Drive-by noise test
Measurement Uncertainty
(Application to Vehicle Categories M3/N3)

STATUS REPORT

Referring to ISO 362-1/R51.03
Prepared for UNECE GRBP IWG-MU

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Document under development, only for IWG-MU review.
Justification of the main impact quantities.

Justification by different approaches:

1. by **measurement** (or simulation) results from specific experiments, e.g. investigations on power train noise at indoor test bench
2. by classic **statistical methods** e.g. parameter studies and correlation analysis (ACEA Tyre study)
3. by **theoretical** derivations based on physical relations e.g. distance law (deviation from centered driving)
Definitions of reproducibility

- ISO 362-1, Scope: "... The specification are to reproduce the level of noise generated by the principal noise sources during normal driving in urban traffic, ... The method is designed to meet the requirements of simplicity as far as they are consistent with reproducibility of results under the operating conditions of the vehicle."

- ISO 362-1, Clause 8.5 definitions of
  - run-to-run – variations expected within the same test laboratory and with slight variations in ambient conditions found within a single test series, *(Should mean the average of 4 passages.)*
  - day-to-day – variations expected within the same test laboratory but with variation in ambient conditions and equipment properties that can normally be expected during the year,
  - site-to-site – variations between test laboratories where, apart from ambient conditions, equipment, staff, and road surface conditions are also different.

- Definition of vehicle-to-vehicle
  - New-to-new …
  - New-to-old respectively …
Assumed source distribution

Reference: GRB-51-inf20e

With balance between the sources, then one of the sources affect the total by 1/5.
## Justification of the main impact quantities.

<table>
<thead>
<tr>
<th>situation</th>
<th>Input Quantity (Uncertainty of vehicle sound emission)</th>
<th>Deviations of the meas. result (peak-peak)</th>
<th>Standard uncertainty</th>
<th>Status</th>
<th>Test</th>
<th>Statistical methods</th>
<th>Theoretical derivations</th>
<th>Same as M1,N1</th>
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</thead>
<tbody>
<tr>
<td>Run to run</td>
<td>Micro climate wind effect – head wind and tail wind</td>
<td>0</td>
<td>0.5</td>
<td>OK</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Deviation from centered driving</td>
<td>0.5</td>
<td>0.3</td>
<td>OK</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td></td>
<td>Speed at BB’ = Start of acceleration (+/-0.5 m), target vehicle speed (+/-5 km/h), (target engine speed (+/-2%)</td>
<td>0.1</td>
<td>OK</td>
<td></td>
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<td></td>
<td>Varying background noise (judge if correction is needed - otherwise no issue - delta &gt;15 dBA =&gt; MU&lt;0.1 dB) (delta &gt;10 dB =&gt; MU&lt;0.5 dB) (Compare also ISO 16254)</td>
<td>0.1</td>
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<td></td>
<td>Warming up routines between runs – operating temperature of engine and tyres (WOT)</td>
<td>0.4</td>
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<tr>
<td>Day to day</td>
<td>Acoustic effects of sound transmission in air</td>
<td>1-2</td>
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<td></td>
<td>Barometric pressure – air density effect on engine power (powertrain behavior based on R85)</td>
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<td>Ambient air temperature – effect on vehicle sound due to air density influence on engine power</td>
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<td>Ambient air temperature effect on ICE vehicles due to tyre noise between 5-40°C;</td>
<td>0.4</td>
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<td>Site to site</td>
<td>Altitude (effect on combustion (R85) 80ka-100) and related acoustics) (0-2000 m)</td>
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<td>Test Track Surface</td>
<td>1-3 - 1.5</td>
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<td>Microphone Class 1 IEC 61672</td>
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<td>Sound calibrator IEC 60942</td>
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<td>X</td>
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<td>Speed measuring equipment continuous at BB</td>
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<td>OK</td>
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<td>Acceleration, Continuous speed measuring equipment, determined between PP’-BB’</td>
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<td>V to Vehicle</td>
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<td>Test mass – variation as a consequence of the definition</td>
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<td>Tyre (Traction)</td>
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**Expanded uncertainty of 0.7 dB for a coverage of 95%. See "Statistical approach on the Measurement Uncertainty Run-to-Run.pdf".**

**Variation of ambient condition representing a year cycle.**

**Vehicle tested at new location with new staff and new equipment.**
A run is defined as complete test with 4 passages with short pause in-between during part of or one day, with minor variations in ambient conditions, but taking into account practical stochastic variations resulting from the test procedure, skill of the driver etc.

