to WOT. While introducing CRS testing for other vehicle classes might seem beneficial for assessing steady-state conditions, this approach has one important factor which must be considered when adding CRS testing to TA procedure. According to the calculation method for L_{urban} used for L3 vehicles (Eq. 2-5), the inclusion of a lower L_{crs} value serves to decrease the final TA value relative to the maximum acceleration noise, L_{wot}. Extending this methodology to other classes could therefore unintentionally weaken the regulation by making compliance easier in case of not reducing the TA limit accordingly. This addition of CRS tests to the existing WOT tests for TA has been done in the past for M and N category vehicles and the knowledge from this transition can be taken into account while still being adapted due to the different characteristics for the different vehicle classes.

Another aspect requiring attention is the length of the measurement zone. Regulation No. 41 includes a 20-meter extension beyond line BB' to account for post-throttle acoustic behaviour, particularly relevant for higher-powered L_3 vehicles. In contrast, Regulations No. 9 and 63 define BB' as the endpoint of the measurement. A harmonized approach by expanding the zone where technically justified, would improve procedural clarity and would cover noisy post-throttle-release behaviours for all vehicles.

Vehicle approach speed definitions ($v_{AA'}$ or $v_{PP'}$) also vary significantly. Regulation No. 41 defines speeds of 40 or $50 \frac{\text{km}}{\text{h}}$ depending on the vehicle's PMR. Regulation No. 9 defines the lowest speed based on several criteria, including thresholds relative to n_{rated} and n_{max}, and Regulation No. 63 uses a fixed speed of $30 \frac{\text{km}}{\text{h}}$ if the maximum speed exceeds this value. Establishing a common approach—such as basing $v_{AA'}$ on a fixed percentage of rated engine speed (as the engine speed is the important factor for noisy behaviour rather than the actual vehicle speed)– could streamline procedures and increase comparability.

There are also discrepancies in how gears are selected for testing. Each regulation applies to its own logic based on engine speeds, fixed thresholds, or gear availability. A harmonized gear selection methodology, perhaps based on minimum utilization of n_{rated}, would reduce ambiguity and help ensure repeatability of results.

Further inconsistencies are found in the application of additional sound emission provisions. Regulation No. 41 includes Real Driving Additional Sound Emission Provisions (RD-ASEP), Regulation

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

No. 9 includes ASEP for L_4 and L_5 vehicles with PMR > 50, while Regulation No. 63 does not mandate any such procedures. Introducing a clear framework for when ASEP or RD-ASEP should apply—and harmonizing the thresholds that trigger their application—could ensure more robust TA, especially for high-performance variants where the ASEP procedure is defined and necessary.
Finally, stationary test procedures, although generally aligned in methodology, should be explicitly standardized in all regulatory texts regarding microphone positioning, target engine speed determination, and throttle release protocols. This would help eliminate subtle but consequential variations in implementation.

Table 4-1: Overview of some differences between the different TA regulations

Aspect.	UN Regulation No. 41	UN Regulation No. 9	UN Regulation No. 63
Vehicle categories	L_3	L_2, L_4, L_5, L_6, L_7	L_1, L_6
Test mass	75 ± 5 kg	70 to 90 kg	70 to 90 kg
In-motion procedure	WOT (wide open throttle) CRS (cruise/ constant speed)	WOT (wide open throttle)	WOT (wide open throttle)
Testing area	AA' to BB'+20m	AA' to BB'	AA' to BB'
Testing speed [target value]	• $\text{PMR} \leq 50$ $v_{test} = 40\,\frac{\text{km}}{\text{h}}$ • $\text{PMR} > 50$ $v_{test} = 50\,\frac{\text{km}}{\text{h}}$	Lowest between • $(n_{AA'} < 0.75 * n_{rated})$ • $n_{AA'} < 0.75 * n_{max}$ • $v_{AA'} = 50\,\frac{km}{h}$	$v_{test} = 30\,\frac{\text{km}}{\text{h}}$
Testing speed [position on test track]	Reached at PP'	Reached at AA'	Reached at AA'
Limit value factor	PMR	Vehicle category	Vehicle speed
ASEP	RD-ASEP for vehicles with $\text{PMR} \geq 50$	ASEP for L_4 and L_5 vehicles with PMR > 50	-

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

To support all these harmonization efforts, the introduction of a consolidated guideline or harmonization annex would be beneficial. Such a document could provide a clear cross-reference matrix of shared and divergent procedures, offering transparency for both approval authorities and manufacturers operating across multiple L-categories and its subcategories.

4.2 Boundary conditions

At this stage, no major modifications to the existing measurement configuration are proposed. This is due to the broad alignment of the current setup with a range of internationally accepted regulations and standards. Specifically, the measurement protocol applied in the LV noise assessment is consistent with the provisions defined in three key regulatory frameworks relevant to LVs. Furthermore, the same or similar setups are also established within the UN ECE Regulation No. 51 [32], which is the TA for M and N category vehicles, and UN ECE Regulation No. 117 [33], the tyre approval regulation. Additionally, the configuration aligns with internationally harmonized testing standards such as ISO 11819-1 [34] for statistical pass-by measurements and ISO 13325 [35] for coast-by test procedures.

The harmonization of the measurement setup across vehicle and tyre categories ensures comparability, consistency, and regulatory coherence. From both a practical and legal perspective, maintaining this alignment is recommended. It reduces redundancy, avoids conflicts between standards, and supports integrative noise policy approaches that span different vehicle types. While the main TA measurement configuration should be maintained, the use of additional microphones could be considered for specific purposes. One option for advanced research and noise source investigation, separate from regulatory emission assessment, is the introduction of near-field microphones placed directly on or near the test object. This could allow for better spatial resolution and deeper insight into noise sources at their origin. However, such measurements face significant challenges regarding reproducibility due to the complex sound field and vehicle variations and are therefore not recommended for standardized regulatory application. A more practical suggestion for improving the emission assessment itself would be to place additional microphones at the standard 7.5m distance but at different longitudinal positions, for instance at lines AA' and BB'. This could help to more accurately identify the highest pass-by sound level, particularly in cases where the maximum noise does not occur precisely when the vehicle is at the microphone line PP'.

Regarding the evaluation criteria used in the noise assessment of LVs, it is recommended to continue applying the A-weighted sound pressure level with Fast time weighting, as currently defined in the applicable regulations and standards. This approach is consistent with the established methodologies in UN Regulation No. 41 [25], UN Regulation No. 9 [2] and UN Regulation No. 63 [4] for LVs, UN Regulation No. 51 for M and N category vehicles [32], and introduced ISO standards such as ISO 11819-1 [34]. As also outlined in Chapter 3.2.1 of this report, the dB(A) metric remains the primary parameter for regulatory conformity. It provides a broadly accepted basis for evaluating environmental and type approval noise levels across vehicle categories.

However, when assessing the noise emissions of LVs the question arises whether traditional A-weighted levels sufficiently reflect the human perception of these sounds [36]. The acoustic character of motorcycles is often described as more intrusive or annoying compared to other vehicles, even

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

when measured sound levels are comparable [37]. This discrepancy highlights the potential role of psychoacoustic parameters – such as loudness or roughness – in complementing traditional level-based assessments.

From a literature-based perspective, there are arguments in favour of integrating psychoacoustic metrics. Studies have shown that psychoacoustic parameters can better explain subjective annoyance and perceived loudness in vehicle pass-by scenarios than the A-weighted sound pressure level alone, particularly for impulsive, modulated, or tonal sources such as those emitted by high-revving or modified motorcycles [36; 37]. Psychoacoustic evaluation may offer more targeted insight into noise mitigation strategies and contribute to the design of quieter, more acceptable sound signatures.

On the other hand, there are also valid concerns and limitations that speak against the regulatory integration of such parameters at this stage. Psychoacoustic metrics are inherently more sensitive to test setup, ambient conditions, and signal processing details as many have a high frequency- and duration dependency [38]. Their reproducibility and standardization across measurement institutions remain challenging as no main psychoacoustic parameters have been standardized yet. Moreover, there is currently no harmonized regulatory framework that defines threshold values, interpretation rules, or pass/fail criteria for psychoacoustic parameters, which would be necessary for legal enforcement and type approval purposes.

In conclusion, while psychoacoustic metrics hold clear potential for improving the perceptual relevance of noise evaluations – especially for character-rich sources such as motorcycles – they are currently better suited for research, monitoring, and design purposes rather than for immediate integration into type approval testing. It is therefore suggested to continue using the established metric for A-weighted sound pressure levels for official evaluations, while encouraging further investigation and standardization of psychoacoustic criteria for possible future inclusion, for instance, to more effectively detect tampered vehicles during roadside enforcement tests.

4.3 Operating conditions

In the following, different operating conditions are discussed as type approval suggestions. This is divided into the in-motion conditions which are in detail explained in Chapter 3.2 and into the stationary measurements which are defined in the Annex 3 for all TA regulations to support roadside enforcement.

4.3.1 Vehicle in motion conditions

The specific real-world operating conditions of LVs in motion are crucial for actual noise emissions and are often inadequately captured by standard TA procedures (WOT, CRS). Additional provisions such as ASEP and RD-ASEP are important advancements, particularly for testing acceleration events. However, the extensive measurement results from the current project (Chapter 3.2.3) indicate a need for further adjustments to ensure a realistic assessment. The analysis of driving patterns in Chapter 3.2.3 (Table 3-2) identifies several groups of operating conditions as particularly noise-relevant, consistently leading to high noise emissions, loudness, and partly also roughness values. Various forms of acceleration are noise-intensive, especially for high-performance vehicles. These include aggressive accelerations from standstill (Pattern 3) and from low speed (Pattern 6), Full throttle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

acceleration from constant speed in various gears (Pattern 8), and accelerations after gear shifts (Patterns 9 and 11). Current ASEP procedures should be reviewed to determine if these specific scenarios are adequately covered. Constant speed driving at high engine speed (Pattern 10) in low gears (especially 1st and 2nd) proved extremely noise- and loudness-intensive. The limitation of such conditions by current regulations is questionable. Intermittent throttle control (Pattern 13) generates highly fluctuating and potentially disturbing noise patterns, exhibiting significant variability and relevance to real-world noise impact. While capturing such dynamic, pulsating noises poses a challenge for standardized tests, their importance for the actual noise impact experienced is undisputed. The comparison between aggressive acceleration from standstill (Pattern 3) and moderate acceleration from standstill (Pattern 4) impressively demonstrates the massive influence of driver behaviour on noise emissions. Sound pressure level, loudness, and roughness are visibly lower with a moderate driving style. This underscores the necessity for test procedures to be designed in such a way that they assess a vehicle's potential for noise generation under defined "worst-case" yet plausible conditions. Deceleration phases (Pattern 14) proved to be acoustically less critical.
The detailed analysis of the driving patterns from Chapter 3.2.2 provides concrete approaches for improving the representativeness of noise tests for LVs. The RD-ASEP upper limit for engine speed, which can be exceeded in urban traffic, should be evaluated. An adjustment might be necessary to ensure that relevant high-engine-speed scenarios at low to medium speeds are covered. The different noise characteristics during accelerations from standstill, from low speed, in various gears, and after gear shifts suggest potentially expanding the ASEP test matrix with more specific acceleration tests or adjusting the weighting of existing tests. The extremely loud driving Pattern 10 (constant speed at high engine speed in a low gear) may not be adequately captured by current acceleration tests. It should be examined whether the ASEP control windows can be extended so that such operating conditions are implicitly included in the assessment or explicitly included as a separate test point, provided they are relevant in real-world driving and do not merely represent theoretical extremes. For operating conditions identified as particularly noise-critical, which are not adequately covered by current standard TA tests (WOT, CRS according to Annex 3 of the respective UN Regulations) and may also not be sufficiently addressed by existing ASEP/RD-ASEP formulations, the introduction of new, standardized reference manoeuvres could be considered. These include a standardized test for aggressive acceleration from standstill (analogous to Pattern 3), with clear specifications for throttle operation or target engine speed gradients to standardize driver influence, and a test for acceleration events including defined gear shift points (analogous to Patterns 9 or 11) to assess dynamic noise during and after gear shifts. The feasibility of such tests, particularly regarding requirements for test track length and reproducibility, must be carefully examined. As driver behaviour has a considerable influence, standardized test manoeuvres must evaluate the potential for noise development. This can be achieved through precise specifications for the throttle position (e.g. full throttle), target speeds, target accelerations or the use of specific transmission programs (for CVTs) in the extended test phases.

4.3.2 Stationary sound measurements

The stationary sound measurement procedure, as outlined in Annex 3 of UN Regulation No. 41, Regulation No. 9, and UN Regulation No. 63, is primarily intended to support roadside enforcement. However, a key issue is that the current roadside test, often limited to a simple sound level check,

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

does not properly detect non-compliant vehicles, and in particular, tampered vehicles. To create a more robust enforcement framework, a multi-faceted inspection approach could be implemented, adding several elements to the procedure:

- Visual inspection of exhaust components for obvious non-compliance, potentially aided by photo comparison with the original vehicle picture from the TA.
- Verification of muffler certification marks and physical dimensions.
- Simple internal muffler inspection (e.g., a "broomstick check") to detect removed baffles.
- Simple sound analysis, for instance via a smartphone app, that can identify acoustic features characteristic of a tampered vehicle.

Such enforcement could also be semi-automated, for example by being integrated into noise camera systems, which could trigger a recall to an official inspection centre. The stationary test itself could also be enhanced by adding operating conditions such as engine start and engine revving, besides the standard throttle release test. Currently, these regulations define only the measurement procedure, while no binding limit values are provided. In recent years, several regions within the EU have introduced their own individual limit values for these stationary sound measurements. Compliance with these local limits is required to access certain roads or areas. As a consequence, new vehicles that meet EU-wide type approval criteria may still be restricted from use in specific regions, creating a fragmented legal landscape within the Union.

To address this, it is proposed that stationary sound measurements—while useful for enforcement—should be accompanied by harmonized, EU-wide legal limit values. These would initially apply only to newly approved vehicles, thereby easing the transition for manufacturers and regulators alike. Over time, such harmonized limits would provide a stable reference for regional enforcement policies.

A transitional approach could be implemented where the stationary noise limit is dynamically defined based on engine speed, similar to the Additional Sound Emission Provisions (ASEP) methodology. Since the measurement itself is tied to engine operating characteristics, such a dependency is both logical and fair. This method also offers flexibility, allowing higher permissible levels for high-performance engines, reducing the burden on OEMs.

The current regional practice of applying a single, fixed limit regardless of engine characteristics is problematic. The procedure outlined in Annex 3, paragraph 3, of the regulations is clearly engine-speed-dependent. Thus, applying a flat limit *contradicts* the very nature of the test. If such regionally defined limitations are to be continued, they must be based on a consistent and harmonized measurement procedure. Therefore, such regional enforcement must be based on the harmonized measurement procedure defined in Annex 3 of the TA regulations. This specifically requires using the target engine speed that was determined for the TA (i.e., 50% or 75% of n_{rated}), which is the engine speed marked on the vehicle's authorization letter. The existing provisions for tolerance ranges (e.g., reducing the target speed by 10% if it cannot be reached) should be applied consistently.

In the LENS project, the main focus was on vehicle-in-motion measurements. However, stationary sound measurements were also conducted using the same general test setup. Three engine speeds were tested—idle, 3000 rpm, and 5000 rpm. The results, presented in Appendix B, show values for A-weighted sound pressure level, loudness, and roughness. In all three cases (Figure B-52 for idle conditions, Figure B-53 for an engine speed of 3000 rpm and Figure B-54 for an engine speed of 5000 rpm), an increase in sound pressure level with increasing engine speed is evident. This reinforces

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

the argument against applying a uniform limit across all engine configurations for one specific engine speed. Furthermore, across all evaluated psychoacoustic and acoustic parameters, the data spread (as seen in violin plots) increases with engine speed, indicating greater variability. The trend of higher engine capabilities correlating with higher noise emissions (over the different Figures) is consistently observed.

Therefore, it is recommended that if stationary measurements are to be used as a basis for access restrictions in certain regions (such as prohibiting motorcycles from entering specific roads in some EU regionals due to exceeding a predefined stationary sound threshold), then the measurement procedure must be uniform for all vehicles. A fixed engine speed should be defined at which the measurement is to be conducted – potentially with stepped adjustments if the nominal engine speed cannot be achieved (e.g., the mentioned 10% tolerances as used in Annex 3 of UN Regulation No. 41). A unified EU-wide noise limit should then also be established and may even be able to overrule the regional limits currently in place. However, care must be taken to avoid creating a "weak compromise"; a single, fixed limit for all vehicles would likely be ineffective. Therefore, to be both fair and effective, such a limit should be defined dynamically but underly consistent procedures. As previously suggested, making the limit dependent on the vehicle's rated engine speed, similar to the ASEP methodology, would be a viable approach to accommodate the diverse range of LVs.

Finally, it must be noted that roadside enforcement conditions are inherently less controlled than official testing environments. Therefore, higher variability is to be expected in these measurements. Appropriate tolerance margins should be incorporated into roadside enforcement practices to reflect these environmental and procedural uncertainties.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

5 Summary

This deliverable presents a comprehensive study of the current type approval (TA) procedures for LVs, focusing on the core regulations UN Regulation No. 41, No. 9, and No. 63. These were examined in detail and compared with each other to identify overlaps, inconsistencies, and regulatory gaps. Additionally, UN Regulation No. 92, which governs replacement exhaust silencers, was considered, as it is particularly relevant for the in-use vehicle fleet. While the dynamic in-motion tests of the main TA regulations apply only to new vehicles, the stationary test procedure outlined within them is also intended for roadside enforcement of the existing fleet. This report highlights that the current stationary test is often ineffective in practice and proposes substantial improvements. These include enhancing the roadside procedure with multi-faceted inspections (e.g., visual and simple acoustic checks) and establishing harmonized, EU-wide, engine-speed-dependent limits to create a more effective and consistent enforcement framework.

The document also provides an overview of the extensive measurement campaigns conducted within the LENS project under Work Packages 3 and 4. These include type approval testing, measurements of RW driving profiles in the actual traffic, and tests of newly defined RW driving patterns. In total, more than 100 individual measurement campaigns were carried out. While the main approaches are briefly described here, further methodological details and analysis results can be found in other deliverables from the project, especially Deliverables D3.5 [8] and D4.3 [39].

The chapter on suggested revisions is structured around three fundamental components of the TA process: harmonization of procedures, boundary conditions, and operating conditions. While a general lowering of existing noise limits may appear to be the most direct strategy, it has two central limitations. First, such a change would only affect newly approved vehicles. Second, it would not sufficiently address those particularly noise-intensive driving scenarios that are confirmed by the project's acoustic data to be a key source of annoyance in real-world settings. The current TA regulations (No. 41, 9, and 63) still contain significant discrepancies, which partly reflect the varying characteristics of L-subcategories. Nevertheless, further harmonization of these procedures could increase consistency, improve comparability across markets, and reduce regulatory complexity. The proposed revisions are, e.g.:

- Test Mass Standardization: The mass of driver and equipment varies slightly between regulations (75 ± 5 kg in R41, 70–90 kg in R9 and R63). Harmonizing this to a fixed standard would simplify vehicle preparation and increase test consistency.
- Driving Test Harmonization: Not all vehicle classes require constant speed (CRS) testing. While R41 mandates both WOT and CRS, R9 and R63 limit the test to WOT. Introducing CRS into the other regulations could improve acoustic representation under steady-state conditions.
- Measurement Zone Extension: R41 includes a 20-meter extension beyond BB' to capture post-throttle noise emissions. Extending this logic to R9 and R63 would allow more complete measurement of noisy driving behaviours.
- Approach Speed and Gear Logic: Currently, the definition of entry speed and gear selection differs by regulation. A harmonized approach based on engine speed (e.g. a fixed percentage of rated engine speed) would provide more representative and reproducible testing.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Substantial differences exist not only in procedural execution but also in how regulations apply ASEP and RD-ASEP to different subcategories. For instance:

- R41 applies RD-ASEP to high-performance motorcycles (PMR > 50), while R9 includes ASEP only for certain L4 and L5 vehicles.
- R63 omits ASEP entirely, despite some L_1 vehicles generating high transient noise
- A unified ASEP/RD-ASEP applicability matrix based on PMR and drive type should be developed

The measurement setup used across different TA regulations and ISO standards (e.g., UN Regulation No. 51, UN Regulation No. 117, ISO 11819-1, ISO 13325) is already largely aligned and therefore should remain unchanged. However, the evaluation criteria as well as flexible but reproducible testing within the real traffic could be reconsidered. For the latter, the following suggestions are made:

- Regulators should permit optional supplementary measurements under semi-controlled urban conditions (e.g., low-speed zones or stop-and-go traffic areas).
- These urban extension tests must remain reproducible and well-defined, possibly through portable measurement systems (e.g., on-board microphones with GPS).
- In parallel, Europe-wide stationary test limits should be introduced, tied to engine speed thresholds, to support roadside enforcement.

With regard to the evaluation criteria, while A-weighted, fast-time-weighted sound pressure levels remain the basis for legal comparability, the consideration of psychoacoustic parameters—especially given the complex and dynamic sound characteristics of motorcycles—may provide added value in future noise assessment frameworks. Acoustic data show that these manoeuvres are high contributors to perceived noise annoyance, especially in urban contexts. Yet, they are not explicitly addressed by current TA or ASEP frameworks. To improve regulatory robustness:

- Specific reference manoeuvres should be defined to reflect these patterns
- These manoeuvres should become part of a standardized test catalogue with defined thresholds and boundary conditions.
- Where feasible, the acoustic metrics should go beyond dB(A) to include psychoacoustic parameters such as loudness (sone) and roughness (asper). This would surely go along with defining limit values for psychoacoustic parameters.

Concerning operating conditions, extensive project measurements revealed that current TA procedures do not sufficiently cover several real-world driving conditions particularly relevant for noise emissions. For vehicles in motion, proposals aim to enhance the real-world representativeness of ASEP (Additional Sound Emission Provisions) and RD-ASEP (Real Driving Additional Sound Emission Provisions). The current RD-ASEP requires that engine speed at the exit of the test zone (BB') remain below 80% of the rated engine speed. However, real-world scenarios often exceed this threshold during high-throttle urban driving or when shifting late in lower gears.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

- Data from the LENS project demonstrate that vehicles can exceed 80% engine speed during ordinary acceleration, questioning the relevance of the current control range.
- Tightening or re-defining the RD-ASEP control range is necessary to capture more noise-relevant real-world operating points, such as full-throttle acceleration in lower gears or abrupt throttle inputs.

