Experimental approach for evaluating uncertainties associated to stationary vehicle noise according to ISO 5725

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Introduction

Determination of uncertainties related to the standard ISO 5130 (Measurements of sound pressure level emitted by stationary road vehicles near the exhaust systems)

Analysis based on the use of the ISO 5725 approach

Uncertainties estimated on different conditions :

- run-to-run (with several operators)
- day-to-day (Atmospheric condition)
- site-to-site (surface condition)
- vehicle to vehicle

Context

European regulation (directive 1999/101/CE and the regulation 51 rev02) presents two acoustical tests :

- A dynamic test which is subject to limit
- A stationary test

The stationary test is also used by national authorities to control vehicle in use:

- Spot test by police
- Periodical test by technical inspection facilities

The stationary test is based on the international standard ISO 5130

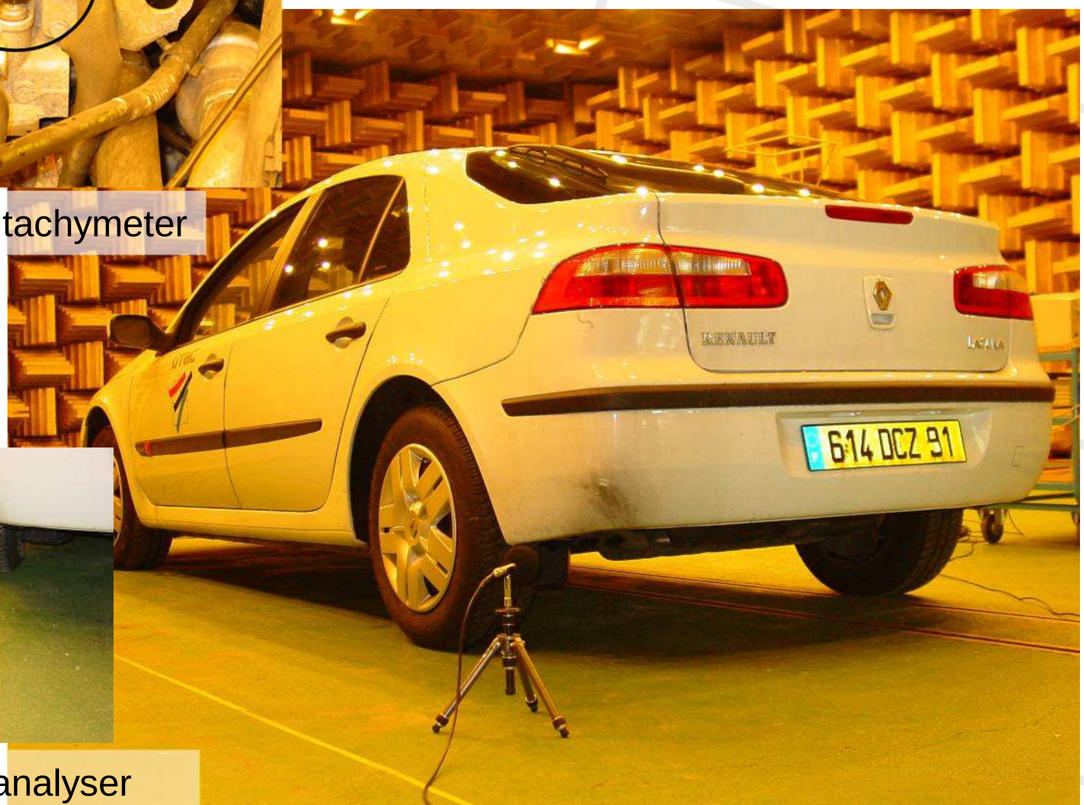
French regulation allows a 5 dB divergence between type approval and in use test values