- Micro climate wind effect – head wind and tail wind
- Deviation from centered driving
- Speed at BB’ – Tolerances vehicle speed (+/-5 km/h) and engine speed (+/-2%) due to start of acceleration (+/-0,5 m),
- Warning up procedure – Variation on operating temperature of engine and tyres (WOT)
  (See ISO 362-1 NOTE concerning warming up procedure)
- Varying background noise (judge if correction is needed - otherwise no issue - delta >15 dBA => MU<<0,1 dB) (delta >10 dB => MU<0,5 dB) (Compare also ISO 16254)
Micro climate wind – effect from head wind and tail wind

References:
1. Theoretical derivation from manufacturer’s model

Observation:
The deviation in propulsion (tractive) force in case of head wind is less than 2% of the capacity of a normal N3.

Conclusion:
The effect of head/tail wind on the test cycle is neglectable.
Proposed uncertainty: N/A
Justification of the main impact quantities.

"DRIVER#1: deviation from centered driving" – justification by theoretical derivation

Invers square law:

\[ \Delta SPL = a \times \frac{10}{3} \times \log \left( \frac{7,5\text{m} + \Delta x}{7,5\text{m}} \right) \]

with:
- \( a \) coefficient for dB/distance doubling
- \( \Delta x \) deviation from center

\[ \Delta SPL = 5 \times \frac{10}{3} \times \log \left( \frac{7,5\text{m} + 0,5\text{m}}{7,5\text{m}} \right) = 0,5\text{dB} \]

Assumption for the calculation: 5dB/distance doubling (monopole source under semi-free field conditions) and 0,5m for the deviation from center.
Speed at BB’ – Tolerances: Start of acceleration (+/-0,5 m), target vehicle speed (+/-5 km/h), (target engine speed (+/-2%)

References:
1. Theoretical (TRN copied from M1/N1 justification)
2. Manufacturers report??

Observation:
The target conditions at BB’ shall be met with certain precision, determined by the rated speed and the available gear ratios (gearbox, rear axle, tyre dimension). The tolerance in starting position (driver dependent) allow for some variations of the achieved speed at BB’, however with the same propulsion power/torque, and thus dispersion in SPL of tires and powertrain.

Conclusion:
Further analysis of recordings would confirm the effect.

Proposed uncertainty: To be further analysed

Tyre Road Noise variation (+/-0,7 km/h or +/-2%)

\[ SPL_{TRN}(v) = a + b \times \log\left(\frac{v}{35 \text{ km/h}}\right) \]

with:
\[ a \quad \text{SPL}_{TRN} \text{ at } 35 \text{ km/h} \]
\[ b \quad \text{coefficient for speed dependency from R117} \]

\[ \Delta SPL_{TRN} = 30 \times \log\left(\frac{36}{34}\right) = 0,5 \text{ dB} \]

Engine speed variation drives PowerTrain Noise variation (+/-2%)

\[ SPL_{PRN}(n) = a + b \times \log\left(\frac{n}{87\% \text{ S}}\right) \]

with:
\[ a \quad \text{SPL}_{PRN} \text{ at } 87\% \text{ S}, \text{ where } S \text{ is the rated speed} \]
\[ b \quad \text{coefficient for speed dependency from XXX} \]

\[ \Delta SPL_{PRN} = \ldots \]
Justification of the main impact quantities.