One of the core limitations of the current regulatory setup is its underrepresentation of noise-intensive real-world driving conditions in test protocols. These include:

- Aggressive acceleration from standstill
- Driving at high engine speed in low gears
- Throttle bursts at intersections or in dense traffic

In conclusion, the findings of this deliverable highlight both the strengths and limitations of the current regulatory framework for LV noise emissions. While the existing procedures provide a solid foundation for type approval, they require targeted updates to reflect real-world driving conditions more accurately, ensure consistency across regulations, and better account for emerging vehicle technologies. The proposed adjustments—ranging from harmonization of technical parameters to the integration of psychoacoustic evaluation and representative driving scenarios—offer a practical path forward. By implementing these measures, regulatory bodies can enhance the environmental effectiveness, fairness, and technical robustness of noise regulation in the L-category segment, ultimately contributing to improved urban soundscapes and public acceptance of powered two- and three-wheelers.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

References

[1] Berge, T.; Mioduszewsk, R.; Ejsmont, Jerzy A.; Swieczko-Zurek, B.: *Reduction of road traffic noise by source measures - present and future strategies*, Noise Control Engineering Journal, pages 549-559, 2017.

[2] UN/ECE - UN Regulation 9: *Uniform provisions concerning the approval of category L2, L4 and L5 vehicles with regard to noise* - Rev2, 07 series of amendments, 2013, https://unece.org.

[3] UN/ECE - UN Regulation 41: *Uniform provisions concerning the approval of motor cycles with regard to noise* - Rev2, 05 series of amendments, 2021.

[4] UN/ECE - UN Regulation 63: *Uniform provisions concerning the approval of L1 category vehicles with regard to sound emission* - Rev2, 2013, https://unece.org.

[5] Barasalia, B.; Triantafyllopoulos, G.; Tzinovas, T.; Dittrich, M.; Ntziachristos, L.: *L-vehicle tampering and undesirable effects* - Deliverable 5.1, Public Report, EU Horizon Europe project "LENS". EMISIA, 2023.

[6] Denayer, H.; Gu, H.; Gryllias, L.; Kupper, M.: *Techniques for tampered/ high-emitting LV detection* - Deliverable 5.2, Public Report, EU Horizon Europe project "LENS". KU Leuven, 2024.

[7] European Climate, Infrastructure and Environment Executive Agency: *Grant Agreement - LENS* - Project 101056777, 2022.

[8] Gabri, A.; Schliephake, C.; Shariatinia, S.; Winter, M.; Riemersma, I.; van Mensch, P.; Aschersleben, J.; Steven, H.: *RW driving patterns to assess LV noise and emissions* - Deliverable 3.5, Public Report, EU Horizon Europe project "LENS". IDIADA, 2025.

[9] European Union - No 168/2013: *Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles*, 2013, https://eur-lex.europa.eu.

[10] European Union - No 134/2014: *Commission Delegated Regulation (EU) No 134/2014 of 16 December 2013 supplementing Regulation (EU) No 168/2013 of the European Parliament and of the Council with regard to environmental and propulsion unit performance requirements and amending Annex V thereof Text with EEA relevance*, 2013, https://eur-lex.europa.eu.

[11] UN/ECE - UN Regulation 92: *Uniform provisions concerning the approval of non-original replacement exhaust silencing systems (NORESS) for vehicles of categories L1, L2, L3, L4 and L5 with regard to sound emission [2023/1714]* - 02 series of amendments, 2023, https://eur-lex.europa.eu.

[12] International Organization for Standardization: ISO 10844: *Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tyres*, 2014, https://dx.doi.org.

[13] International Organization for Standardization: ISO 13472-2: *Acoustics - Measurement of sound absorption properties of road surfaces in situ - Part 2: Spot method for reflective surfaces*, 2010, https://dx.doi.org.

[14] International Organization for Standardization: ISO 5130: *Acoustics - Measurements of sound pressure level emitted by stationary road vehicles*, 2019.

[15] Kraftfahr-Bundesamt: *Bestand an Krafträdern am 1. Januar 2025 nach Fahrzeugklasse und Aufbauart sowie Bundesländern*, 2025.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

[16] Dittrich, M.; van Mensch, P.; Riemersma, I.; Paschinger, P.; Steven, H.; Karamanlis, N.; Degeilhe, P.: *Real world driving conditions and requirements for the LENS test programme* - Deliverable 6.1, Public Report, EU Horizon Europe project "LENS". TNO, 2023.

[17] IMMA: *R41 ASEP Revision* - Informal document GRBP-71-19-Rev.1. 71st GRBP, 2020.

[18] ECE/TRANS/WP.29/2019/7 (GRBP): *Proposal for the 02 series of amendments to UN Regulation No. 92 (Replacement exhaust silencing systems for motorcycles)*, 2019.

[19] ECE/TRANS/WP.29/2025: *Proposal for the 03 series of amendments UN Regulation No. 92 (Replacement Exhaust Silencing Systems for Motorcycles)*, 2025.

[20] Diemel, C.; Uszynski, O.: *Method and system for on-board noise measurement* - Deliverable 3.2, Demonstrator, EU Horizon Europe project "LENS". Institute for Automotive Engineering (ika), RWTH Aachen University, 2023.

[21] Diemel, C.; Uszynski, O.; Yordanov, V.; Städtler, L.: *Sensor System for Noise and Positioning Data Acquisition*, ATZ Worldwide 11, pages 30‑35, 2023.

[22] Diemel, C.; Uszynski, O.; Weber, A.: *Entwicklung einer Methodik zur Ermittlung akustisch relevanter Fahrsituationen von Fahrzeugen der Klasse L*, DAGA, Hannover, 2024.

[23] Diemel, C.; Uszynski, O.; Yordanov, V.; Werner, D.; Urban, P.: *Investigation of Noise-Intensive Driving Patterns under Real Driving Conditions*, Aachen Acoustics Colloquium, Aachen, 2024.

[24] Peeters, B.: *Assessment Programme for Parameters of the "general" European vehicle fleet* - Deliverable 3, Public Report, EU Horizon Europe project "IMAGINE". M+P, 2006.

[25] UN/ECE - UN Regulation 41: *Uniform provisions concerning the approval of motor cycles with regard to noise* - Rev2, 04 series of amendments, 2012, https://unece.org.

[26] Dittrich, M.; Wessels, P.; Staats, F.: *Monitoring luide voertuigen in Amsterdam (Monitoring of loud vehicles in Amsterdam, in Dutch)* - TNO report ref. TNO 2022 R10053. TNO, 2022, https://openresearch.amsterdam.

[27] Dittrich, M.; Wessels, P.; Staats, F.: *Monitoring luide voertuigen in Den Haag (Monitoring of loud vehicles in The Hague, in Dutch)* - TNO report ref. TNO 2023 R10459. TNO, 2023.

[28] Dittrich, M.; Wessels, P.; Staats, F.: *Monitoring luide voertuigen in Rotterdam (Monitoring of loud vehicles in Rotterdam, in Dutch)* - TNO report ref. TNO 2023 R10157. TNO, 2023.

[29] Lu, M,: Jen, M.: *Target setting and source contribution for sound quality of a motorcycle*, Inter-Noise, Melbourne, 2014.

[30] Fiebig, A.; Jakobs, C.: *Psychoacoustic properties of tire-road noise and the relation to noise annoyance*, Inter-Noise, Glasgow, 2022.

[31] Letens, U.; Oetjen, A.; Goecke, D.; Maiberger, D.: *Practical experience with psychoacoustics in automotive engineering*, International Congress on Acoustics, Aachen, 2019.

[32] UN/ECE - UN Regulation No. 51: *Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their noise emissions [2018/798]* - Supplement 2 to the 03 series of amendments, 2018, http://data.europa.eu.

[33] UN/ECE - Regulation No. 117: *Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and/or to adhesion on wet surfaces and/or to rolling resistance [2016/1350]* - Supplement 8 to the 02 series of amendments, 2016, http://data.europa.eu.

[34] International Organization for Standardization: ISO 11819-1 - Part 1: Statistical pass-by method: *Acoustics - Measurement of the influence of road surfaces on traffic noise*, 2023.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

[35] International Organization for Standardization: ISO 13325: *Tyres - Coast-by methods for measurement of tyre-to-road sound emission*, 2019, https://dx.doi.org.

[36] Fiebig, A.; Guidati, S.; Goehrke, A.: *Psychoacoustic Evaluation of Traffic Noise*, NAG/ DAGA, Rotterdam, Netherlands, 2009.

[37] Herbst, L.; Lienhard, M.; Lercher, P.; Cik, M.; Fellendorf, M.: *Psychoacoustic analysis of motorcycle noise*, Forum Acusticum, Lyon, France, 2020.

[38] Genuit, K. (Ed.): *Sound-Engineering im Automobilbereich* - Methoden zur Messung und Auswertung von Geräuschen und Schwingungen. 978-3-642-01414-7. Springer. Heidelberg, 2010.

[39] Schliephake, C.; Shariatinia, S.: *Noise measurement data from standardised tests* - Deliverable 4.3, Public Data, EU Horizon Europe project "LENS". Institute for Automotive Engineering (ika), RWTH Aachen University, 2025.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

A Appendix A: Noise masking analysis

The objective of the noise masking activity is to assess the influence of the different systems/sub-systems of the LVs during exterior noise testing. In order to study the potential noise reduction of the different systems/sub-systems, a Noise Source Ranking (NSR) testing information has been gathered on the most representative vehicles measured in LENS.

A.I Vehicle's selection justification

The vehicle selection has been defined according to the following criteria and Table A-1 summarizes the vehicles selected for this study (6 vehicles in total) and its specifications:

- Test the vehicles perceived as more relevant in terms of noise impact on the European public roads.
- Include a wide range of powertrain configurations.
- Represent the current fleet of vehicles in Europe (L3e and L5e sub-categories).

Table A-1: Task 4.2 vehicle selection for Noise Masking

UN-Regulation	PMR	Category / Sub-category	Engine type	Gear / Transmission	Target specifications	Name in this report *
R.41.04	PMR > 50	L3e-A3	PI	Locked / Manual	Sport Naked	***Sport Naked***
		L3e-A3	PI	Locked / Manual	Sport TRAIL	***Sport TRAIL***
		L3e-A3	PI	Non-locked / Automatic	Sport TRAIL (Automatic)	***Sport TRAIL_Auto***
		L3e-A3	PI	Locked / Manual	Sport TRAIL (Manual)	***Sport TRAIL_Manual***
R.09.08	PMR ≤ 50	L5e-B	PI	Locked / Manual	Bodied Tricycle	***Bodied Tricycle***
	PMR > 50	L5e-A	PI	Non-locked / CVT	Unbodied Tricycle	***Unbodied Tricycle***

- Sport naked: Are versatile, general-purpose street motorcycles. They are recognized primarily by their upright riding position, partway between the reclining rider posture of the cruisers and the forward leaning sport bikes. Footpegs are below the rider and handlebars are high enough to not force the rider to reach too far forward, placing the shoulders above the hips in a natural position. Because of their flexibility, lower costs, and moderate engine output, standards are particularly suited to motorcycle beginners.
- Sport Trail: Dual-purpose or on/off-road motorcycles or adventure motorcycles, are street legal machines that are also designed to enter off-road situations. Typically based on a dirt bike chassis, they have added lights, mirrors, signals, and instruments that allow them to be licensed for public roads. They are higher than other street bikes, with a high centre of gravity and tall seat height, allowing good suspension travel for rough ground.
- Unbodied: Unbodied tricycle. A tilting three-wheeled scooter. It is noted for its combination of two front wheels and a single rear wheel. General-purpose city motorcycle.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

- **Bodied**: Bodied tricycle. In Asian and Southeast Asian countries, motorized trikes are used as small freight trucks and commercial vehicles. Nicknamed "three-wheelers" or "tuk-tuks" in popular parlance, they are a motorized version of the traditional pulled rickshaw or cycle rickshaw. While they are mostly used as taxis for hire, they are also used for commercial and freight deliveries. They are particularly popular in cities where traffic congestion is a problem.

A.II Testing procedures

NSR study is based on testing each vehicle according to the testing procedures defined above and relative to each vehicle category:

- L3e UN Regulation 41.04 – CRS and WOT (1 or 2 gears) as explained in Chapter 2.1
- L5e: UN Regulation 9.08 – WOT test as explained in Chapter 2.2

Stationary sound tests and ASEP tests have not been considered for this study. Noise tests reported herein have been carried out on test tracks certified according to ISO 10844:2014, as stated in the related regulation. NSR test is based on the exterior noise sound level of each vehicle is the sum of the contribution of different noise sources generated during the test. Masking each one of the noise sources, the influence of each source can be determined. For this study, the following noise sources have been considered. Each system/sub-system has been masked using different techniques, according its main characteristics. Used techniques are described below.

- Exhaust
- Engine
- Transmission (gearbox)
- Driveline (chain and final drive)
- Intake

Exhaust

Exhaust was masked using a “jumbo” or “infinite” muffler. For this study, a passenger vehicle muffler was used, covered by rock wool material to minimize exhaust shell noise.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-1: "Infinite" muffler used for exhaust noise masking

Engine/ Transmission / Driveline

These parts were masked using specific covers designed for each vehicle. These covers were built of different layers:

- Rock wool to absorb system noise
- Lead (2 mm plate) to reduce sound transmission
- Fireproof polyurethane foam to maintain all layers together on its correct position around each studied system

For some vehicles and due to the closeness of the different sources, some systems have been considered as a unique noise source.

Figure A-2: Example of engine cover

Intake

Intake noise was masked using an "infinite" intake muffler. A specific muffler was designed and 3-D printed for the LVs study.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-3: "Infinite" muffler used for intake noise masking

For each tested vehicle, every configuration is measured according to the following test protocol:

- Baseline test
- Full mask test (all systems covered or muffled)
- Intake unmuffled
- Driveline uncovered
- Transmission uncovered
- Engine uncovered
- Exhaust unmuffled – Baseline repetition

Each configuration is measured separately on all test conditions, i.e. the test is carried out in accordance with UN R41 or R9, depending on the L-cat vehicle, and for each component test at NSR. A minimum of two runs is measured and analysed per each test condition (mean value is reported). The comparison between the noise level of each configuration shows the influence of the corresponding systems.
Noise source contribution results are measured and calculated over test distance (-15 m from PP' line, centre of the test track, to +15 m from PP' line. AA' line is placed at -10 m from PP' and BB' line is placed at +10 m from PP' from Figure 2-1). Actual test acquires noise level every 0.10 m against the vehicle position. Using dB subtractions of every tested configuration, individual contribution of each noise system can be calculated (for each test condition). As explained, this calculation is made over distance, but focus needs to be placed on the maximum noise level position. At the end, this value is the one used for the L_{urban} level global calculation. It needs to be noticed that according UN Regulation 41.04 procedure (L_3-category only), L_{urban} calculation is a combination of the maximum sound level measured during acceleration test and constant speed test as described in Eq. 2-5.

A.III Results

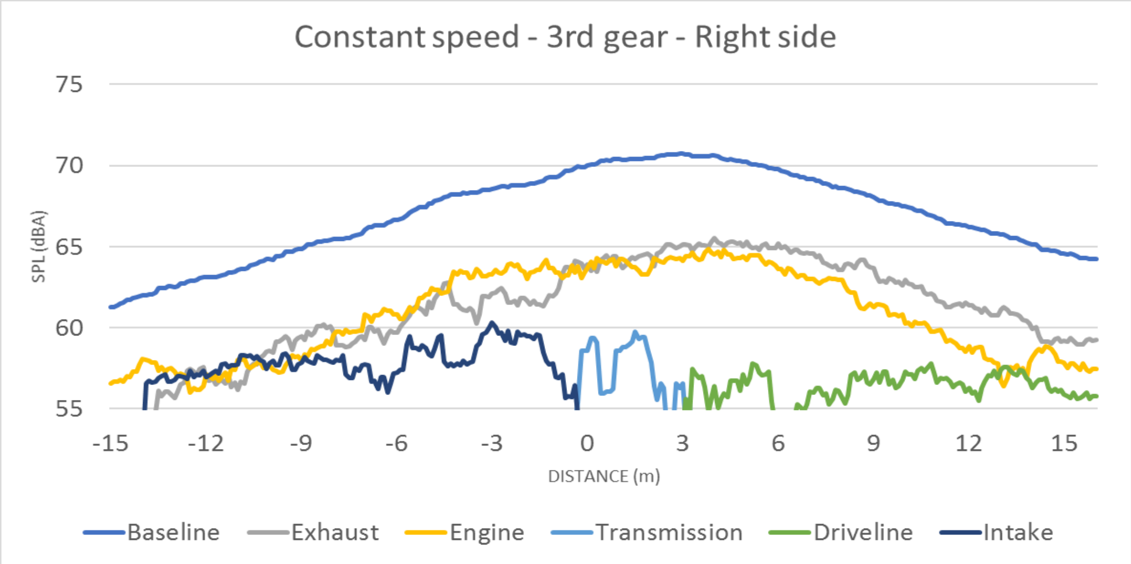
L3e-A3 vehicle type: Sport TRAIL AUTO

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

In the figures below, the term 'Baseline' denotes the initial configuration of the vehicle and the term 'Full masked' means that all parts checked for SNR are shielded. Figure A-4, Figure A-5 and Figure A-6 show the results from the constant speed tests in third gear.

Figure A-4: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777



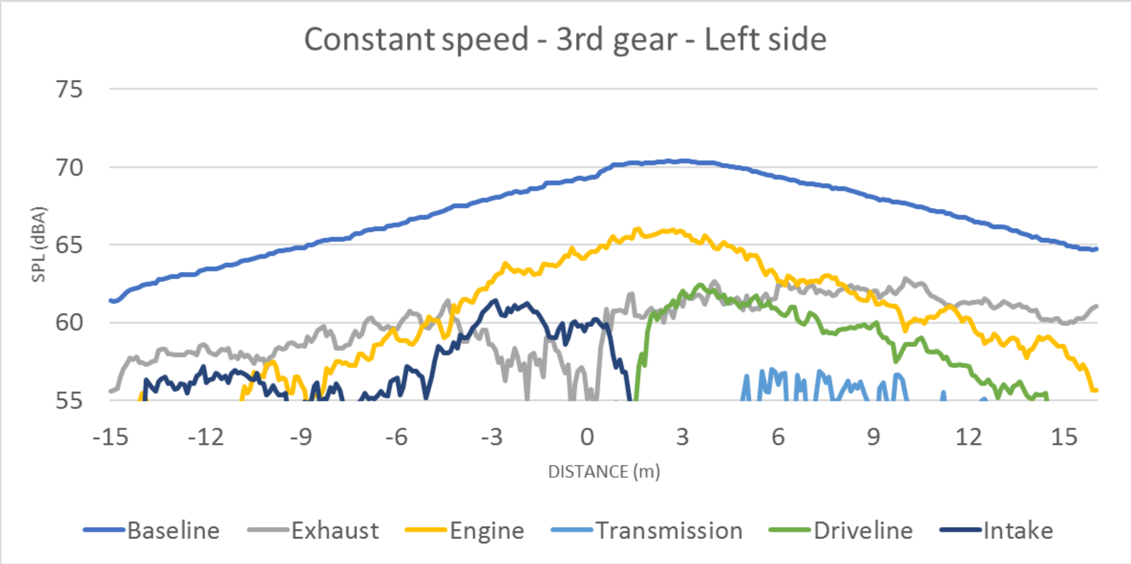


Figure A-5: Noise contribution of each system over distance

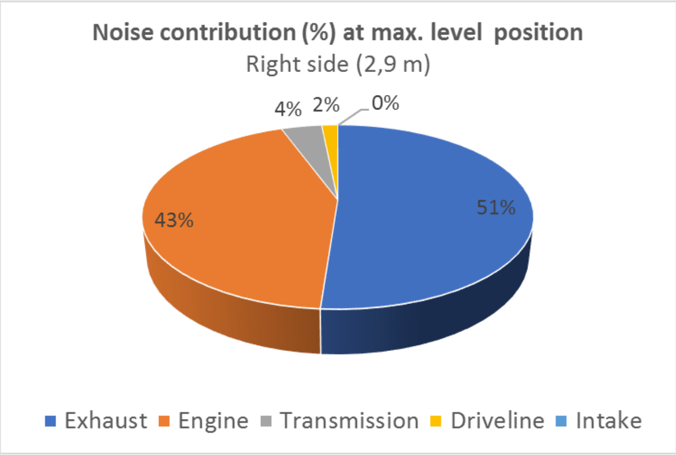


Figure A-6: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-7, Figure A-8 and Figure A-9 show the results for the fourth gear.