Measuring procedure

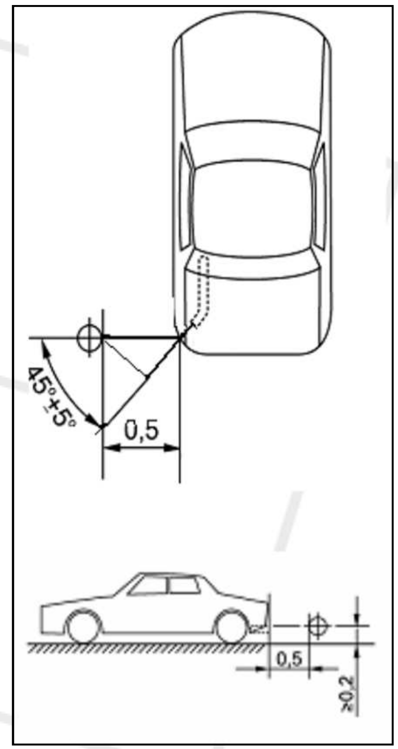
Reference value (type approval test)

80 dB(A) at 3000 rpm

Vibration tachymeter



Microphone with analyser
or sound meter (IEC 60651)



Microphone position

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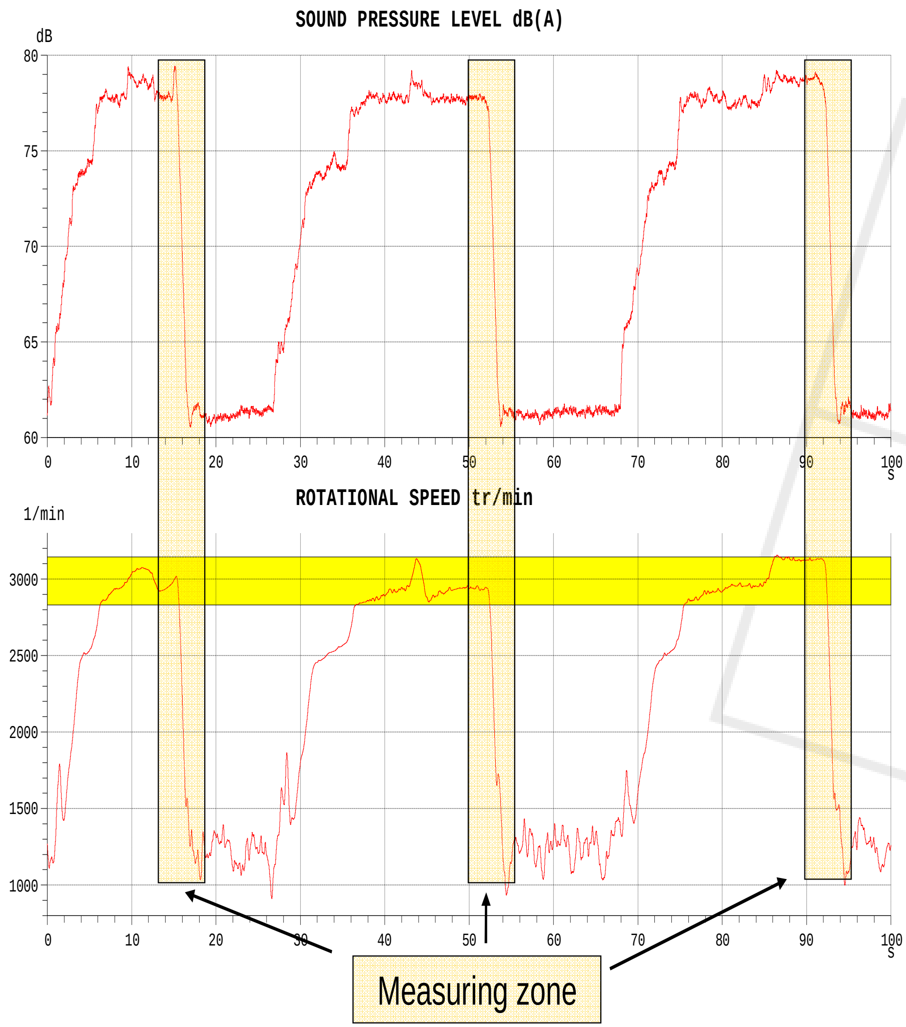
Measuring procedure