„Varying background noise“ – justification by measurement

- Background shall be measured before and after a series of measurements. During a measurement it is not possible to determine the background noise.
- While the background noise might be low during its measurement, transient broadband events with up to 60 dB(A) may occur.
- Such events are typical for test centers with multiple tracks and events, but hardly noticeable during pass-by measurements.
- These transient noises will be counted as vehicle signal and can especially affect cruise measurement up to 1.0 dB to 1.2 dB higher values. In a 1/3rd share of the cruise test to Lurbau, the impact on Lurbau is estimated up to 0.4 dB.

ΔSPL\text{urban}: 0.0 – 0.4 dB
Engine conditioning – variation of temperature between runs due to warming-up routines (See note in ISO 362-1)

References:
1. Regulation 85
2. Manufacturers report??

Observation:
Assumed that the warm-up effect relate only to the intake/charge air temperature.

Conclusion:
Proposed coefficient: Under development
Tyre conditioning – variation of temperature between runs due to warming-up routines (See note in ISO 362-1)

References:
1. Reference TPMSTI-07-09
2. ISO/CD TS 13471-2, 2020-10-22
3. Manufacturers report??

Observation:
Assumed that the warm-up effect relate only to the tire compound/surface temperature.

Conclusion:
Proposed coefficient: Under development
Day-to-day

Day-to-day is defined as *within the same test laboratory but* with variation of ambient conditions that can be expected during a year:

- Barometric pressure (+/-80 hPa) (powertrain behavior due to air density)
- Ambient air temperature variation – +/-17.5°C (+5 to +40°C) – effect on vehicle sound due to engine power linked to air density;
- Ambient air temperature effect on **ICE vehicles** due to tyre noise between 5-40°C;
Acoustic effects of sound transmission in air - influence of air density on sound pressure level

References:
1. IWGMU-06-07

Observation:
According to acoustic theory.

Conclusion:
Reference temperature need to be defined, e.g. 20 deg. C.

Proposed coefficient:
Temperature: -0.03 dB/°C => Δp-p = 1.0 dB
Barometric pressure: 0.009 dB/hPa => Δp-p = 0.9 dB

Sound pressure level difference normalized to 15°C

Sound pressure level difference normalized to 1013 hPa.
Barometric pressure – air density effect on engine power

References:
1. UN Regulation 85, clause 5 (ISO1585, clause 6)
2. ČECH, TOMČÍK; Measurement of combustion engine power characteristics, correction factors

Conclusion:
The engine torque, and thus the Sound Pressure Level can vary as a result of the variation of the density of the air due to the variation in barometric pressure and ambient temperature.

However the combustion and the exhaust emission may also vary for other reasons due to ambient air conditions, and are as well under control of the ECU/ECM/PCM, why the effect is unambiguous. [2]

Uncertainty: Under development

\[ P_\alpha = P \alpha = P f_a f_m \left( \frac{99}{P_s} \right)^{0.7} \left( \frac{T}{298} \right)^{1.5} \]

- \( P_\alpha \) is the corrected power (under reference atmospheric conditions)
- \( \alpha \) is the correction factor and equals \( f_a f_m \)
- \( P \) is the measured power
- \( f_a \) is the atmospheric factor
- \( f_m \) is the characteristic parameter for each type of engine and adjustment
  - \( f_m = 1.2 \) for fuel flow, \( q_c \) higher than 40 mg/(l.cycle)

For diesel engines: 283 K ≤ T ≤ 313 K, 80 kPa ≤ Ps ≤ 110 kPa

The correction factor is valid for WOT and \( \alpha \) must be within 0.9 < \( \alpha \) < 1.1.

Ref. UN Regulation 85
Ambient air temperature variation – effect on vehicle sound due to engine power dependent to air density

References:
1. UN Regulation 85
2. ISO 15550 (Internal combustion engines — Determination and method for the measurement of engine power …)
3. ČECH, TOMČÍK; Measurement of combustion engine power characteristics, correction factors

Observation:
Day-to-day variation over a year: Temperature = +/-17.5°C (+5 to +40°C)

Conclusion:
However the combustion and the exhaust emission may also vary for other reasons due to ambient air conditions, and are as well under control of the ECU/ECM/PCM, why the effect is unambiguous [3].