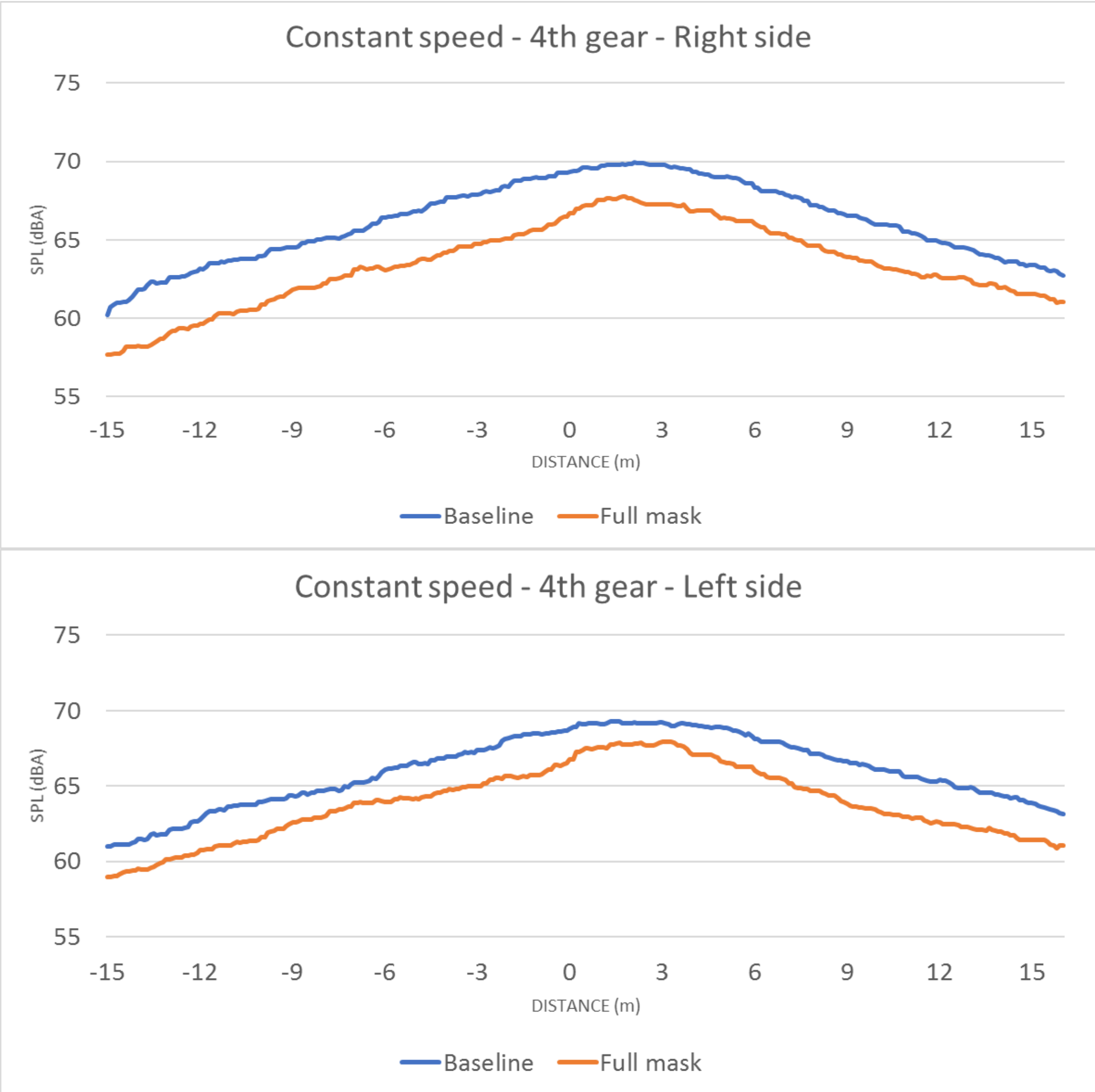


Figure A-7: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

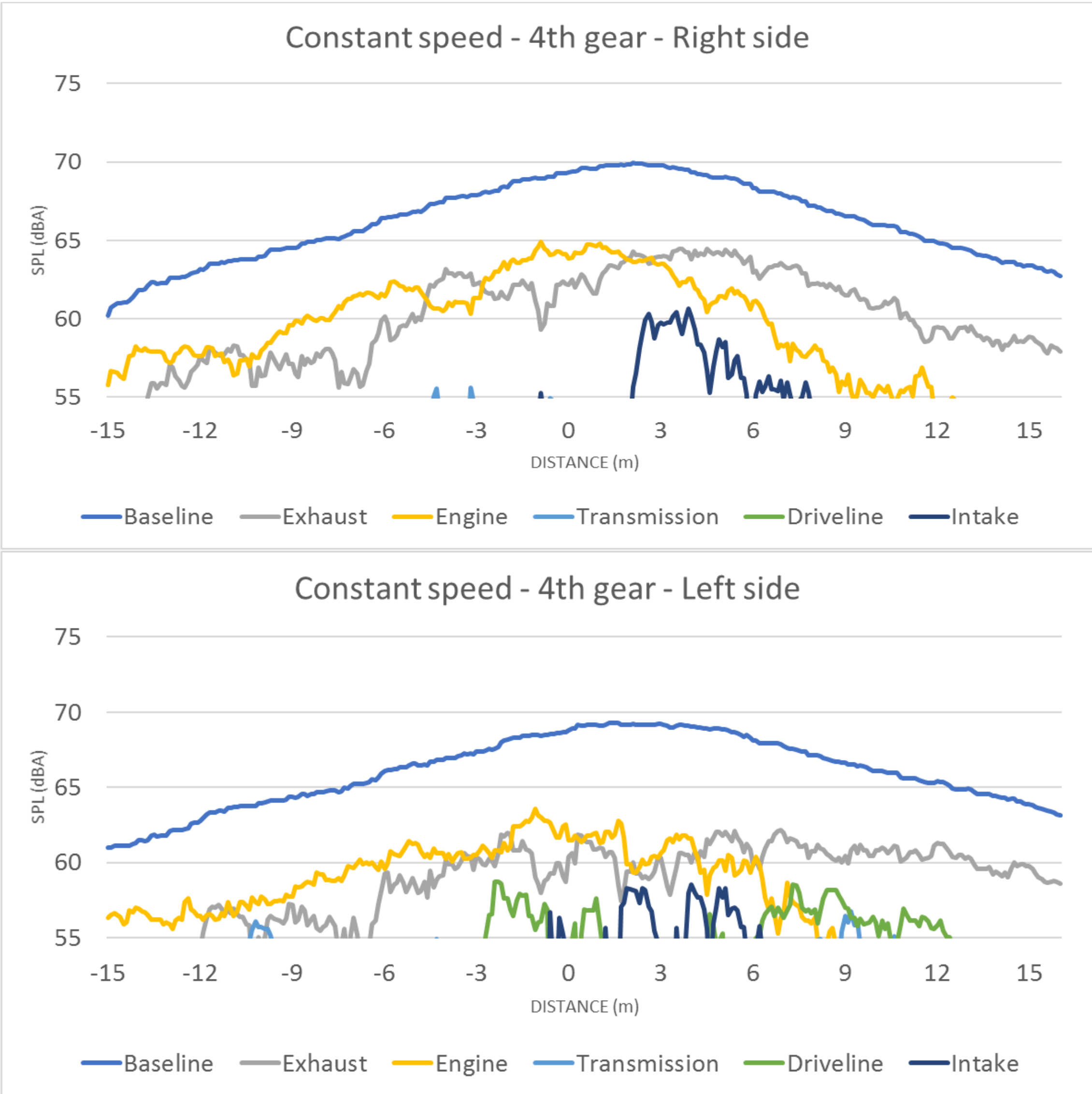


Figure A-8: Noise contribution of each system over distance

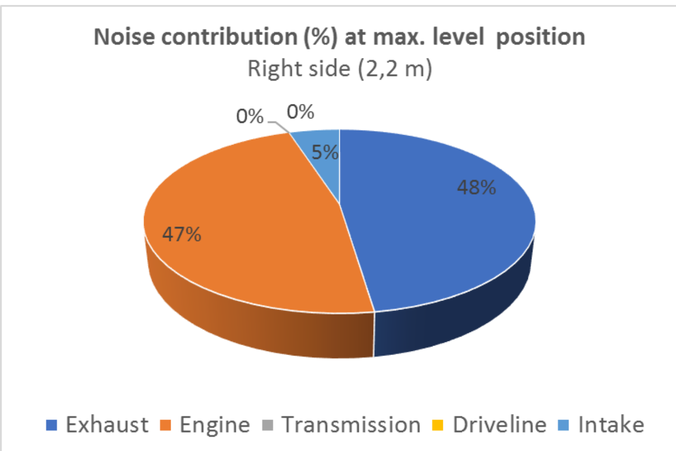


Figure A-9: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-10, Figure A-11 and Figure A-12 show the results for the acceleration in 3rd gear.

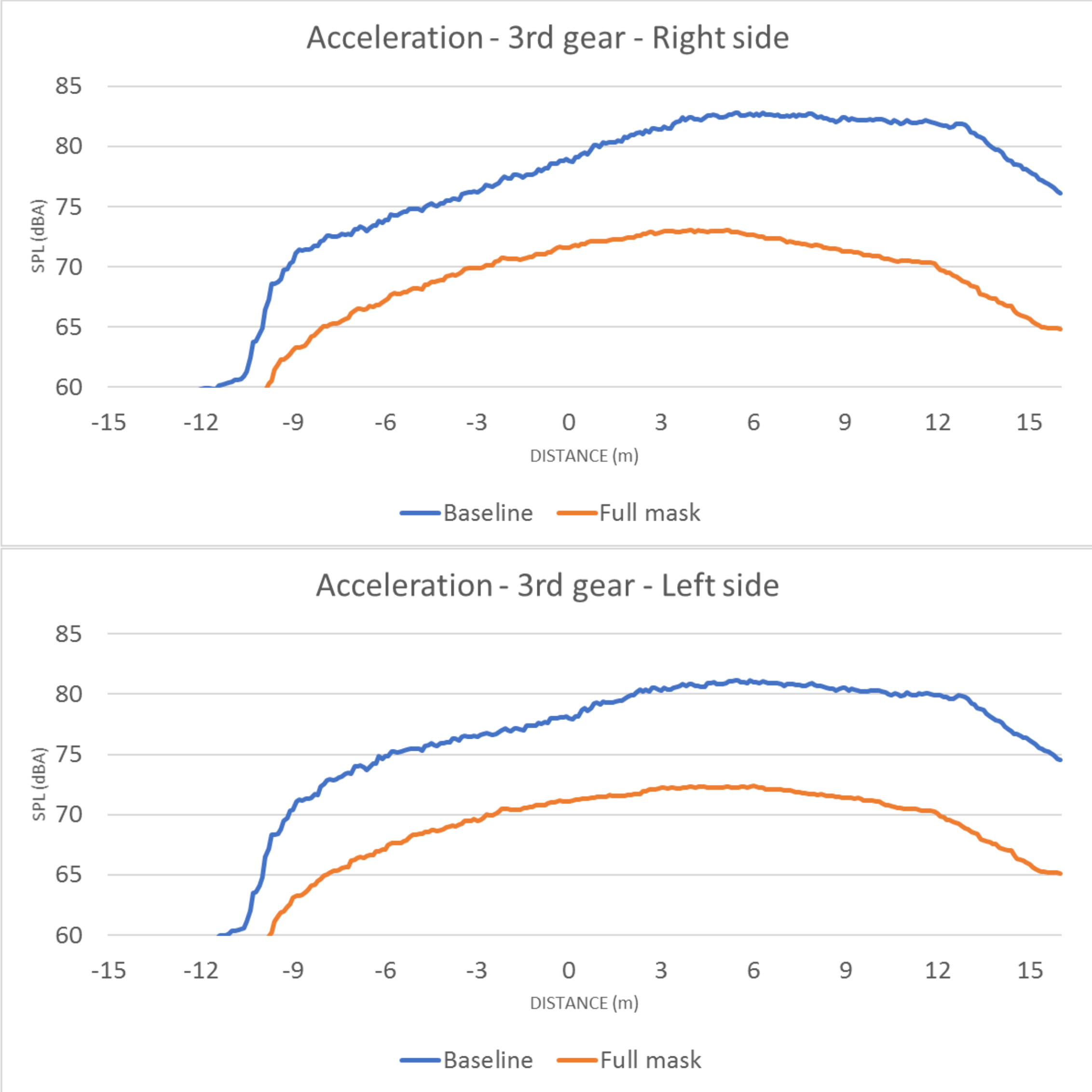


Figure A-10: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

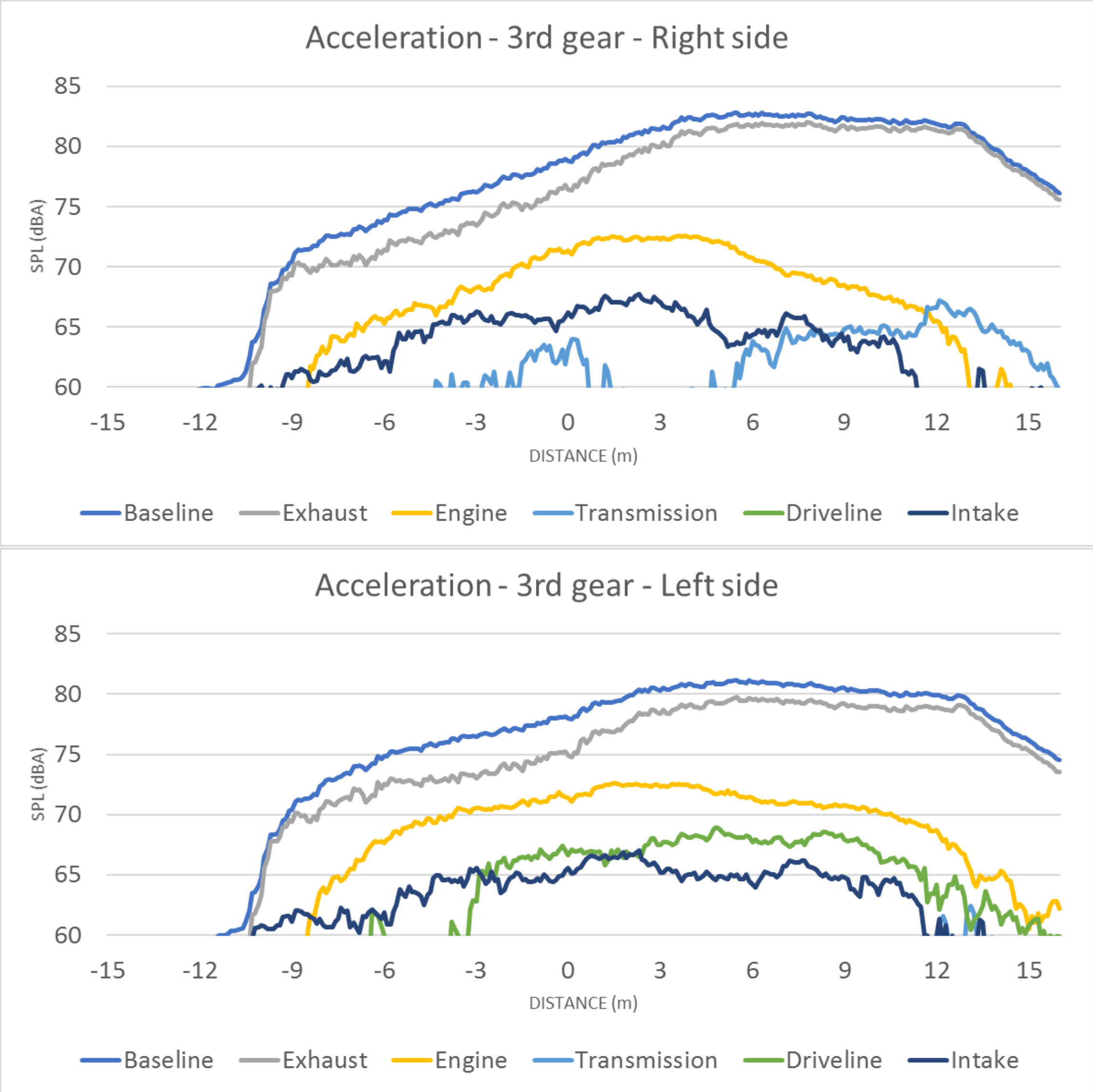


Figure A-11: Noise contribution of each system over distance

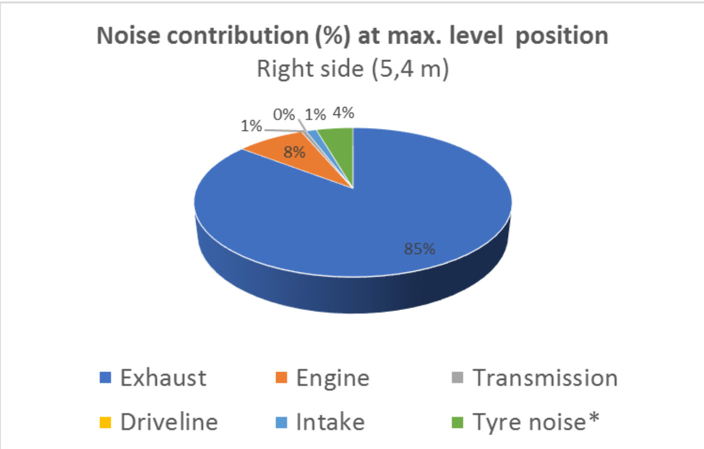


Figure A-12: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-13, Figure A-14 and Figure A-15 show the results for the acceleration in 4th gear.

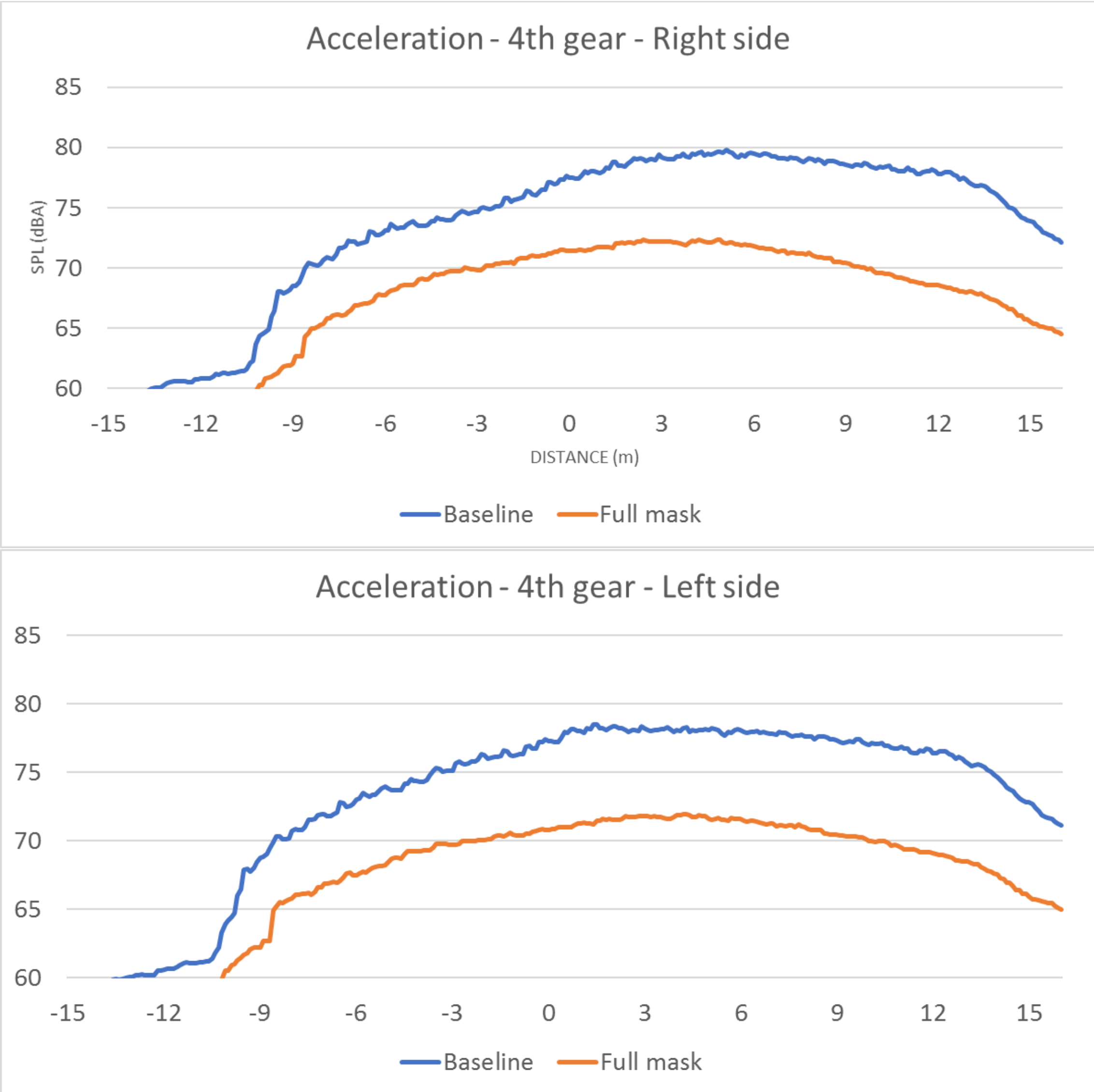
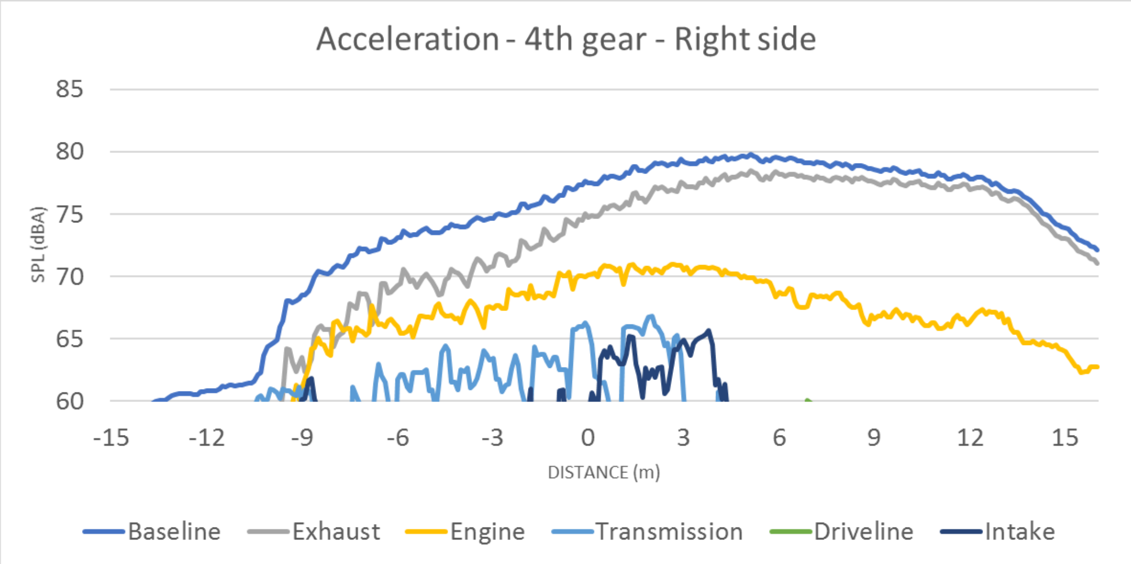


Figure A-13: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777



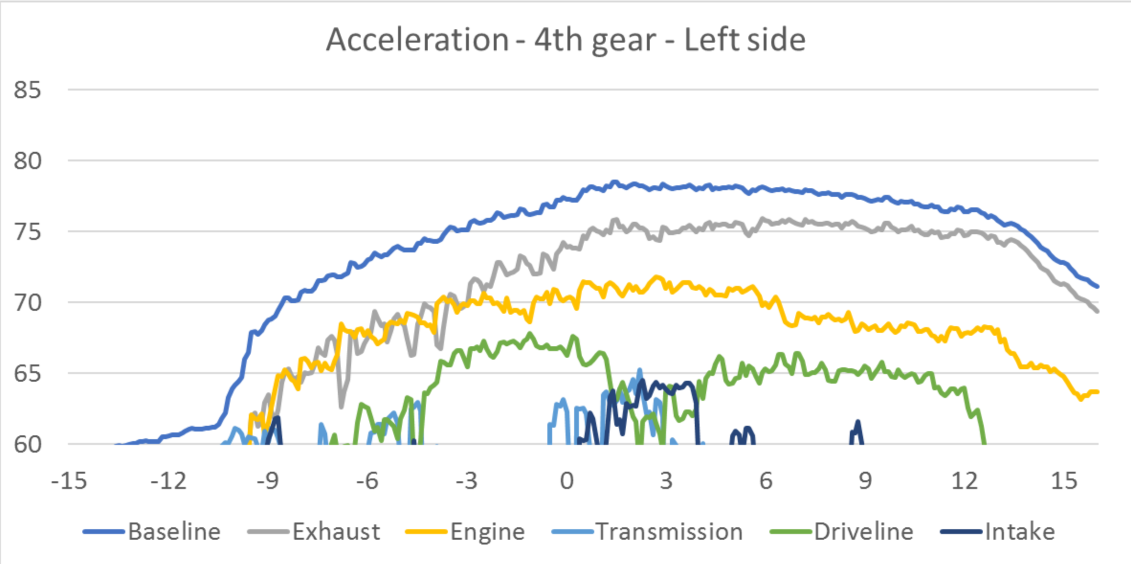


Figure A-14: Noise contribution of each system over distance

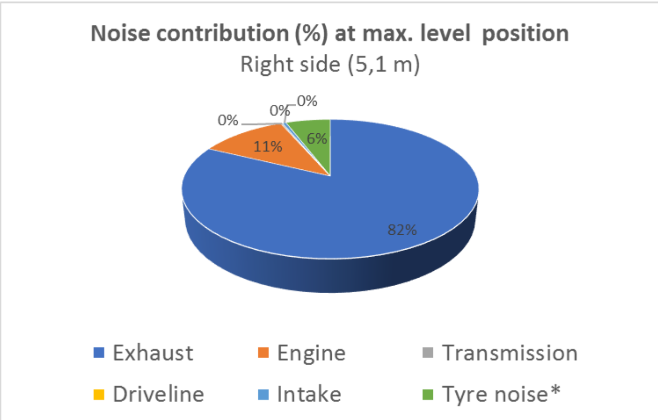


Figure A-15: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Finally, the Figure A-16 shows the results regarding L_{urban}.