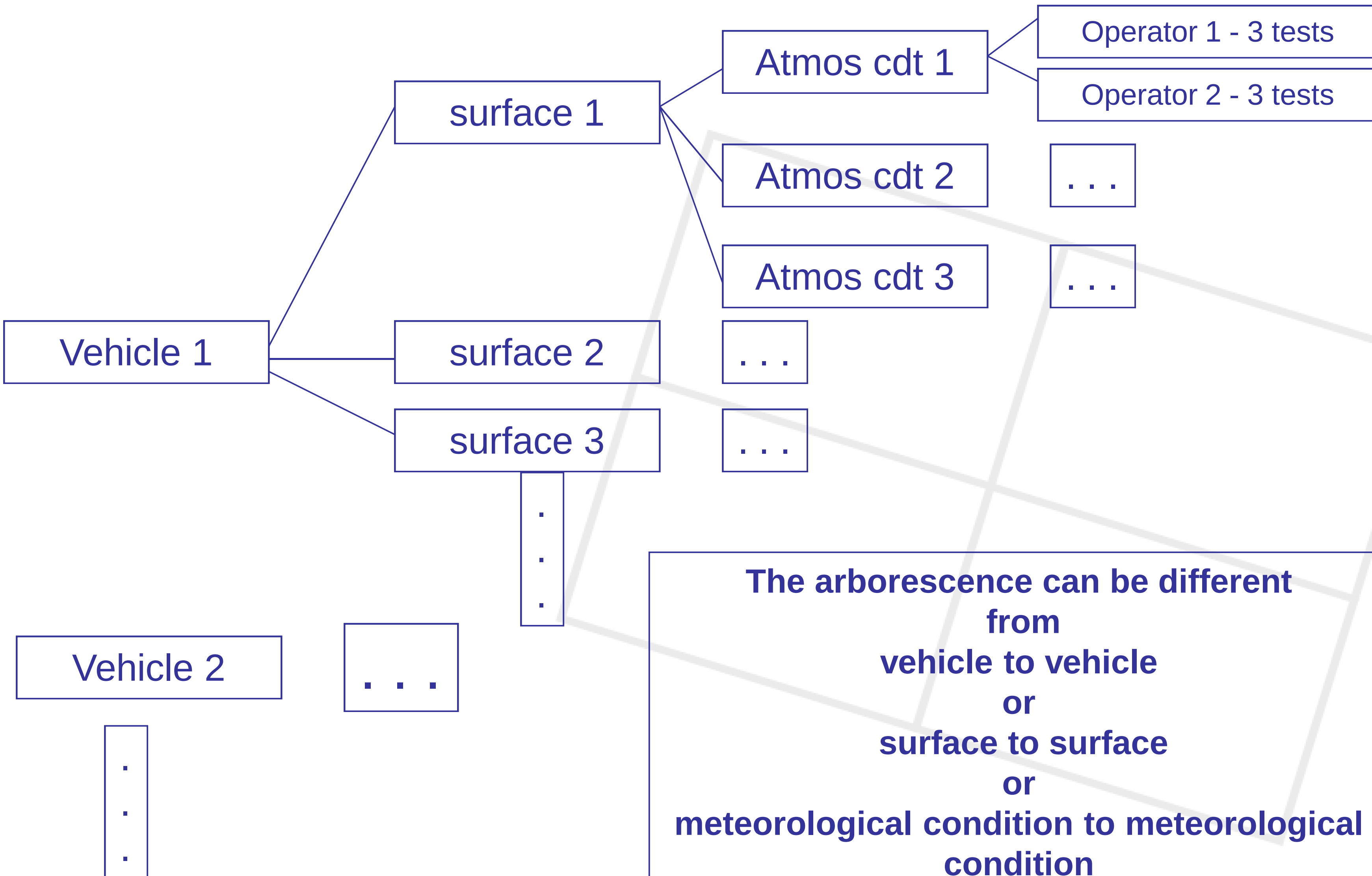
<u>Conditions of engine operation :</u>

- *Engine speed stabilized at a reference value*
- *Throttle rapidly returned to the idling position.*