Proposed coefficient: To be further elaborated

\[ P_0 = P \alpha = P f_a f_m \left( \frac{99}{P_S} \right)^{0.7} \left( \frac{T}{298} \right)^{1.5} \]

- \( P_0 \) is the corrected power (under reference atmospheric conditions
- \( \alpha \) is the correction factor and equals \( f_a f_m \)
- \( P \) is the measured power
- \( f_a \) is the atmospheric factor
- \( f_m \) is the characteristic parameter for each type of engine and adjustment
  - \( f_m = 1.2 \) for fuel flow, \( q_c \) higher than 40 mg/(l.cycles)

For diesel engines: 283 K \( \leq T \leq 313 \) K, 80 kPa \( \leq P_s \leq 110 \) kPa

The correction factor is valid for WOT and \( \alpha \) must be within 0.9 \( < \alpha < 1.1 \).

Ref. UN Regulation 85
Tire – Temperature correction

Reference:
1. Bühlman, van Blockland [LINK]
2. ISO/CD TS 13471-2, 2020-10-22

Observation:
Reference 1 and 2 suggest correction factor -0.06 to -0.05 dB/°C air temperature.

Conclusion:
Reference temperature need to be defined, e.g. 20 deg. C.
Proposed coefficient for tire noise: -0.06 dB/°C air temperature
Day-to-day includes +5 to +40 °C)
Day-to-day (ICE): 1/5 x -0.06 x 35 °C = 0.4 dB p-p
Day-to-day (EV): -0.06 x 35 °C = -2 dB p-p
Site-to-site

Site-to-site is defined as variations between test laboratories where, apart from ambient conditions, equipment, staff, and road surface conditions are also different

- Altitude (effect on combustion (R85) 80ka-100) and related acoustics - general approach) (0-2000 m)
- Test Track Surface
- Equipment:
  - Microphone Class 1 IEC 61672
  - Sound calibrator IEC 60942
  - Speed measuring equipment continuous at BB
  - Acceleration, Continuous speed measuring equipment, determined between PP'-BB'
- Staff
Variation barometric pressure due to altitude (0-2000m)

References:
1. UN Regulation 85
2. ISO 15550 (Internal combustion engines — Determination and method for the measurement of engine power — General requirements)
3. ISO 2534 (Road vehicles – Gross power)
4. ISO 20762:2018 (… power for propulsion of HEV)
5. Official paper/report
6. Manufacturers report??

Observation:

Conclusion:

Proposed coefficient:

➢ To be further developed
Test track surface

References:
1. ISO 10844
2. VDA study on M1/C1
3. Official source regarding HCV
4. Manufacturers report??

Observation:
ACEA members (N3): p-p 1,5 dBA
JAMA members (N2): p-p 1,3 dBA

Conclusion:
Proposed coefficient: To be further developed
Justification of the main impact quantities.

„Microphone Class 1 IEC 61672“ – justification by measurement (calibration)

The deviation from reference of today used microphones is normally in a range of +/- 0.5 dB. The maximum error during measurement by using two different sound level meters can be up to 1 dB. The frequency range of interest of pass by test is up to 5000 Hz (example in the left diagram, 99% of the OAL @5000Hz)
Justification of the main impact quantities.

"Sound calibrator IEC 60942" – justification by measurement (calibration)

The maximum allowed deviation determined by DIN EN 60942:2018 “Electroacoustics. Sound calibrators” is +/- 0.25 dB. The maximum error during measurement by using two different sound calibrators can be up to 0.5 dB.

<table>
<thead>
<tr>
<th>Set value</th>
<th>Measured value</th>
<th>Deviation from set value</th>
<th>Level fluctuations</th>
<th>Allowed deviation</th>
<th>Confirmation</th>
</tr>
</thead>
<tbody>
<tr>
<td>94.00</td>
<td>94.03</td>
<td>0.03</td>
<td>&lt; 0.05</td>
<td>0.25</td>
<td>pass</td>
</tr>
<tr>
<td>114.00</td>
<td>114.02</td>
<td>0.02</td>
<td>&lt; 0.05</td>
<td>0.25</td>
<td>pass</td>
</tr>
</tbody>
</table>

\[ \Delta \text{SPL}_{\text{urban}} = 0.5 \, \text{dB} \]

Excerpt from a calibration report
Justification of the main impact quantities.