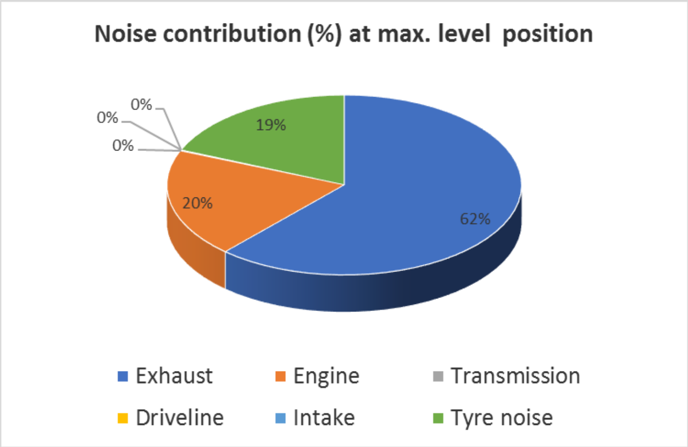


Figure A-16: Noise contribution of each system for L_{urban} of Sport TRAIL AUTO vehicle

A.III.i L3e-A3 vehicle type: Sport TRAIL MANUAL

Figure A-17, Figure A-18 and Figure A-19 show the results for the CRS test in 3rd gear in the manual mode.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

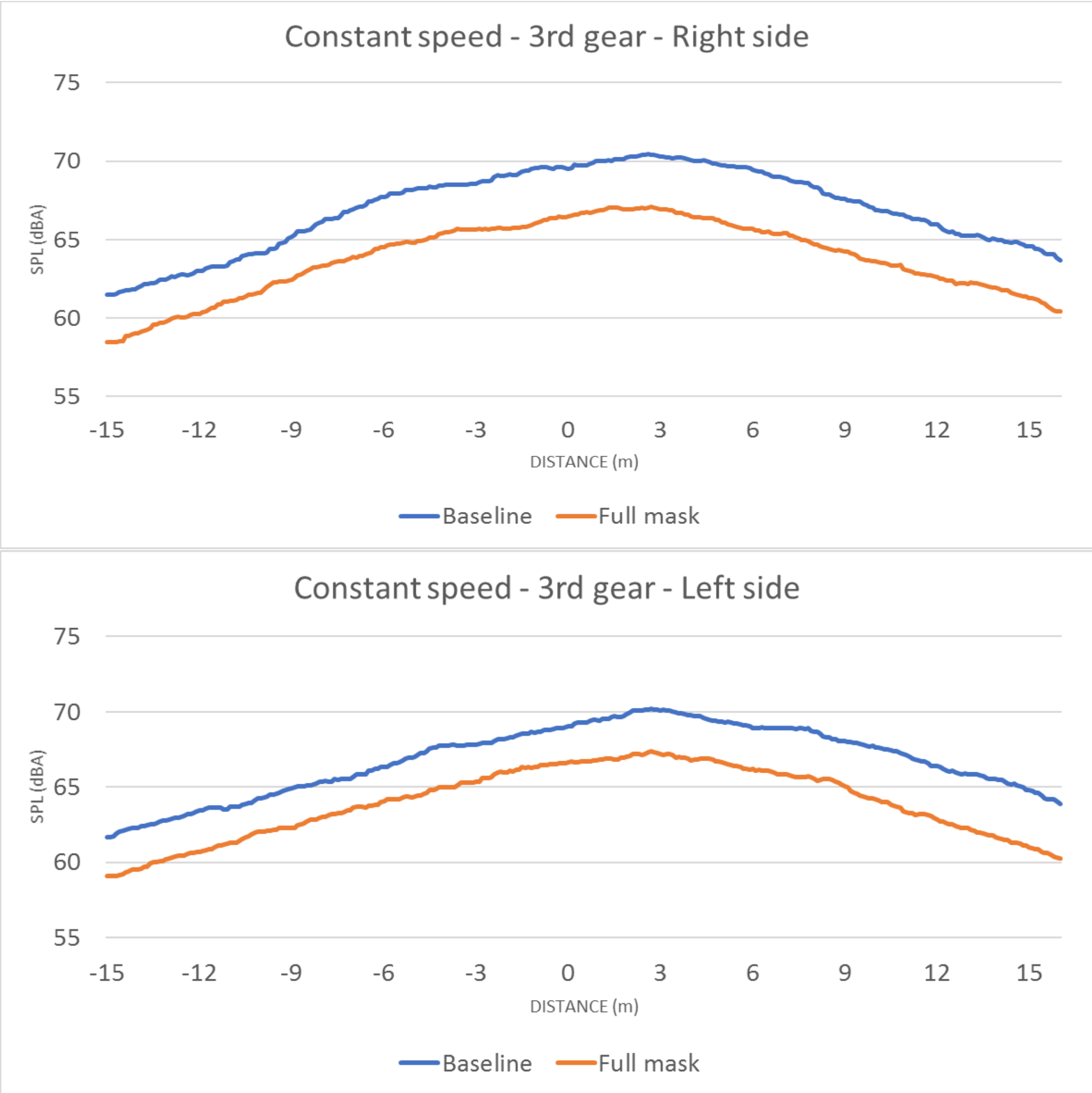


Figure A-17: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

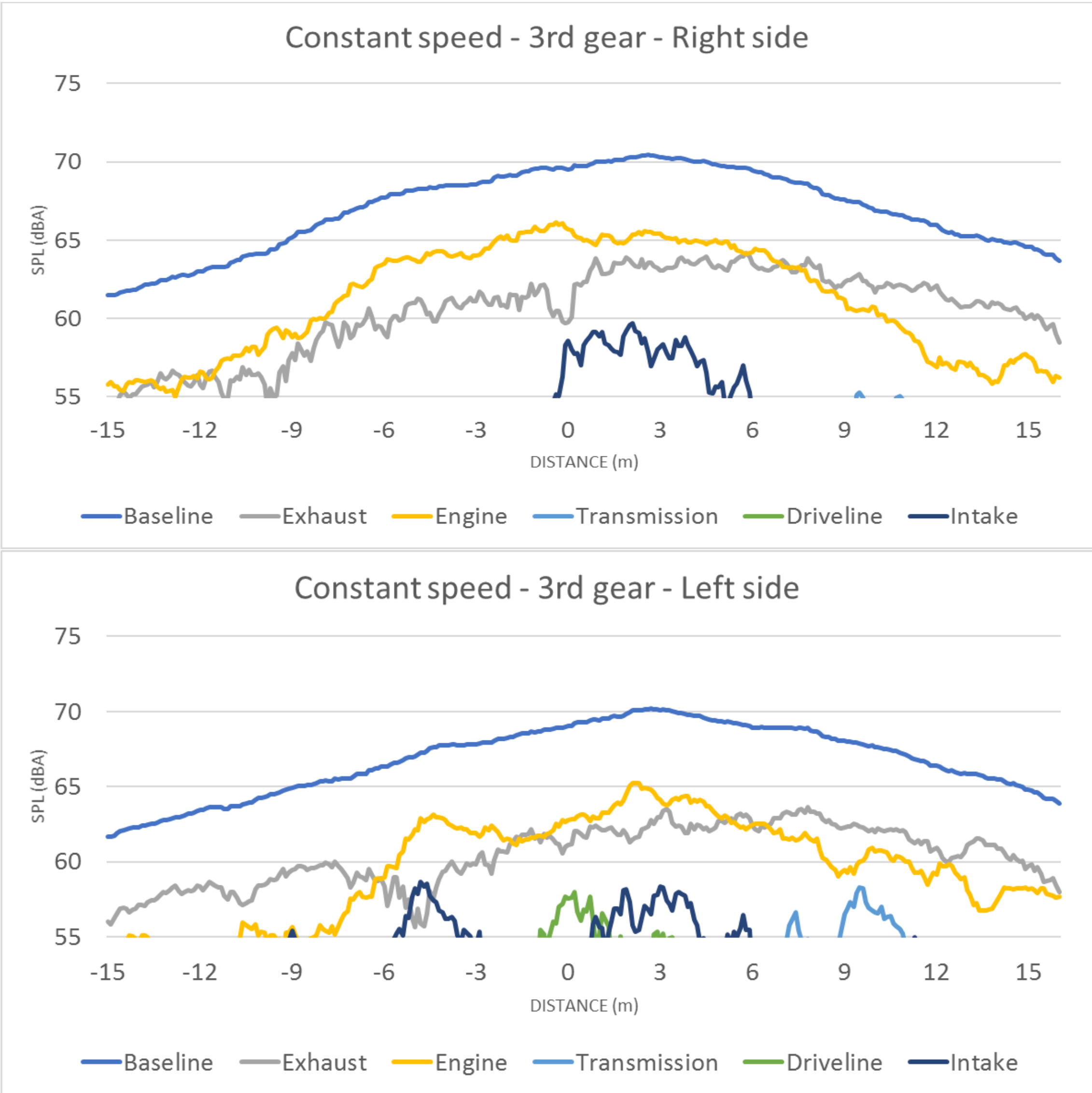


Figure A-18: Noise contribution of each system over distance

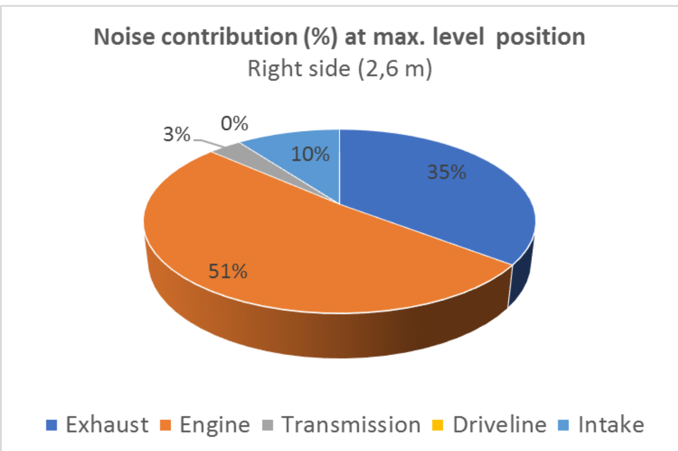


Figure A-19: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-20, Figure A-21 and Figure A-22 show the results for the 4th gear constant speed test.

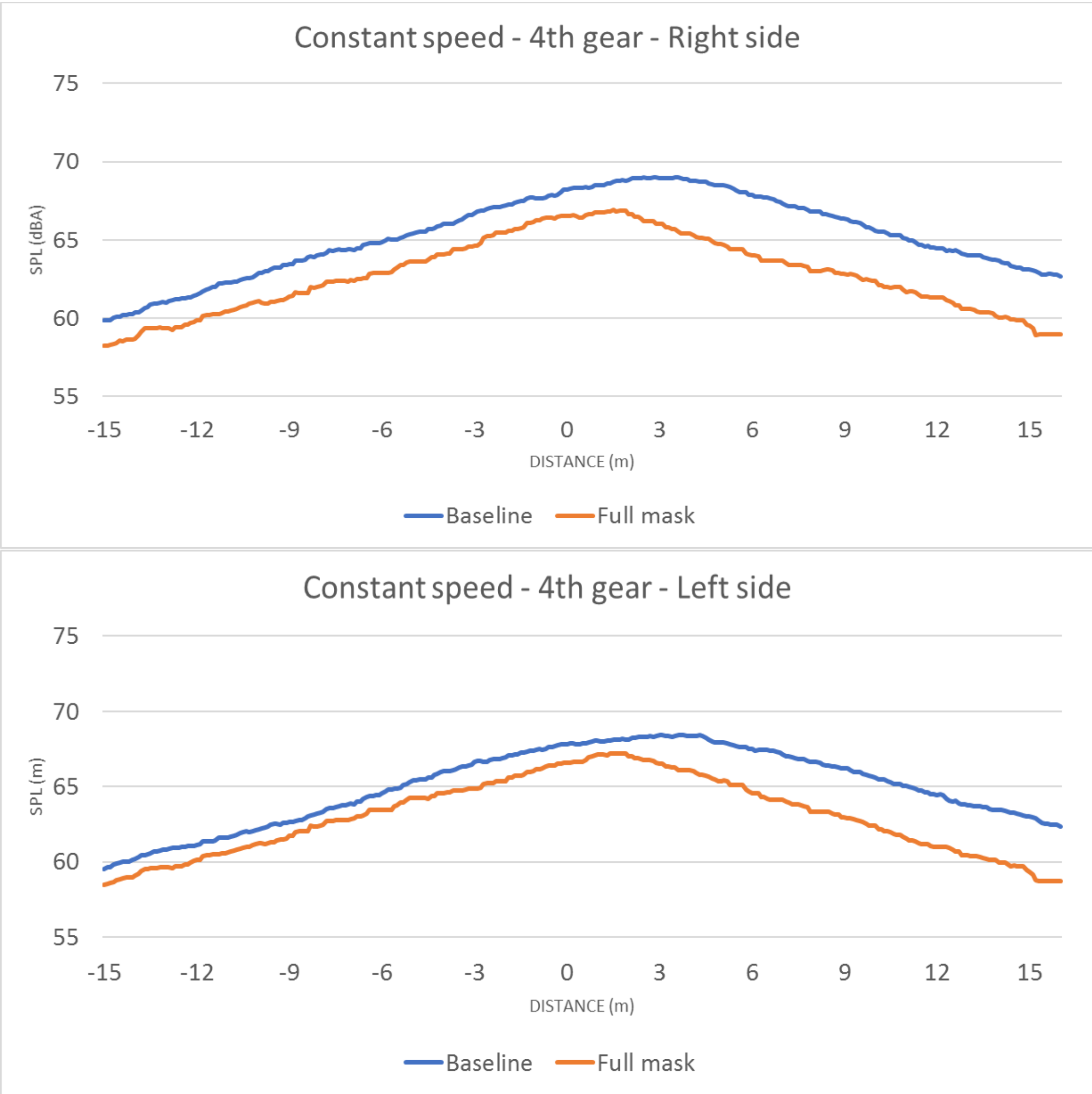


Figure A-20: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

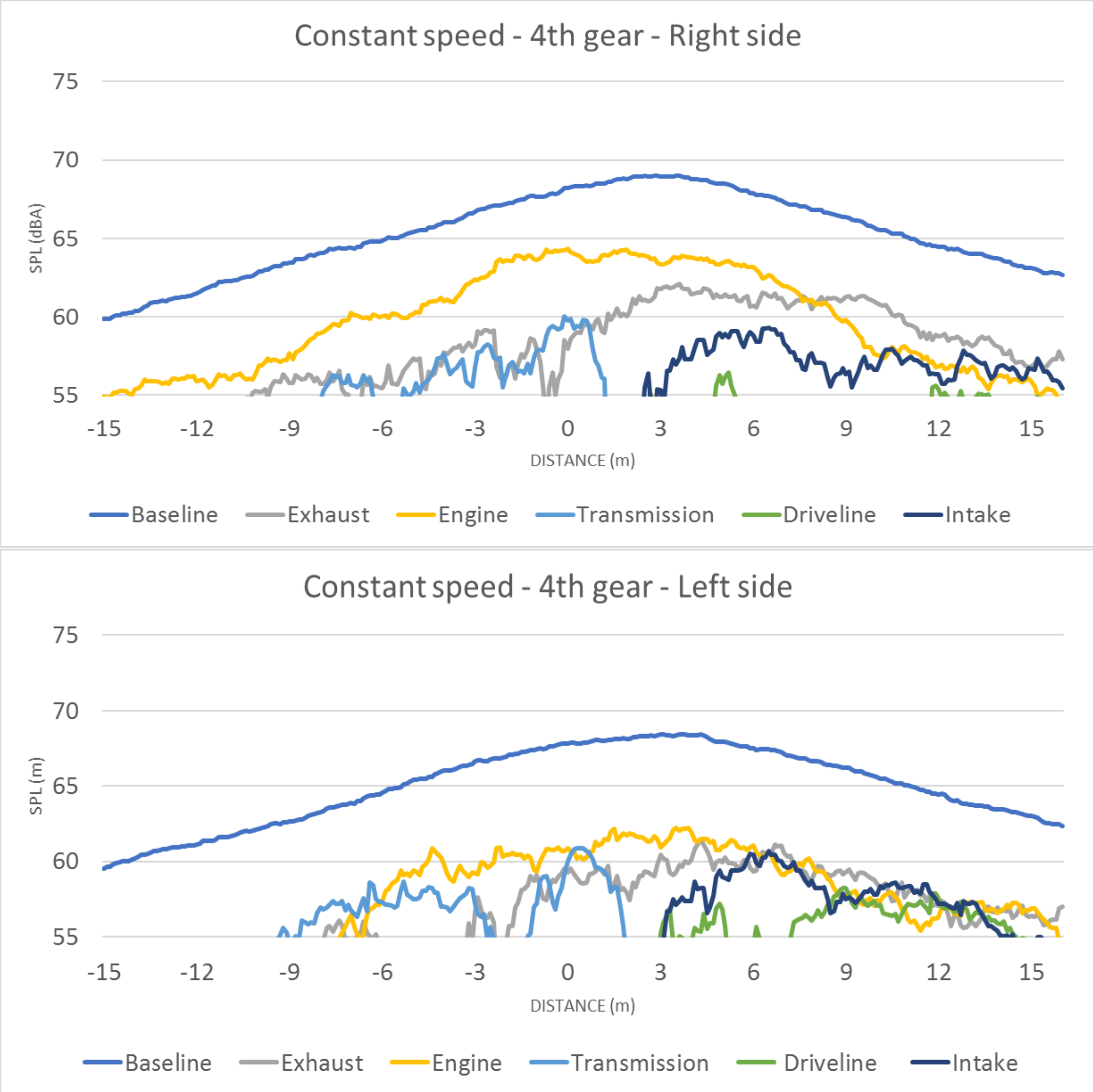


Figure A-21: Noise contribution of each system over distance

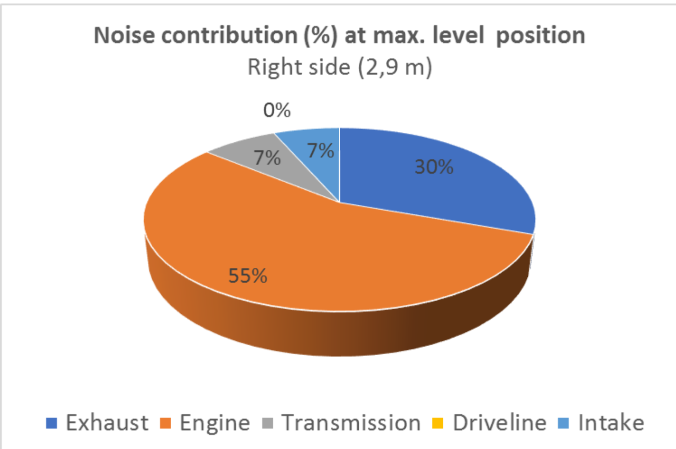


Figure A-22: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-23, Figure A-24 and Figure A-25 show the result for the acceleration tests in 3rd gear.