<u>Conditions of acoustical measurement :</u>

- *Sound level measured over this operating period*
- *Maximum sound-level meter reacting being taken as the test result (dB(A) – FAST)*
- *Three measurements*
- *Final result is the mean these 3 values*

Structure of the study



The arborescence can be different from vehicle to vehicle or surface to surface or meteorological condition to meteorological condition

- Definition
- GUM approach
- ISO 5725 approach

Definition (1)

- Estimation of the range which contains the **true value** (VIM 1984)

- Parameter, associated with the result of a measurement that characterizes the **dispersion** of the value that could reasonably be attributed to the measurement (VIM 3.9 1993)

Definition (3)

- Coverage interval : GUM 2.3.5 "interval that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

$$\left[y - ku_c(y), y + ku_c(y)\right]$$

Two approaches

- "GUM approach"
- "ISO 5725 approach“

These two approaches are complementary and are not exclusive. In both cases variances estimates are calculated. Furthermore it’s possible to use the two approaches together.

GUM approach (1)

- The model $$Y = f(X_1, X_2, ..., X_n)$$
- Y is determined from n other quantities
- Representation of a process of measurement
- First-order Taylor series approximation

$$\sigma_Y^{\ 2} = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial X_i} \right)^2 \sigma_{X_i}^{\ 2} + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial X_i} \frac{\partial f}{\partial X_j} \sigma_{x_i} \sigma_{x_j} \rho_{ij}$$

GUM approach (2)

- It is necessary to find the functional relationship f
- Not exhaustive
- suited for metrology/calibration rather than tests laboratories
- Ascending approach

ISO 5725 approach (1)

- Accuracy of measurement method.
  - Precision
  - Trueness

ISO 5725 approach (2)

- Precision : the closeness of agreement between independent test results obtained under stipulated conditions.
  - Repeatability : precision under repeatability conditions, expressed by a standard deviation.
  - Reproducibility : precision under reproducibility conditions expressed by a standard deviation.

- Trueness: the closeness of agreement between the average value from a large series of test results and an accepted reference value.
  - The measure of trueness is expressed in terms of bias

ISO 5725 approach (4)

- Model of analysis of variance:

$$Y_{ij} = m + L_i + \varepsilon_{ij}$$

where

Y_{ij} — j^{th} test result from laboratory i,

m — general mean,

L_i — laboratory effect i, i=1 to p, with variance σ_L^2

ε_{ij} — residue on the j^{th} result from laboratory i, j = 1 to n, σ_ε^2

ISO 5725 approach (5)

Effects	Sum of square	Degree of freedom	Mean square	Expected
Laboratory	$\sum_{i=1}^{i=p}\sum_{j=1}^{j=n}(\bar{y}_i-\bar{y})^2=B$	$p-1$	$\sum_{i=1}^{i=p}\sum_{j=1}^{j=n}(\bar{y}_i-\bar{y})^2 \big/ p-1$	$n\sigma_L^2+\sigma_\varepsilon^2$
Residual	$\sum_{i=1}^{i=p}\sum_{j=1}^{j=n}(y_{i,j}-\bar{y}_i)^2=W$	$np-p$	$\sum_{i=1}^{i=p}\sum_{j=1}^{j=n}(y_{i,j}-\bar{y}_i)^2 \big/ np-p$	σ_ε^2
Total	$\sum_{i=1}^{i=p}\sum_{j=1}^{j=n}(y_{i,j}-\bar{y})^2=T$	$np-1$		

$$T=B+W$$

ISO 5725 approach (6)

- Precision evaluation :
  - Repeatability standard deviation : $\sigma_r = \sigma_\varepsilon$
  - Reproducibility standard deviation : $\sigma_R = \sqrt{\sigma_\varepsilon^{\,2} + \sigma_L^{\,2}}$

⇨ Variance components estimation

$$s_r = s_\varepsilon \qquad s_R = \sqrt{s_\varepsilon^{\,2} + s_L^{\,2}}$$

- Trueness evaluation :
  - $\delta = m - \mu$ where μ is the reference value when it exists.
  - Estimated by : $\hat{\delta} = \hat{m} - \mu$