Same approach as „DRIVER#3: speed variations of +/- 1km/h“

Precision of today’s speed measuring systems: approx.:

$\pm 0,2 \text{ km/h}$

$\Delta SPL_{TRN} = 30 \times \log \left( \frac{50,2 \text{ km/h}}{49,8 \text{ km/h}} \right) = 0,1 \text{ dB}$

$\Delta SPL_{urban}: 0,1 \text{ dB}$

See „DRIVER#3: speed variations of +/- 1km/h“
Acceleration, Continuous speed measuring equipment, determined between PP'-BB'

...
Vehicle-to-vehicle is defined as variations between test vehicles of the same kind where, apart from laboratories, ambient conditions, equipment, staff, and road surface conditions are also different.

- Tolerances in manufacturing (COP)
- Type/Family definition (COP)
- Mileage (Market Surveillance)
- Service and maintenance (Market Surveillance)
- Vehicle bodywork and equipment (Market Surveillance)
Tyre – generic dispersion (combined effect)

References:
1. Informal Document GRB-51-20 (51st GRB, 15-17 February 2010)
2. JAMA: Drive-by noise test with 8 different tires and one worn tire, corrected to 15°C.

Observation:
• Normal tires variations over four passage is typically within 1 dBA. (2)
• Normal tires of different brand/model vary +/-3 dB (95% coverage interval) (3)

Conclusion:
• R51.03 recommends tests with normal tires, with rib pattern.
• (The limit values where defined under the circumstances using normal tires.) (May need further explanation in a "reference document" at GRBP.)

Uncertainty std deviation: 0,5 dB => Δp-p = 1,7 dB

Generic dispersion/uncertainty on total vehicle related to tyres:
• Temperature
• Rubber hardness
• Inflation pressure
• Tyre tread depth
• Torque variation
• Speed variation
• Tire brand/design

Deviation of drive-by noise for 8 different 19,5" C3 tires (Tire sample #2 as reference)

Average Drive-by level: 79,3 dBA
Δp-p: 1,7 dB
Standard deviation: 0,5 dB
95% coverage: 1,0 dB
Test mass – variation as a consequence of the definition

References:
1. UN Regulation 51.03
2. Manufacturers report??

Observation:
The test mass can deviate from vehicle to vehicle as a consequence of rated power and rear axle capacity.

Conclusion:
The resulting vehicle/engine speeds at BB’ will vary within the allowed target speed window, however cause potential SPL dispersion.

Proposed coefficient:
EV battery state of charge

References:
1. Official source
2. Manufacturers report??

Observation:

Conclusion:

Proposed coefficient: To be further developed
Background documents
Tyre – torque influence

References:
1. GRBP Session 51
2. Manufacturers report??

Observation:

Conclusion:
(tyre effect) 0,12 dB/kNm at drive axle
(vehicle effect) 0,12 x 1/5 = 0,024 dB/kNm
Tyre – normal vs traction tires

References:
1. GRB-51-20 (51st GRB, 15-17 February 2010)
2. GRB-53-17 (53rd GRB, 15-17 February 2011)

Observation:
Ref. 1 & 2 Tyres with block tread pattern on the drive-axle can vary stochastically, due to the tonality of such tyres, with consequences to run-to-run uncertainty. Ref. 3 explain for C1 tires: “The model shows a gradient of approximately -0.05 dBA/°F. Regarding the influence of vehicle speed, the test showed that for the surface studied tire/pavement noise increases an average of 2.5 dBA for every 10 mph of increased speed.”

Conclusion: R51.03 recomends tests with normal tires, with rib pattern.

Proposed coefficient for tire contribution:
- C3 Rib tires (Ref.): 0,4 dB/(km/h)
- C3 Lug tires (Ref. 2): 0,6 dB/(km/h)
- C1 tires (Ref. 3): 0,25 dB/mph