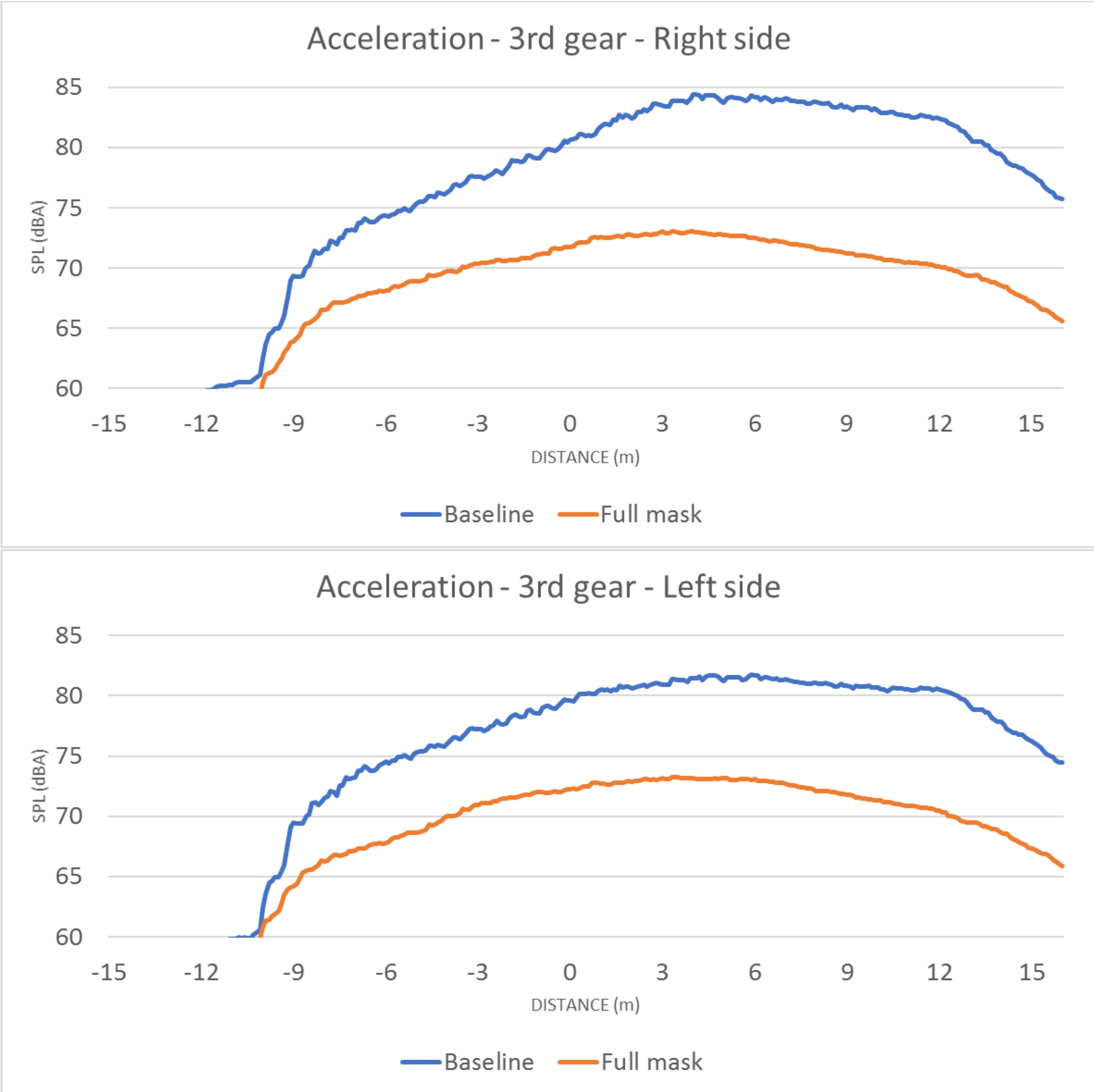


Figure A-23: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

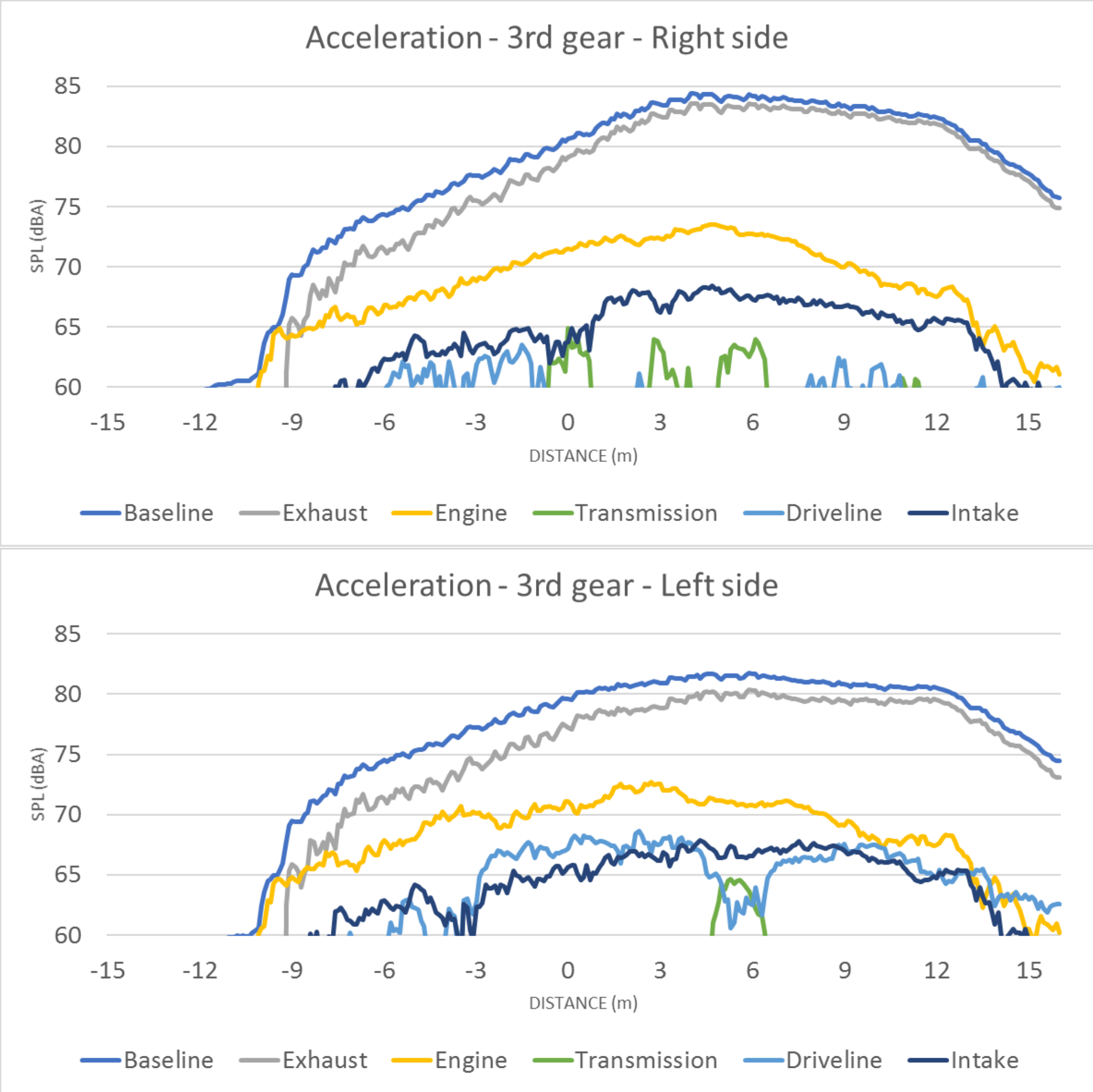


Figure A-24: Noise contribution of each system over distance

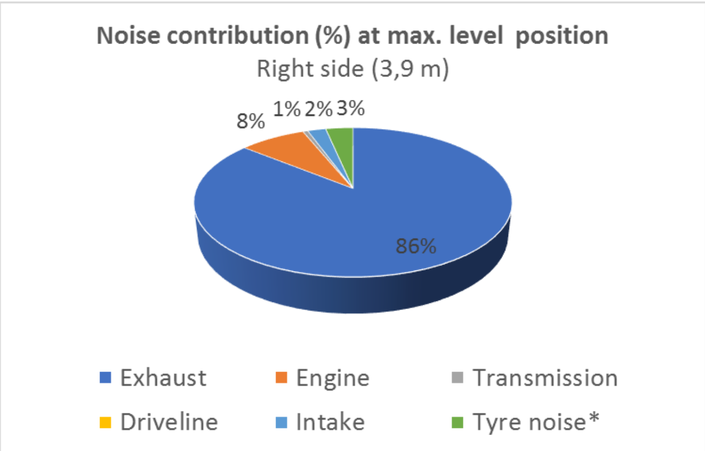


Figure A-25: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Figure A-26, Figure A-27 as well as Figure A-28 show the results for the 4th gear acceleration test.

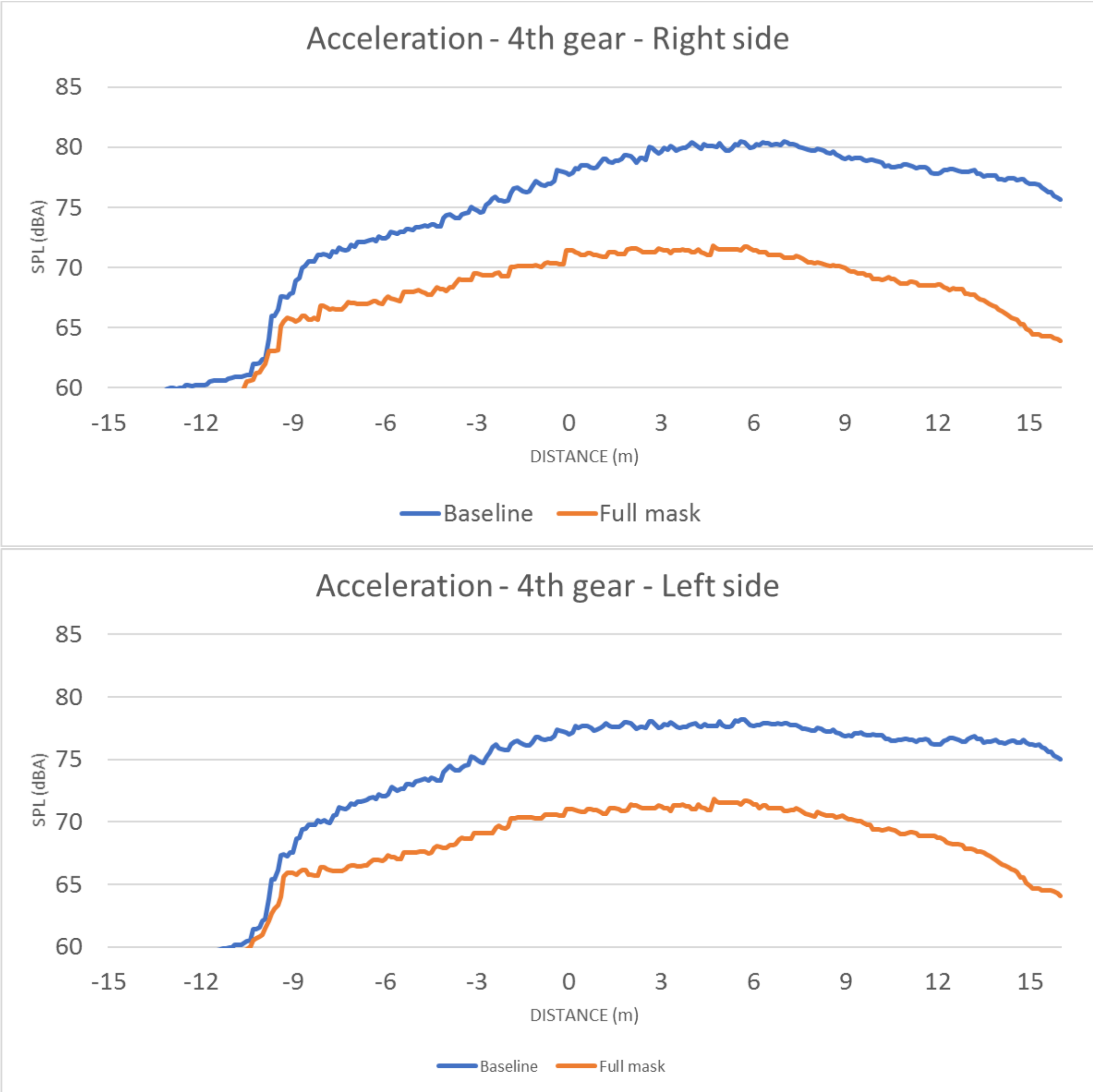


Figure A-26: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

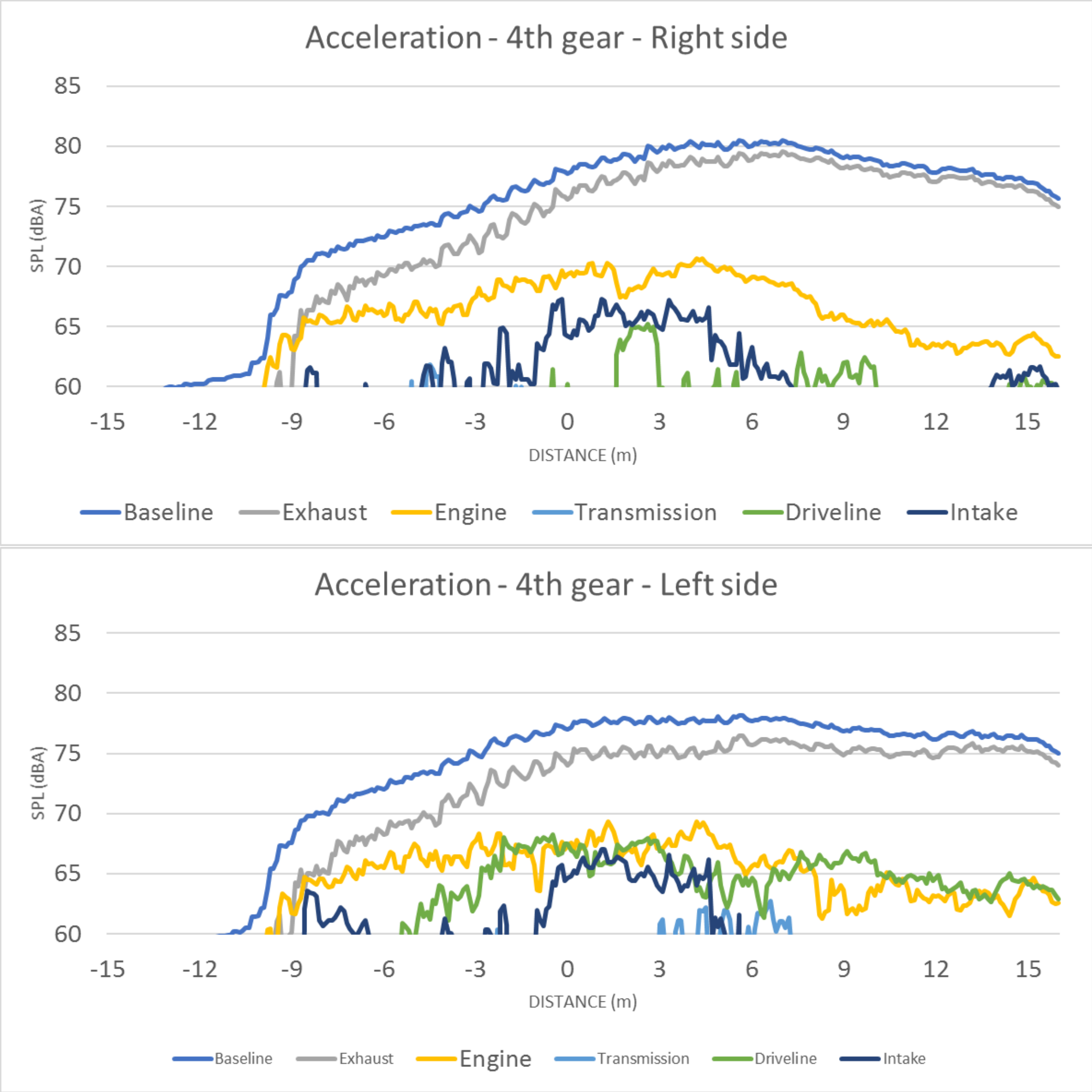


Figure A-27: Noise contribution of each system over distance

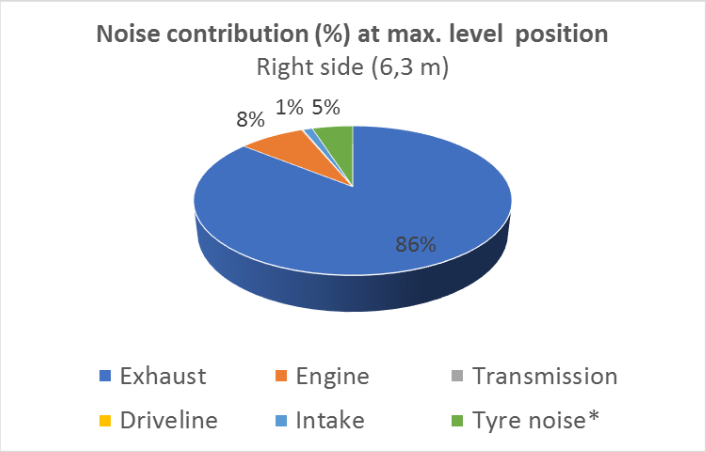


Figure A-28: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

Analogue to Figure A-16, Figure A-29 shows the L_{urban}.results for the measurement campaign.

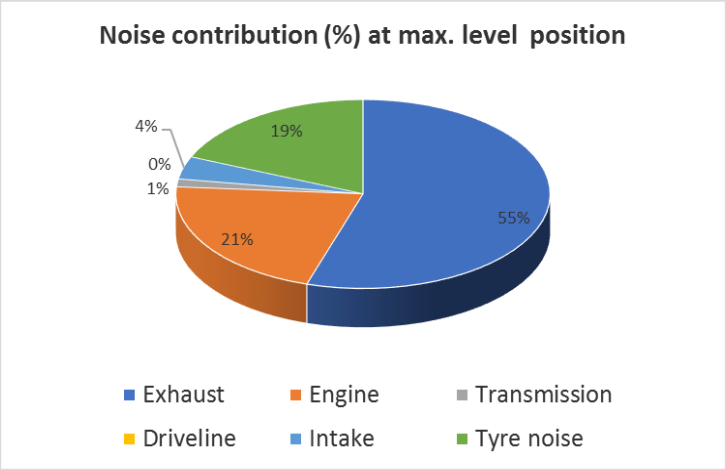


Figure A-29: Noise contribution of each system for L_{urban} of Sport TRAIL MANUAL vehicle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

A.III.ii L3e-A3 vehicle. Sport NAKED

For a naked bike, Figure A-30, Figure A-31 and Figure A-32 show the results for the constant speed tests in 3rd gear and Figure A-33, Figure A-34 and Figure A-35 show the corresponding acceleration tests in the 3rd gear. Lastly, the Figure A-36 shows the results for L_{urban} for this vehicle.

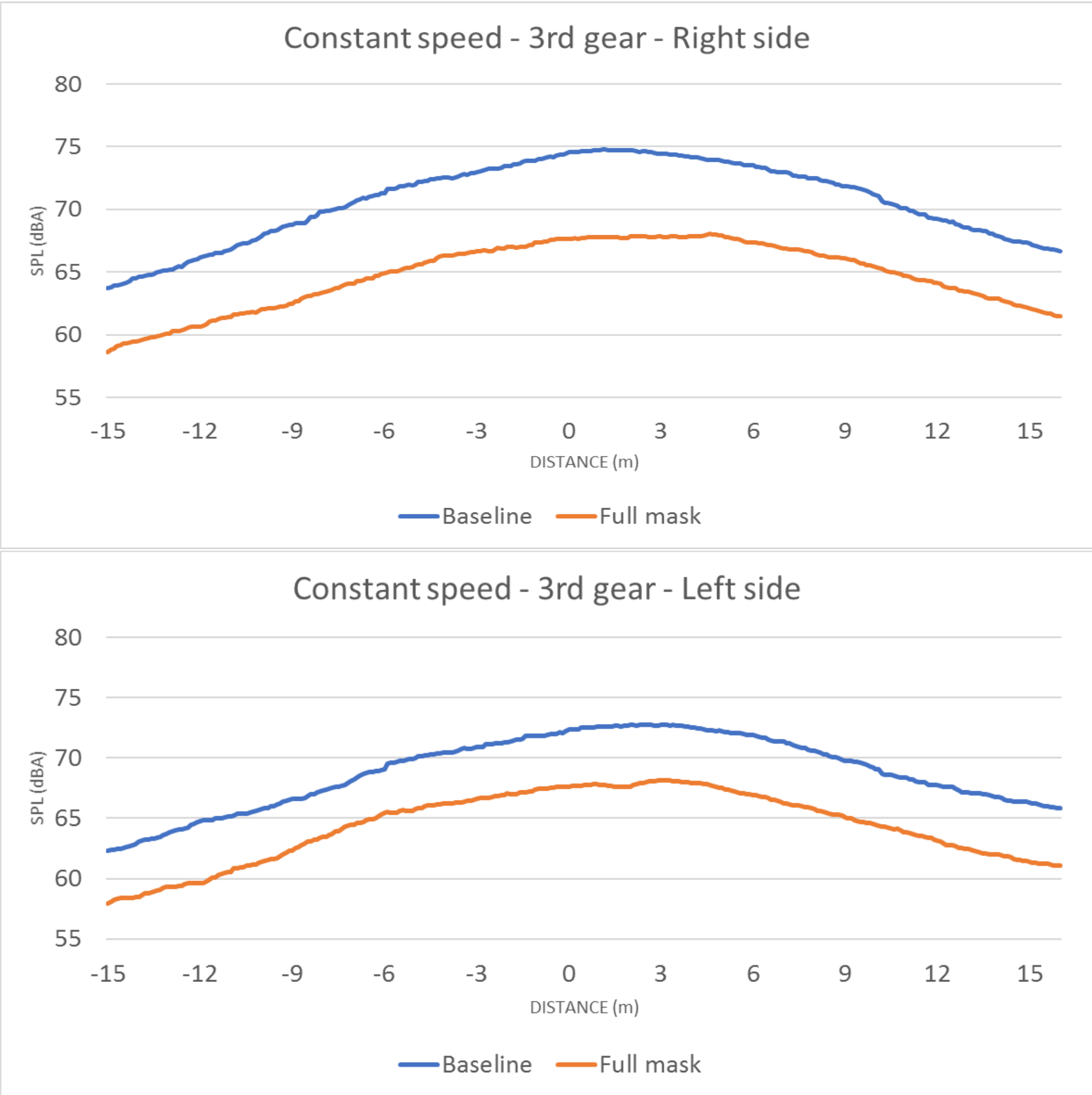


Figure A-30: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

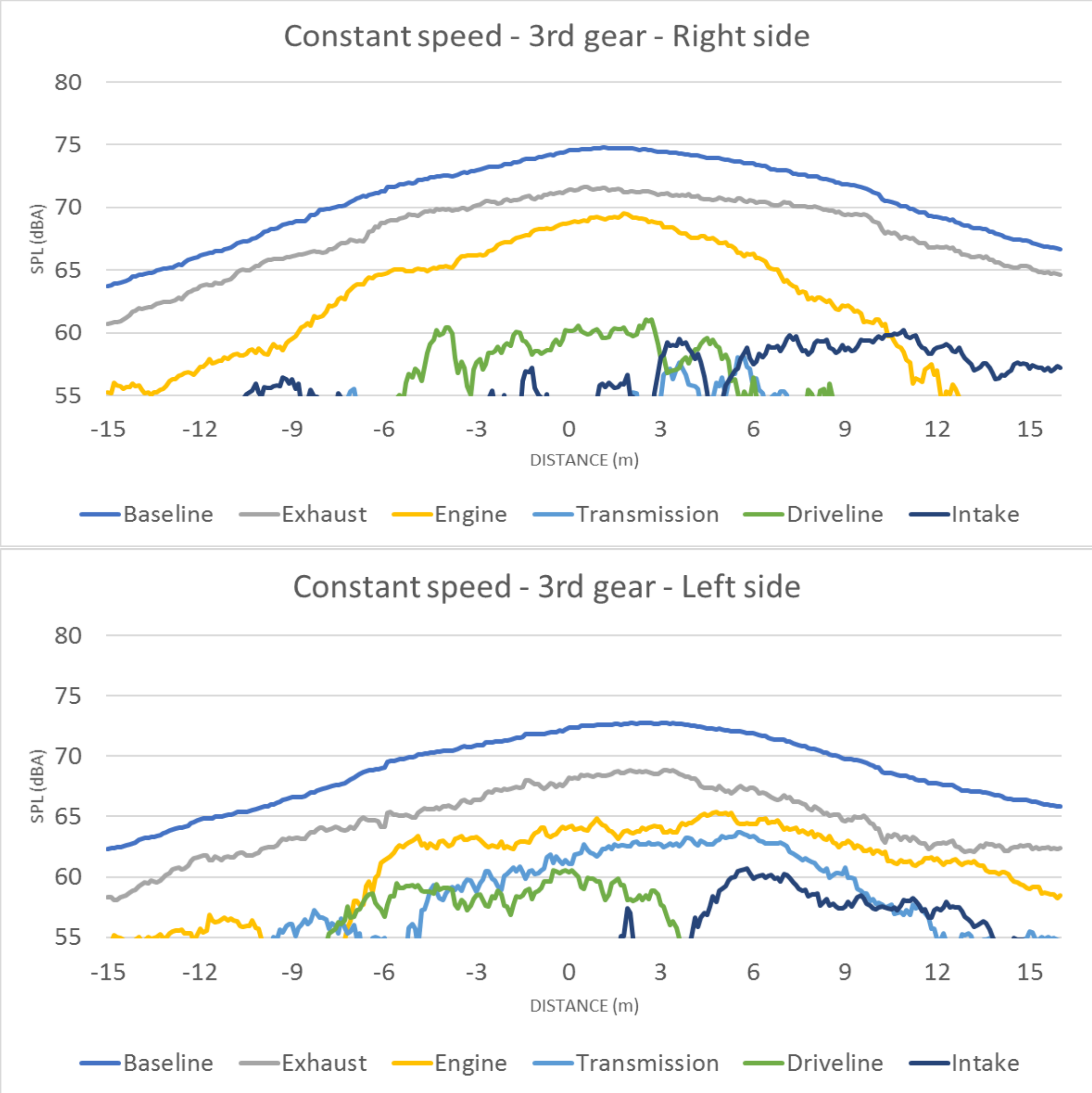


Figure A-31: Noise contribution of each system over distance

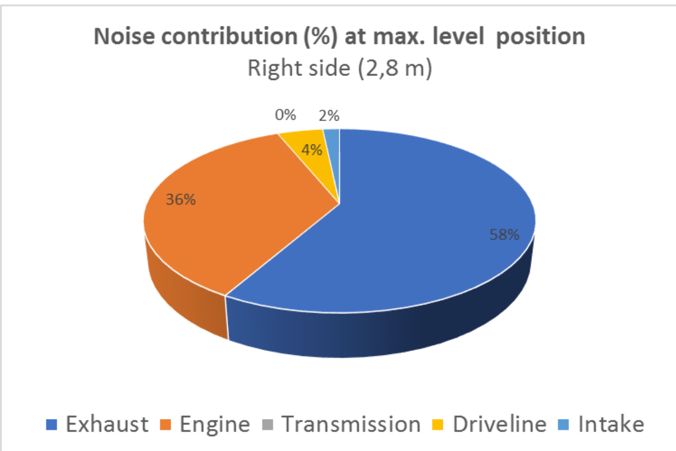


Figure A-32: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

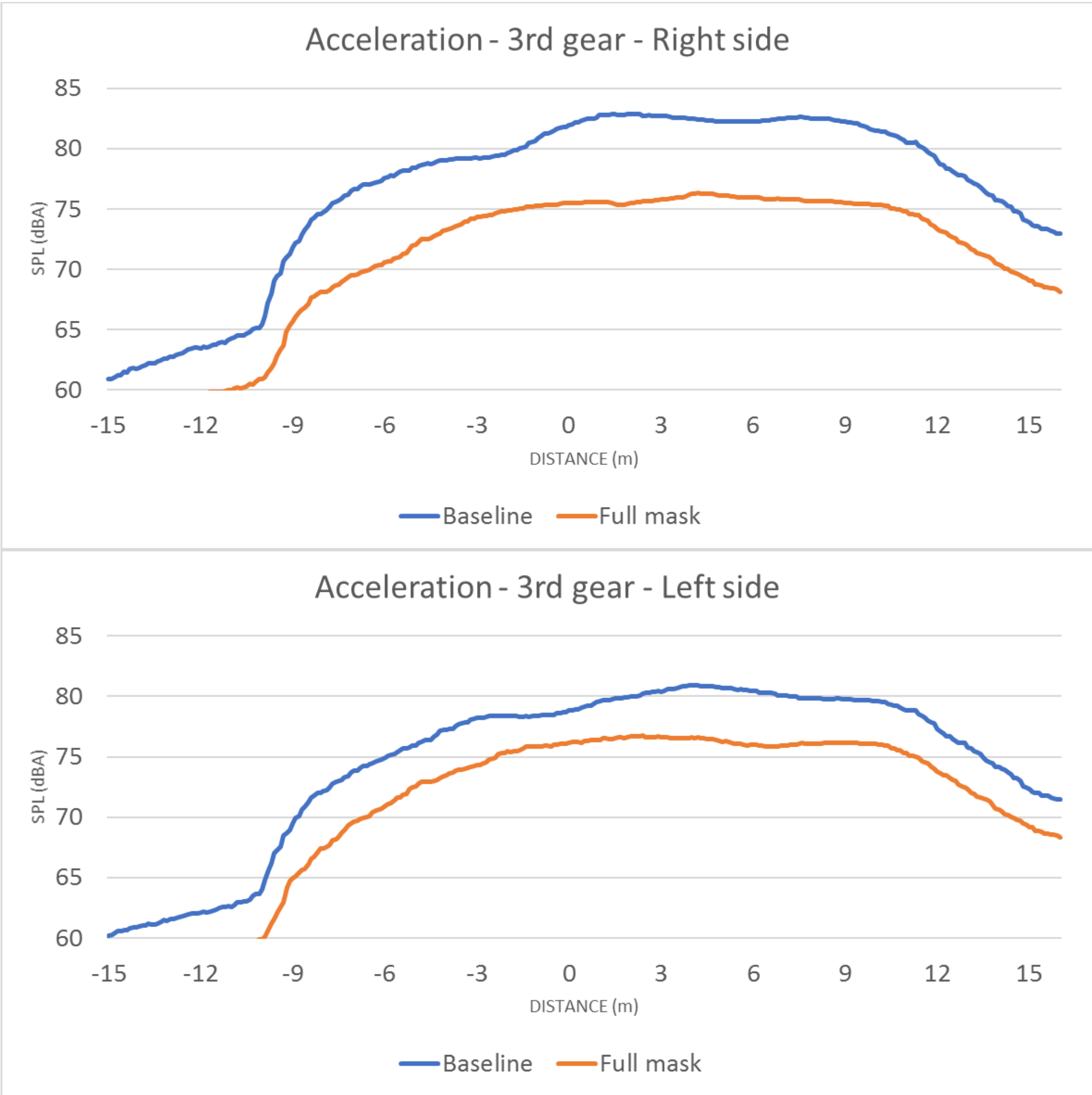


Figure A-33: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

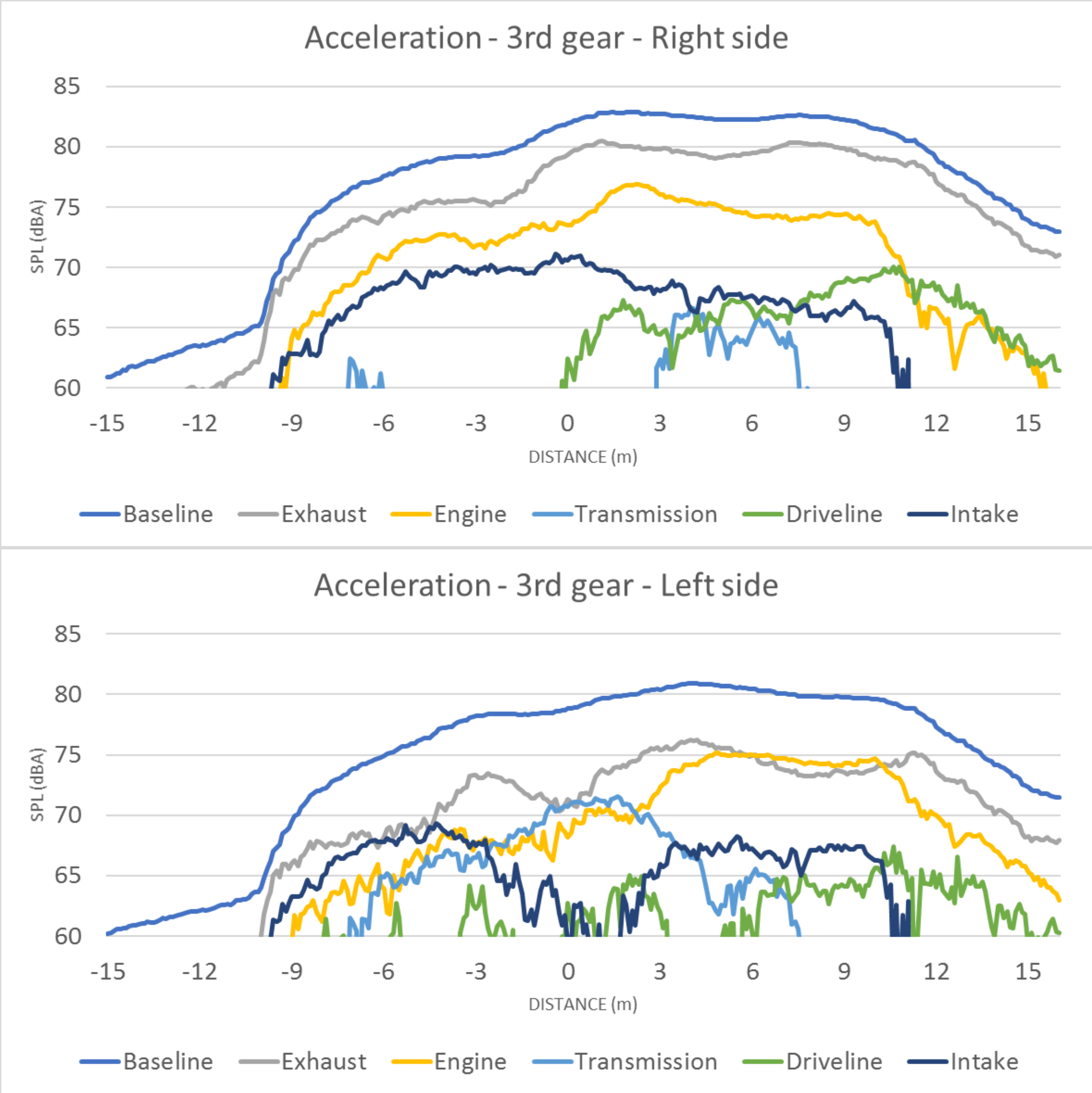


Figure A-34: Noise contribution of each system over distance

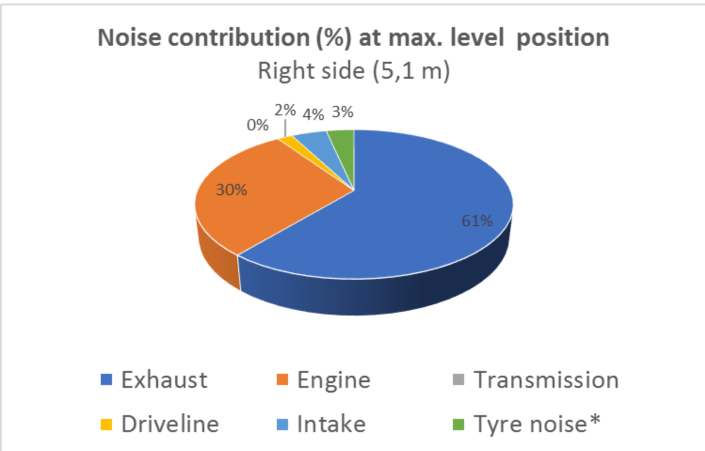


Figure A-35: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

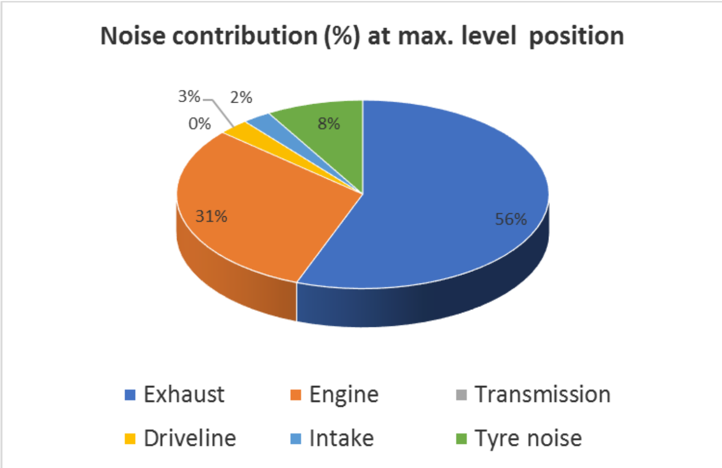


Figure A-36: Noise contribution of each system for L_{urban} of Sport NAKED vehicle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

A.III.iii L3e-A3 vehicle. Sport TRAIL

In Figure A-37, Figure A-38 and Figure A-39, the results for the 4th gear constant speed testing is displayed, whereas the acceleration tests for this L3e-A3 vehicle is shown in Figure A-40, Figure A-41 and Figure A-42. The overall results for the TA value L_{urban} is then again visible in Figure A-43.

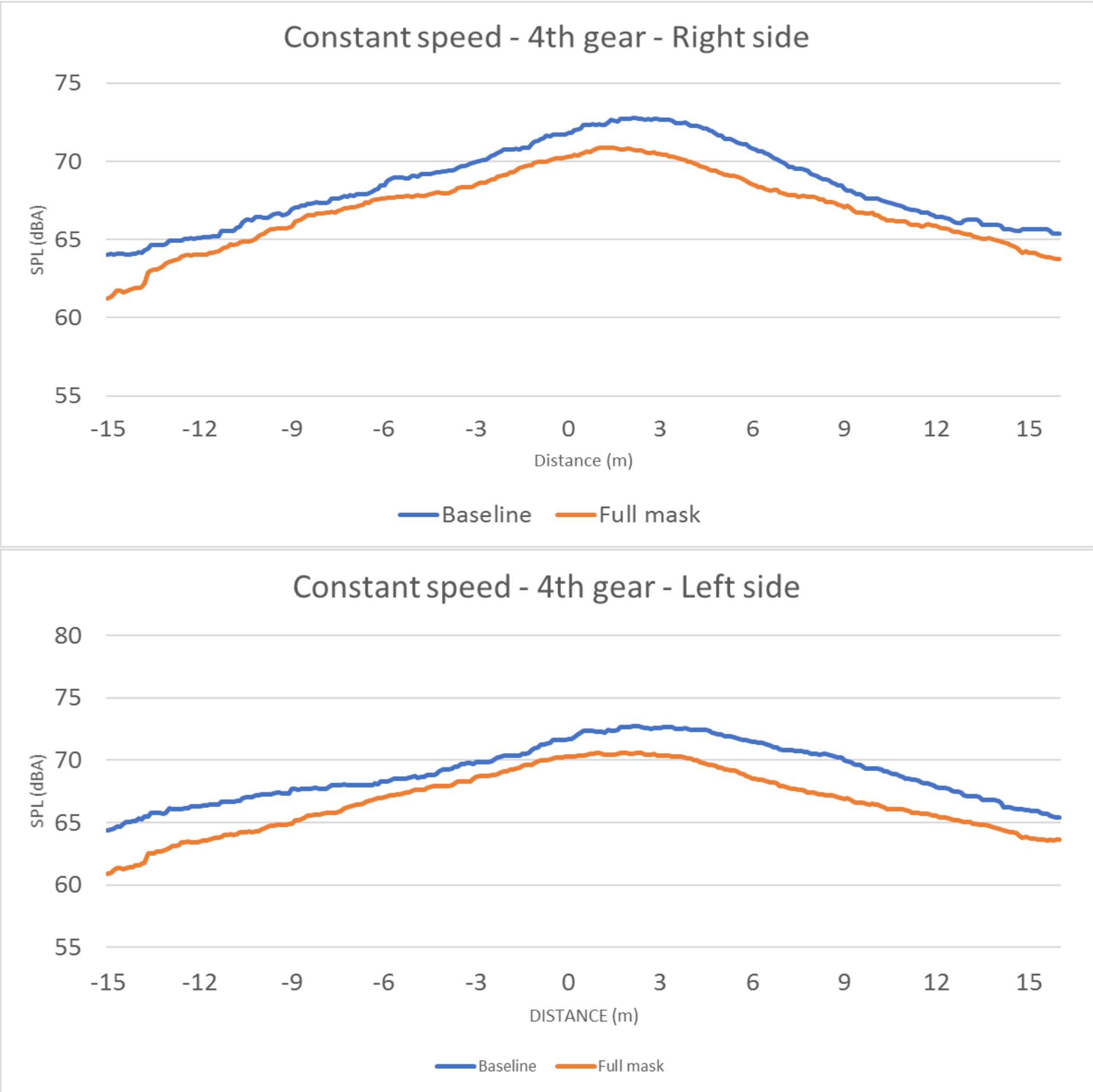


Figure A-37: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

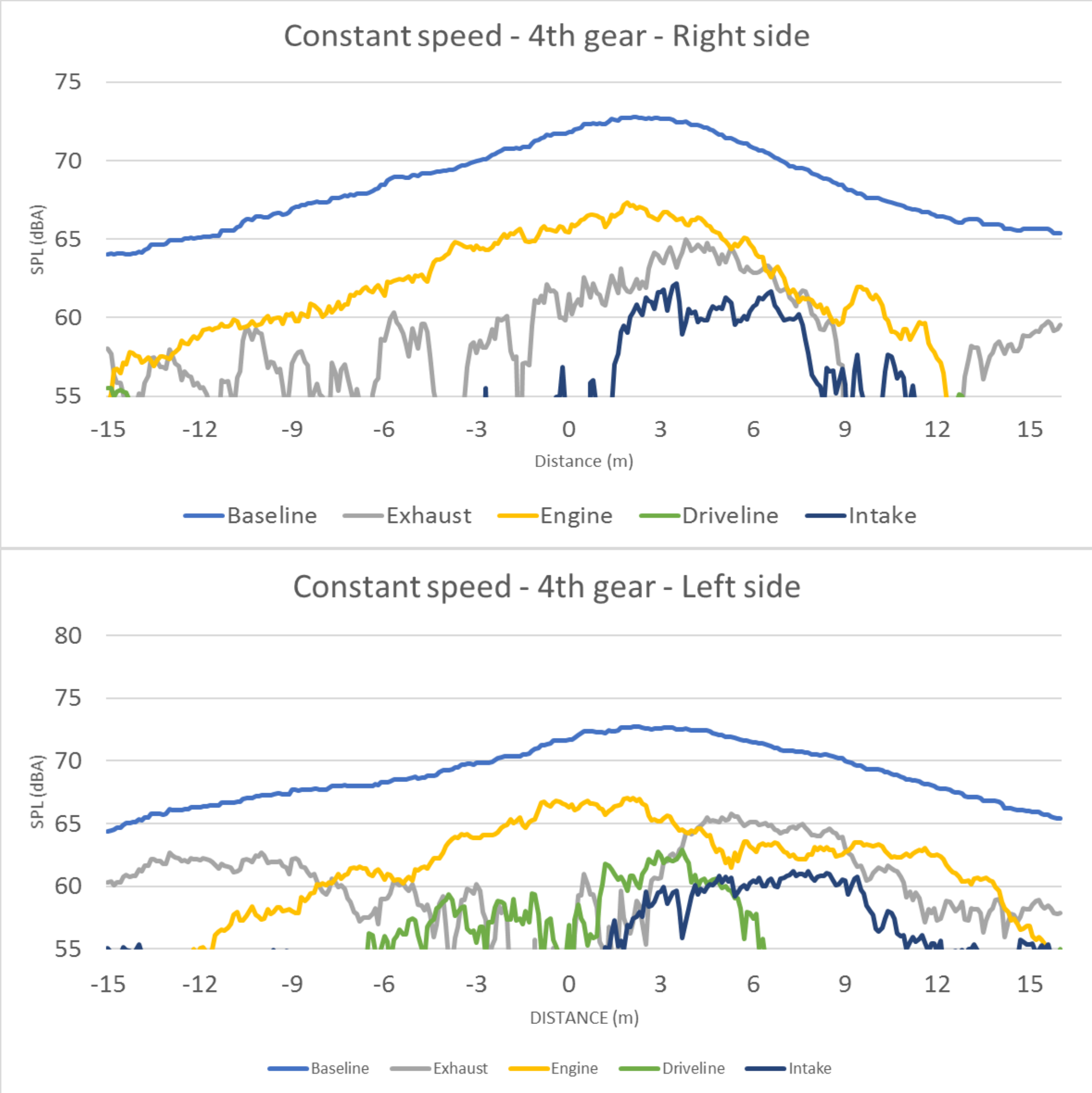


Figure A-38: Noise contribution of each system over distance

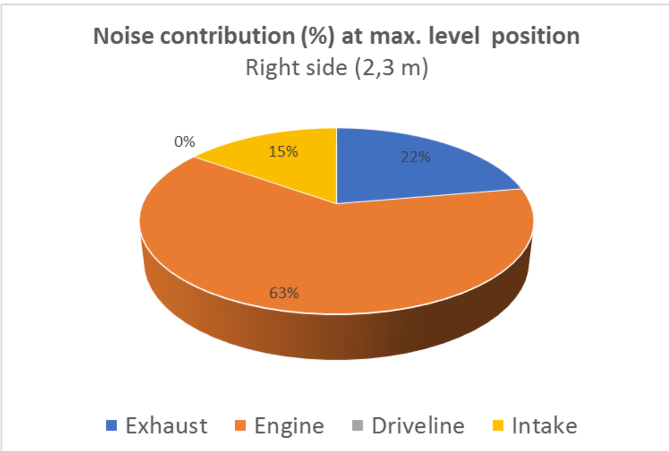


Figure A-39: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

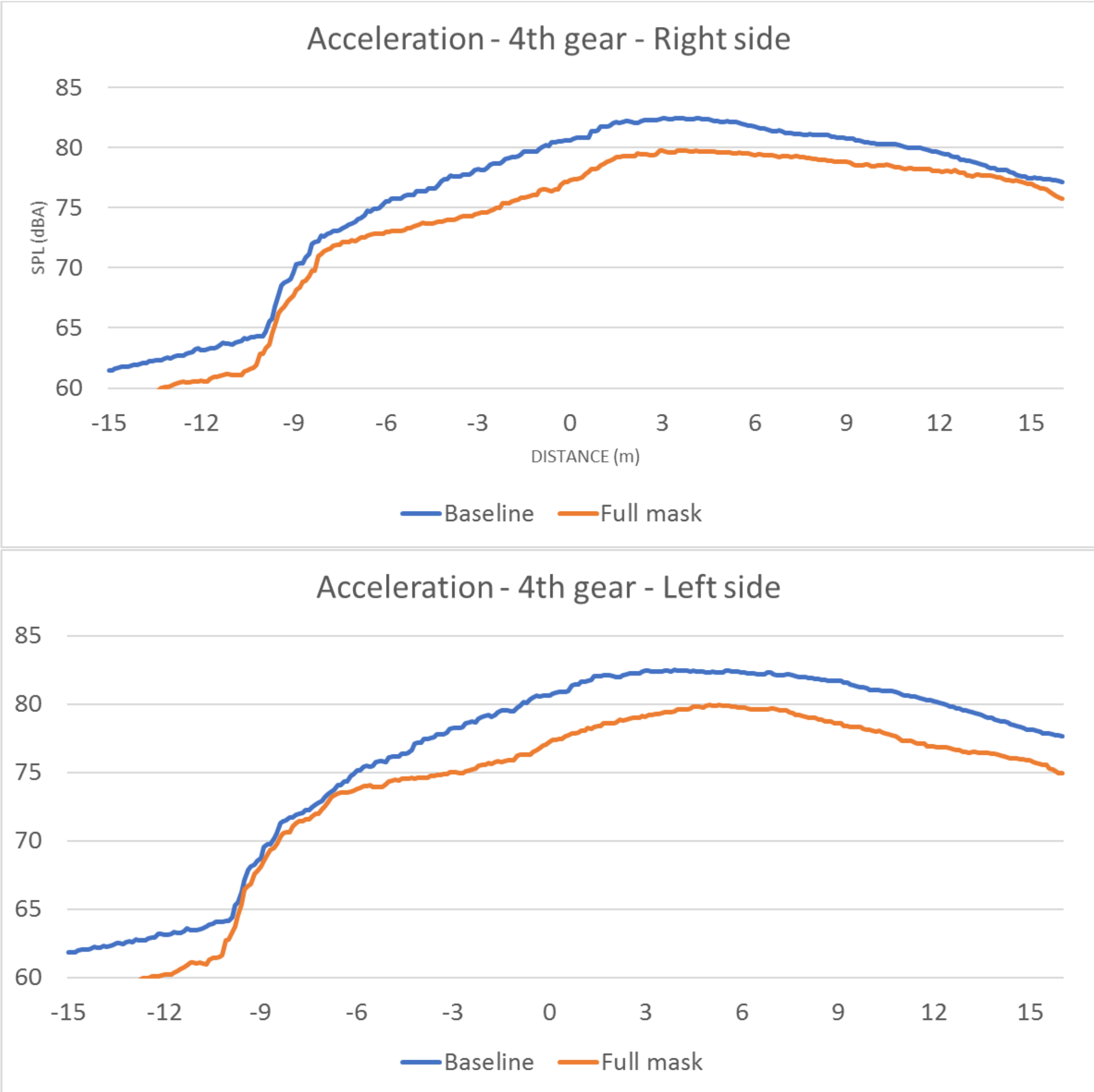


Figure A-40: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

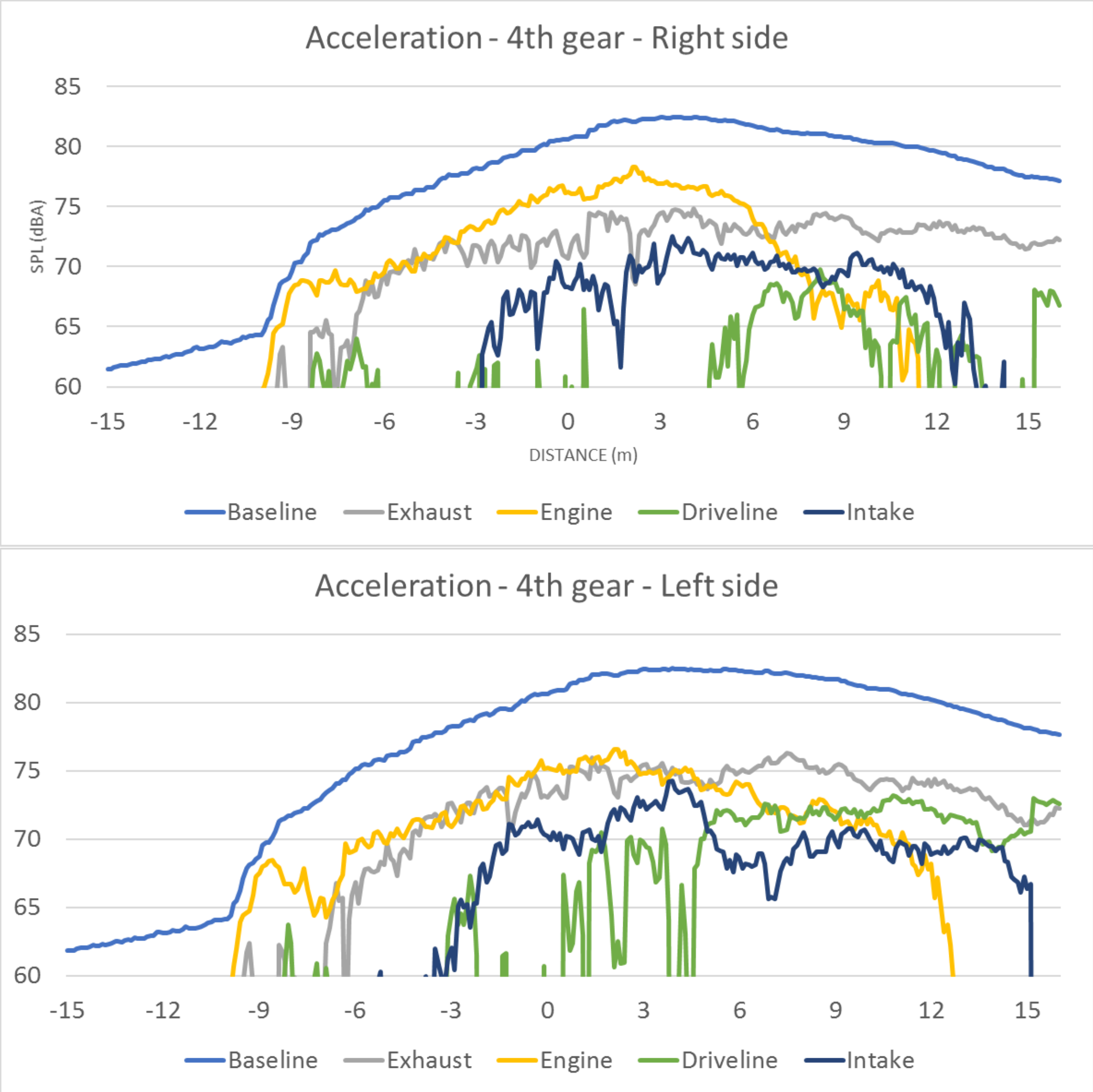


Figure A-41: Noise contribution of each system over distance

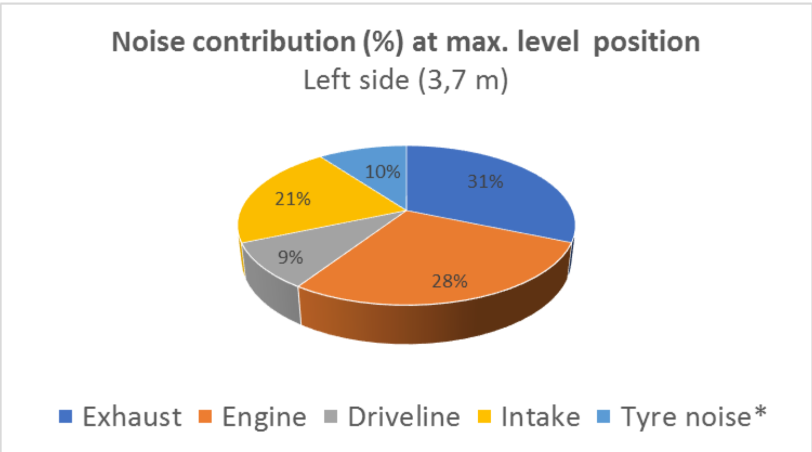


Figure A-42: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

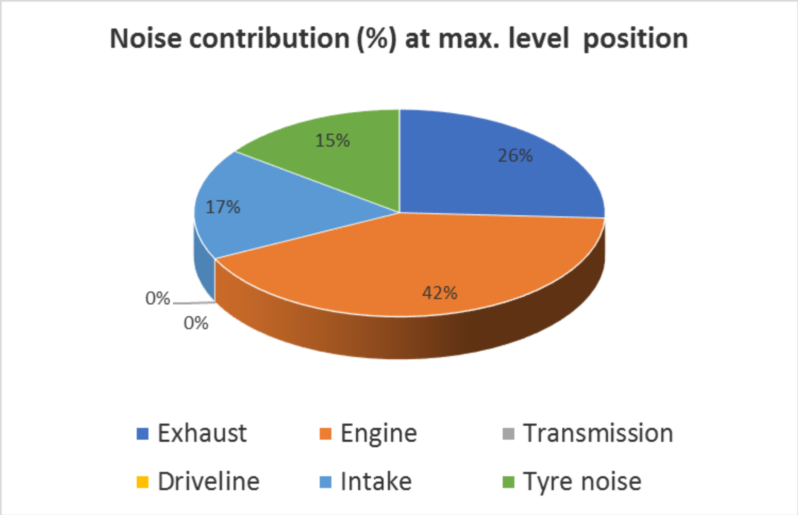


Figure A-43: Noise contribution of each system for L_{urban} of Sport TRAIL vehicle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

A.III.iv L5e-A vehicle. Unbodied Tricycle

As mentioned above, of an L5e-A vehicle, only WOT tests need to be measured. The results for this test in the 2nd gear are shown in Figure A-44, Figure A-45 and Figure A-46 with then also the final TA results shown in Figure A-47

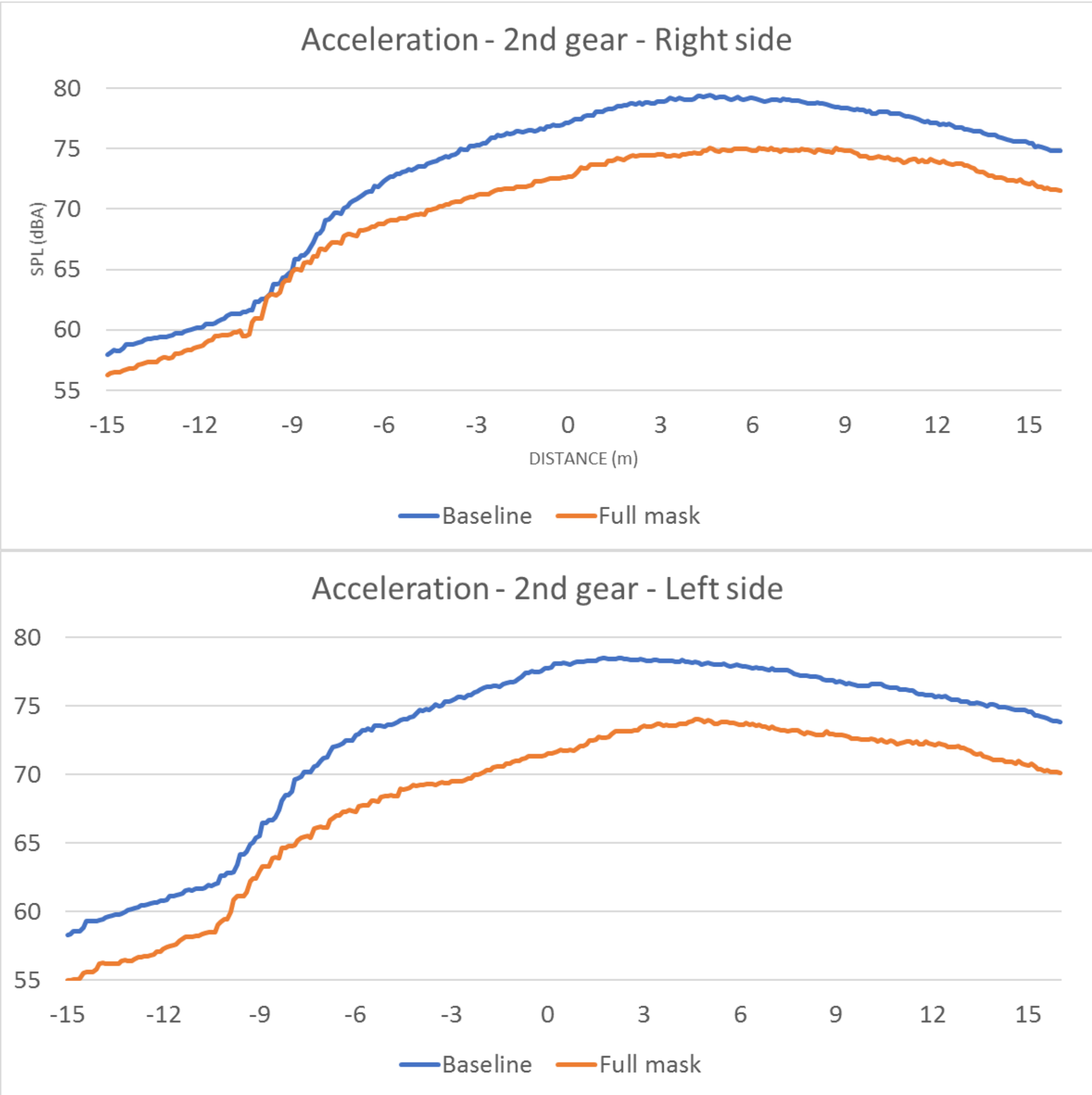


Figure A-44: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

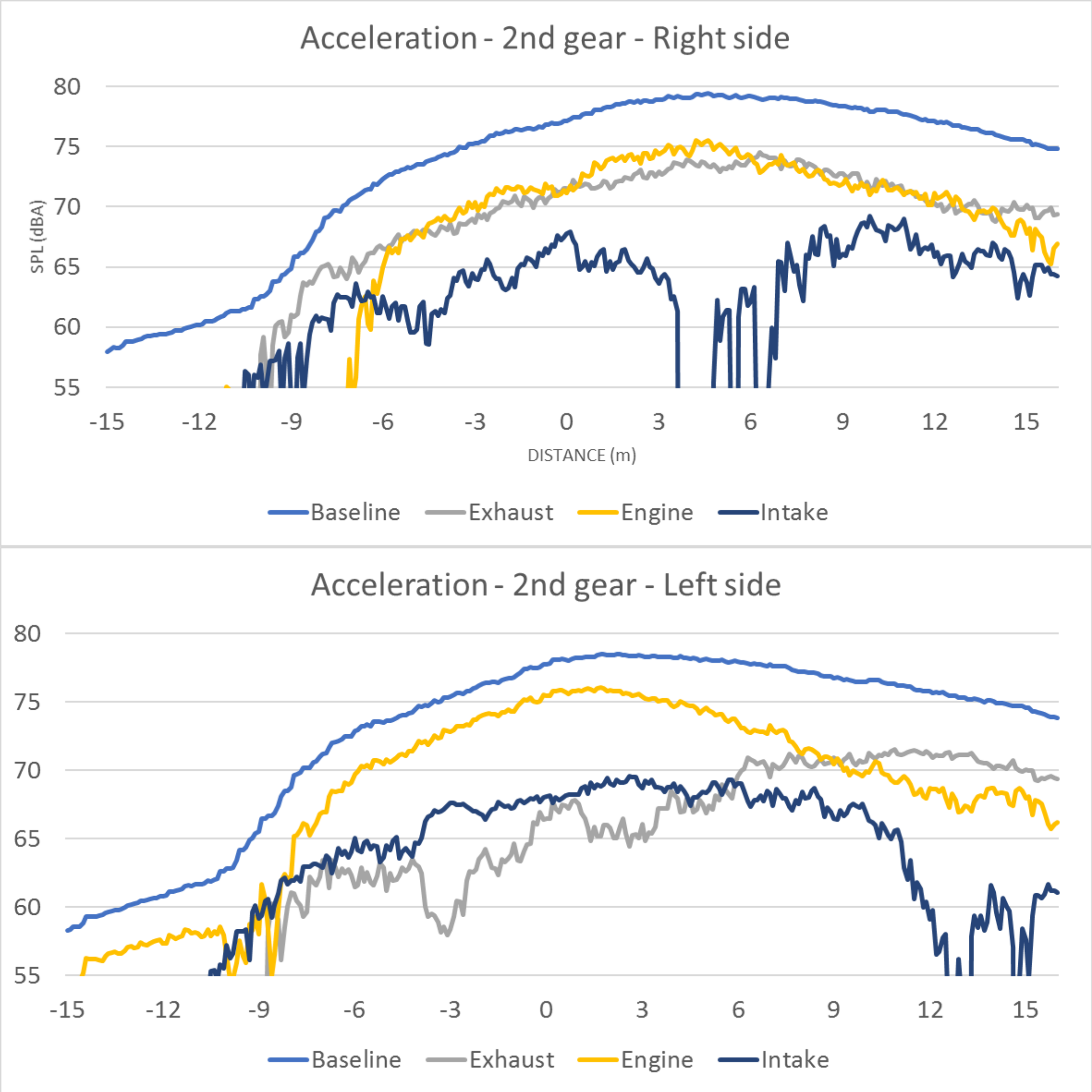


Figure A-45: Noise contribution of each system over distance

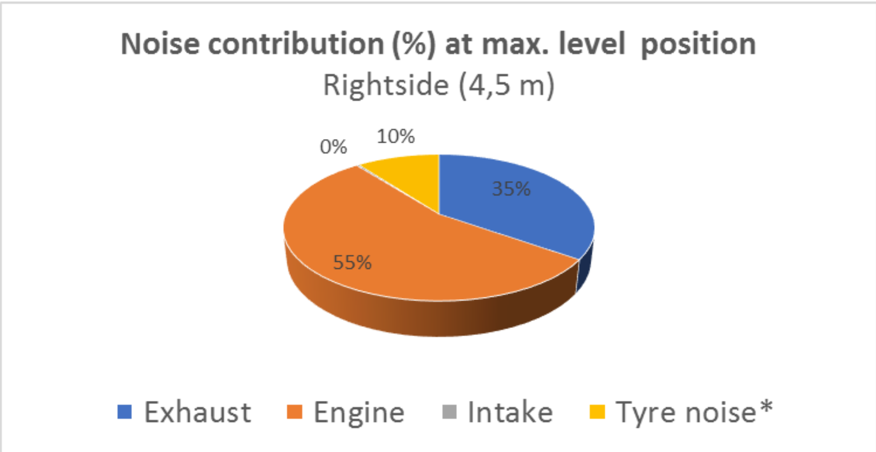


Figure A-46: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

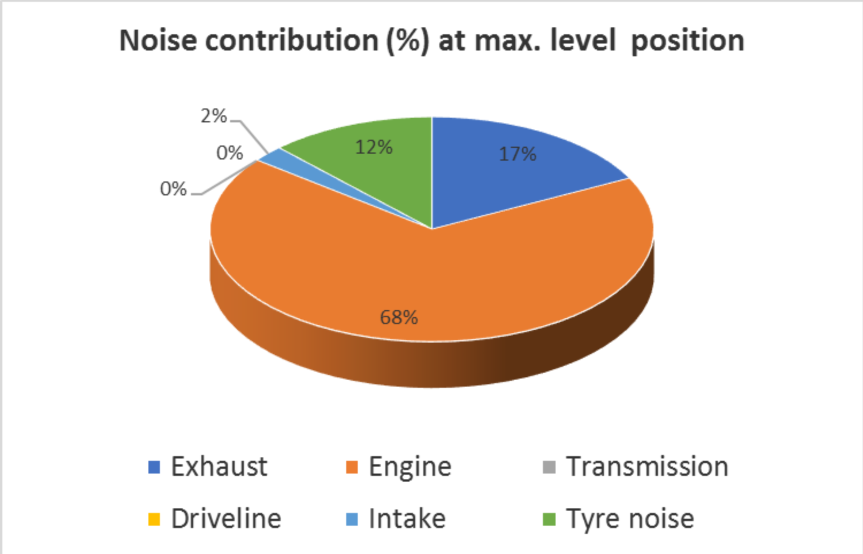


Figure A-47: Noise contribution of each system for L_{urban} of Unbodied Tricycle vehicle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

A.III.v L5e-B vehicle. Bodied Tricycle

In accordance with Chapter A.III.iv, WOT tests for an L5e-B vehicle are shown in Figure A-48, Figure A-49 and Figure A-50 and the corresponding TA value in Figure A-51.

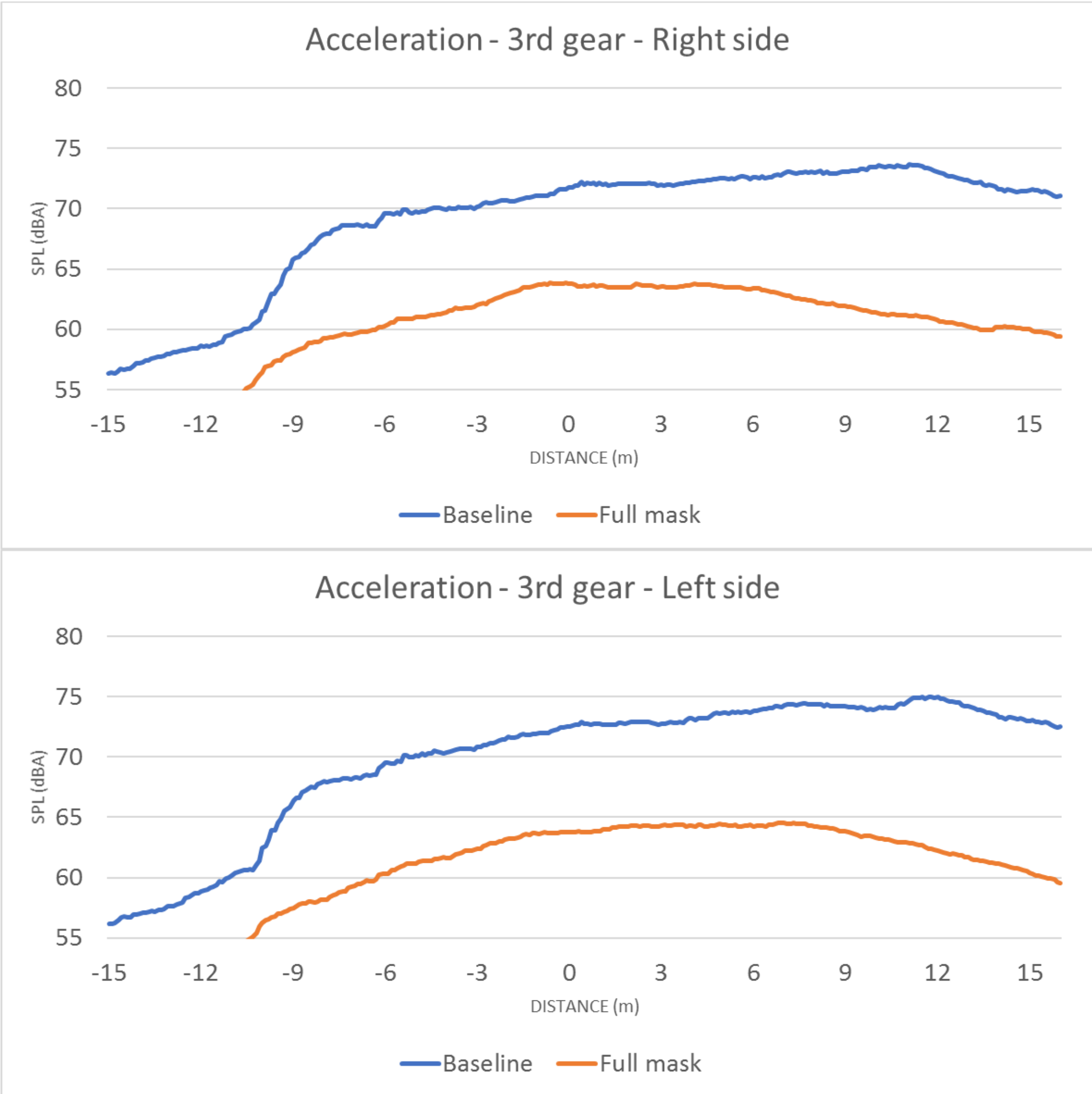


Figure A-48: Baseline versus full mask noise test

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

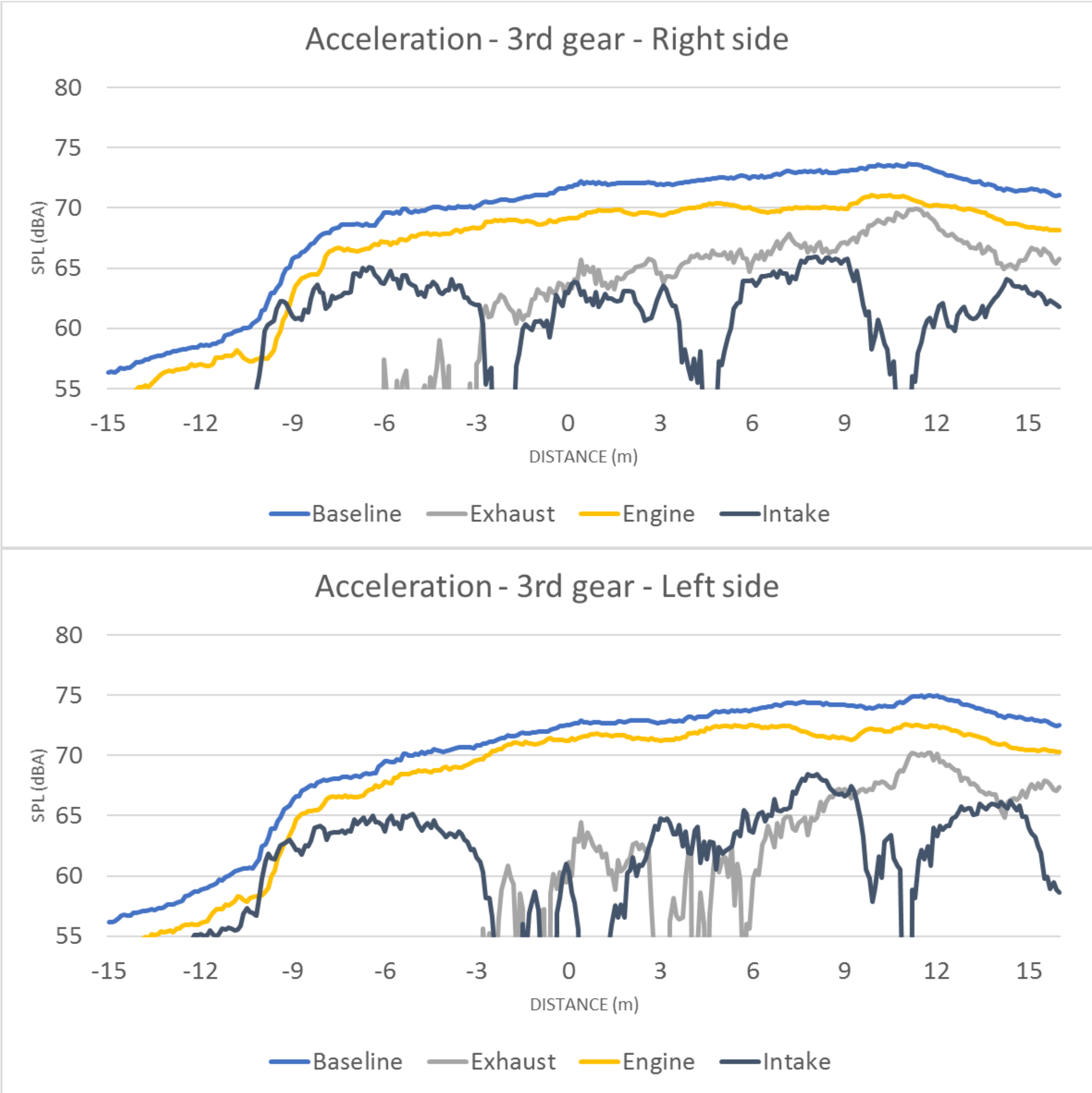


Figure A-49: Noise contribution of each system over distance

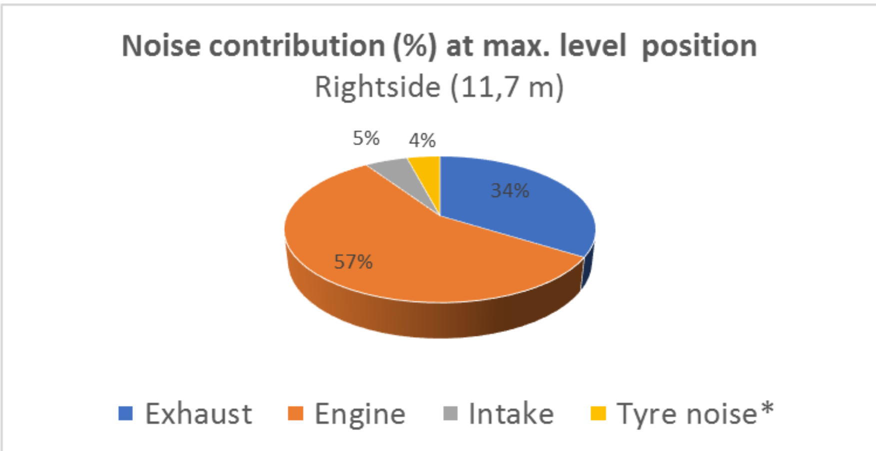


Figure A-50: Noise contribution of each system at maximum noise level vehicle position

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

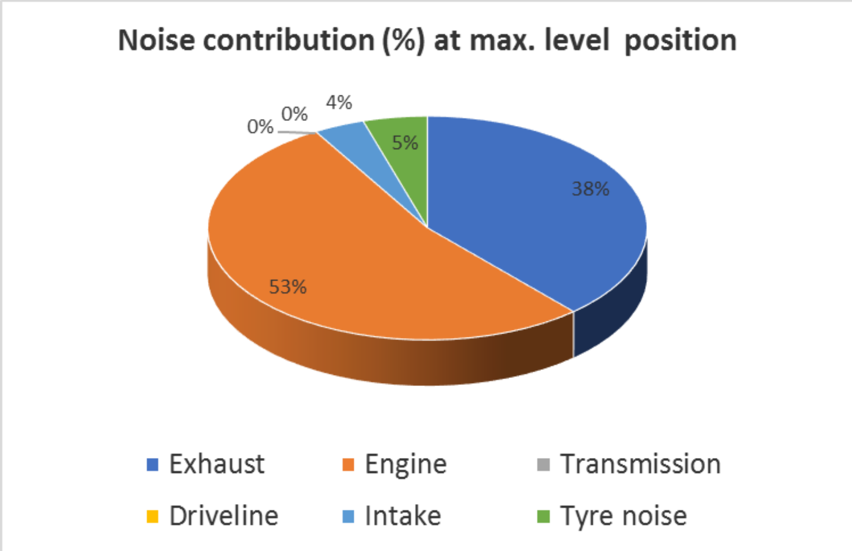


Figure A-51: Noise contribution of each system for L_{urban} of Bodied Tricycle vehicle

A.IV Conclusions

The analysis in the previous sections shows a global conclusion that can be generalised for all the vehicles studied herein. Table A-2 below summarizes the results of the NSR presented in the figures above. We note that for the measured L-vehicle sub-categories, the main noise contributions in the value of L_{urban} are due to the exhaust system and the engine. This suggests that for these L-vehicles the most effective way of reducing L_{urban} is by acting on these two vehicle components. This is shown in the last six columns of Table A-2 that show the brake down, in acoustic energy terms (expressed in %), of the L_{urban} values measured for the six L-vehicle sub-categories as the sum of the contributions from the exhaust system, the engine, the transmission, the driveline, the intake and the tyres **respectively.**

Table A-2: Summary of the Noise Source Ranking for the various L-vehicle subcategories*

			Lcrs (3rd)						Lcrs (4th)						Lwot (2nd)						Lwot (3rd)						Lwot (4th)						Lurban					
UN-Reg.	PMR	Name in this report *	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %	Lex %	Leng %	Lt %	Ld %	Li %	Lty* %
R.41.04	PMR > 50	*Sport Naked*	58	36	0	4	2	0													61	30	0	2	4	3							56	31	0	3	2	8
		Sport TRAIL							22	63	0	0	15	0													31	28	1	9	21	10	26	42	0	0	17	15
		Sport TRAIL_Auto	51	43	4	2	0	0	48	47	0	0	5	0							85	8	1	1	1	4	82	11	1	0	0	6	62	20	0	0	0	19
		Sport TRAIL_Manual	35	51	3	1	10	0	30	55	7	1	7	0							86	8	0	1	2	3	86	8	0	0	1	5	55	21	1	0	4	19
R.09.08	PMR ≤ 50	*Bodied Tricycle*																			34	57	N/A	N/A	5	4							38	53	0	0	4	5
	PMR > 50	*Unbodied Tricycle*													35	55	N/A	N/A	0	10													17	68	0	0	2	12

In Table A-2, the meaning of the symbols at the head of the columns are:

- L_{ex}: Acoustic energy contribution due to the exhaust system (%)
- L_{eng}: Acoustic energy contribution due to the engine (%)
- L_t: Acoustic energy contribution due to the transmission (%)
- L_d: Acoustic energy contribution due to the drive line (%)
- L_i : Acoustic energy contribution due to the intake (%)
- L_{ty} : Acoustic energy contribution due to the tyres (%)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

B Appendix B: Preliminary tests

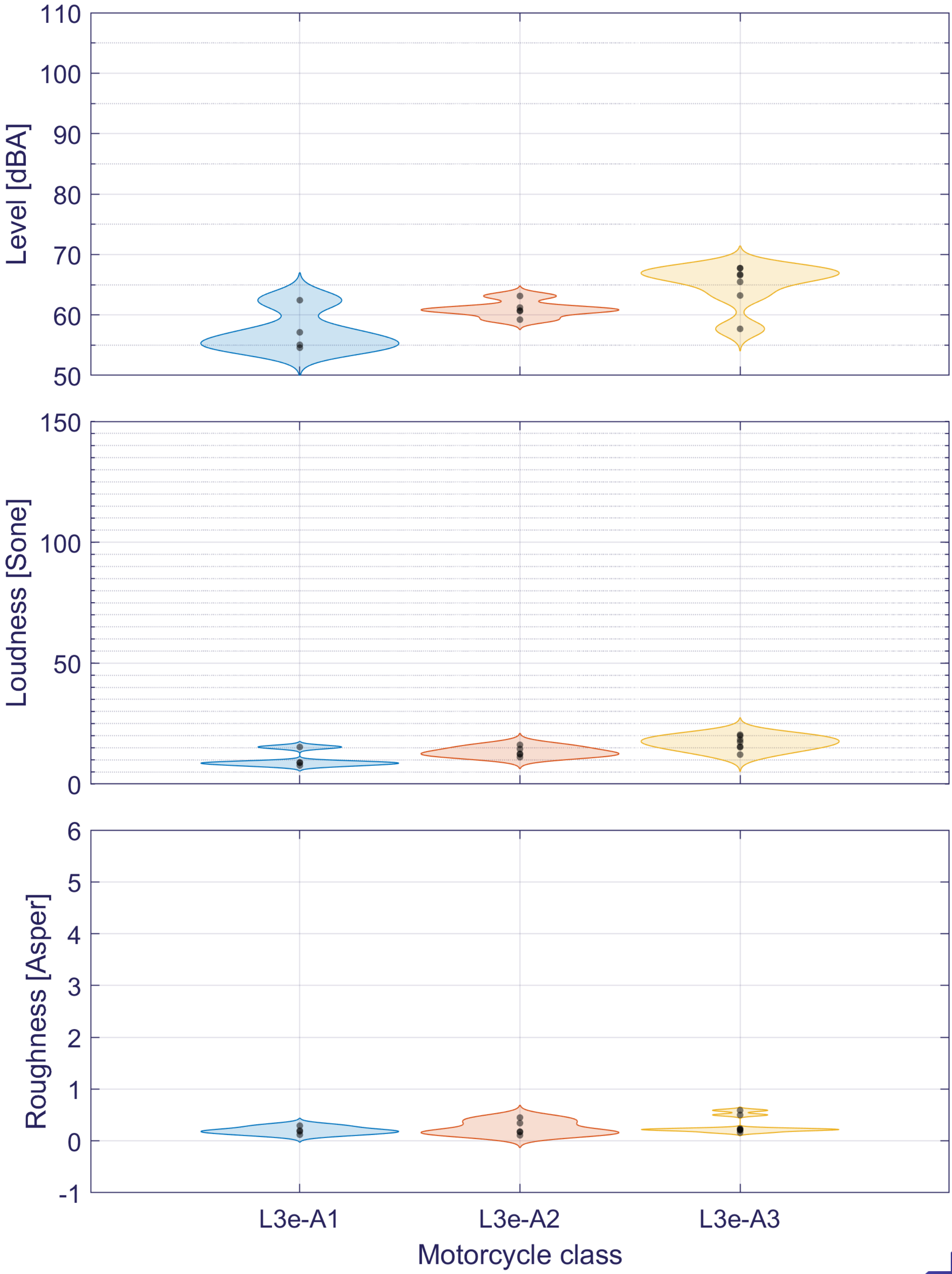


Figure B-52: Acoustic parameters vs. subcategory for stationary test, idle

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

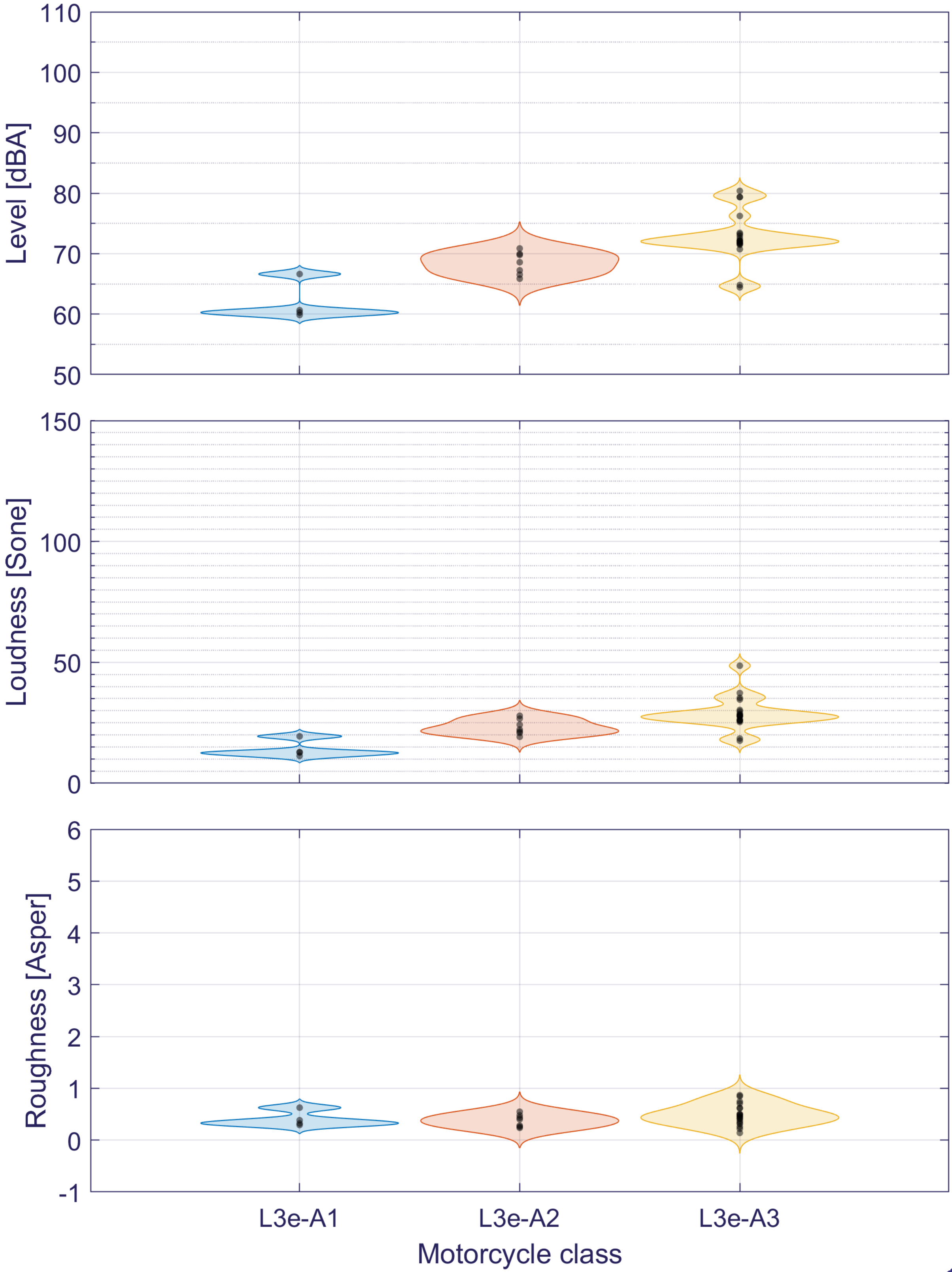


Figure B-53: Acoustic parameters vs. subcategory for stationary test, 3000 rpm

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777

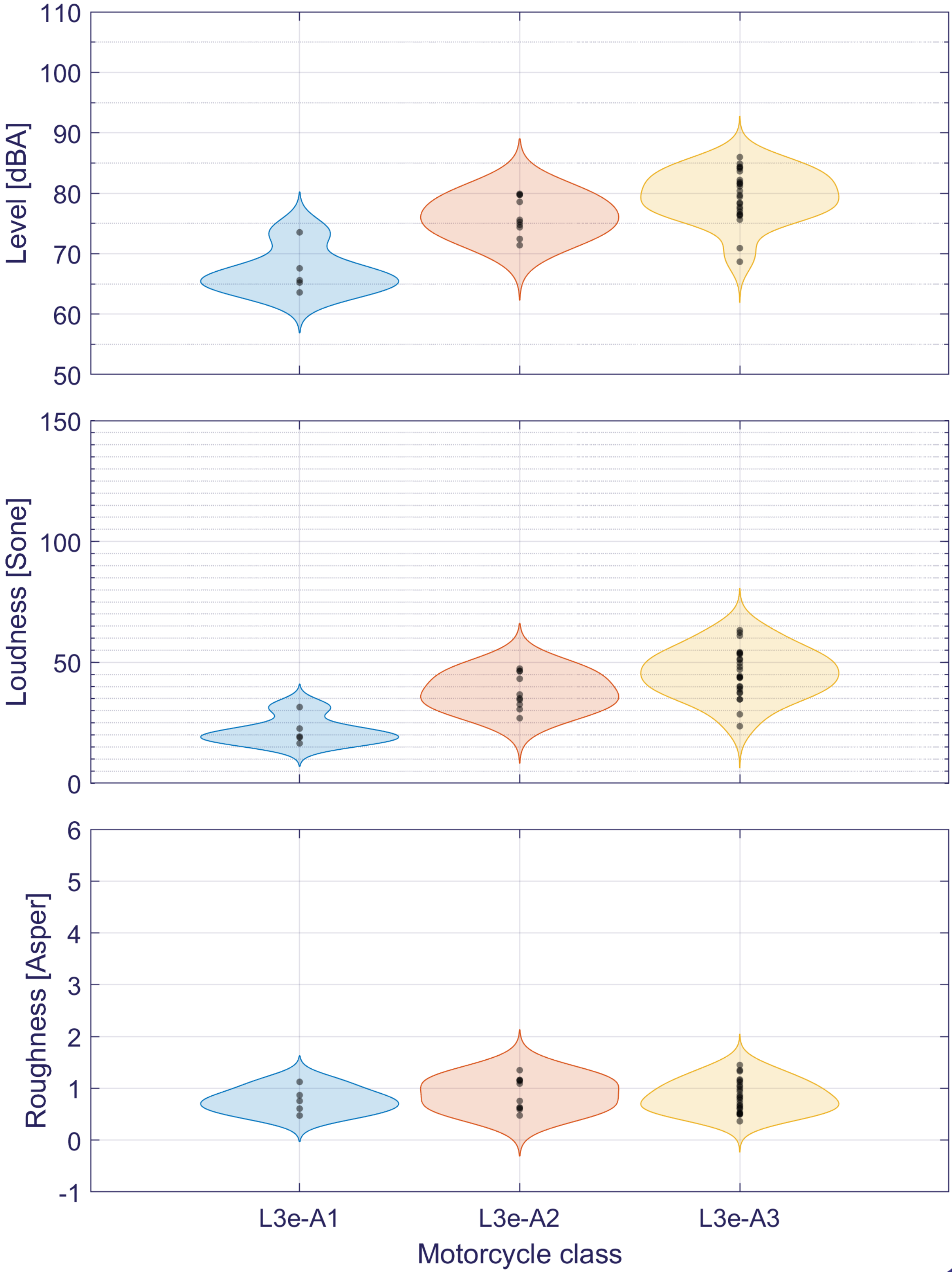


Figure B-54: Acoustic parameters vs. subcategory for stationary test, 5000 rpm

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101056777