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ISO 5725 approach (7)

- Our model is more complicated

$$y_{ijklm} = \mu + V_i + AC_j(V_i) + TS_k(AC_j(V_i)) + O_l(TS_k(AC_j(V_i))) + \varepsilon_{ijklm}$$

y_{ijklm} represents the value of the studied characteristic of the mth repetition for the lth operator of kth test surface of jth atmospheric condition of ith vehicle,

μ

V_i the effect due to ith vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_V^2

$AC_j(V_i)$ effect due to the jth atmospheric condition of ith vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_{AC}^2

$TS_k(AC_j(V_i))$ σ_{TS}^2

$O_l(TS_k(AC_j(V_i)))$ σ_O^2

ε_{ijklm} residue of the mth repetition for the lth operator of kth test surface jth atmospheric condition of ith vehicle,with mean 0 and variance σ_ε^2

ISO 5725 approach (8)

- Estimation of the variance components

$$s_r = s_\varepsilon$$

$$s_{fi(1)} = \sqrt{s_r^2 + s_o^2}$$

$$s_{fi(2)} = \sqrt{s_r^2 + s_O^2 + s_{TS}^2}$$

$$s_{fi(3)} = \sqrt{s_r^2 + s_O^2 + s_{TS}^2 + s_{AC}^2}$$

$$s_R = \sqrt{s_r^2 + s_O^2 + s_{TS}^2 + s_{AC}^2 + s_V^2}$$

ISO 5725 approach (9)

- the combined standard uncertainty $u_c(y)$ comes from the values of precision:
- in conditions of repeatability, $u_c(y) = s_r$
- in conditions of intermediate precision, $u_c(y) = s_{fi}$
- in conditions of reproducibility $u_c(y) = s_R$
- the expanded uncertainty. $U = k \times u_c(y)$

ISO 5725 approach (10)

studied characteristic	*Stationary Noise (in dB(A))*
Standard deviation of repeatability, with constant vehicle, atmospheric condition, test surface and operator	0.3
Limit of repeatability, with constant vehicle, atmospheric condition, test surface and operator	0.8
Expanded uncertainty in conditions of repeatability, with constant vehicle, atmospheric condition, test surface and operator	**0.6**
Intermediate standard deviation of precision, with constant vehicle, atmospheric condition and test surface, whatever the operator	0.4
Intermediate limit of precision, with constant vehicle, atmospheric condition and test surface, whatever the operator	1.1
Expanded uncertainty in conditions of intermediate precision, with constant vehicle, atmospheric condition and test surfaces, whatever the operator	**0.8**
Intermediate standard deviation of precision, with constant vehicle and atmospheric condition , whatever the test surface and the operator	0.5
Intermediate limit of precision, with constant vehicle and atmospheric condition, whatever the test surface and the operator	1.5
Expanded uncertainty in conditions of intermediate precision, with constant vehicle and condition atmospheric, whatever the test surface and the operator	**1.1**
Intermediate standard deviation of precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator	0.5
Intermediate limit of precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator	1.5
Expanded uncertainty in conditions of intermediate precision, with constant vehicle, whatever the atmospheric condition, the test surface and the operator	**1.1**
Standard deviation of reproducibility, whatever the vehicle, the atmospheric condition, the test surface and the operator	1.0
Limit of reproducibility, whatever the vehicle, the atmospheric condition, the test surface and the operator	2.8
Expanded uncertainty in conditions of reproducibility, whatever the vehicle, atmospheric condition, the test surface and the operator	**2.0**

ISO 5725 approach (11)

- Better suited for test laboratories
  - use of the data which are available
  - use of the precision value issued from interlaboratories test
- Descending approach

Thank you for attention

Standardization works

- ISO/TC 69/SC 6
  - WG 1 Accuracy of measurement methods and results
  - WG 5 Limits of determination
  - WG 7 Statistical methods to support measurement uncertainty evaluation.
- JCGM/WG1
  - WG1 Measurement uncertainty (VIM GUM)

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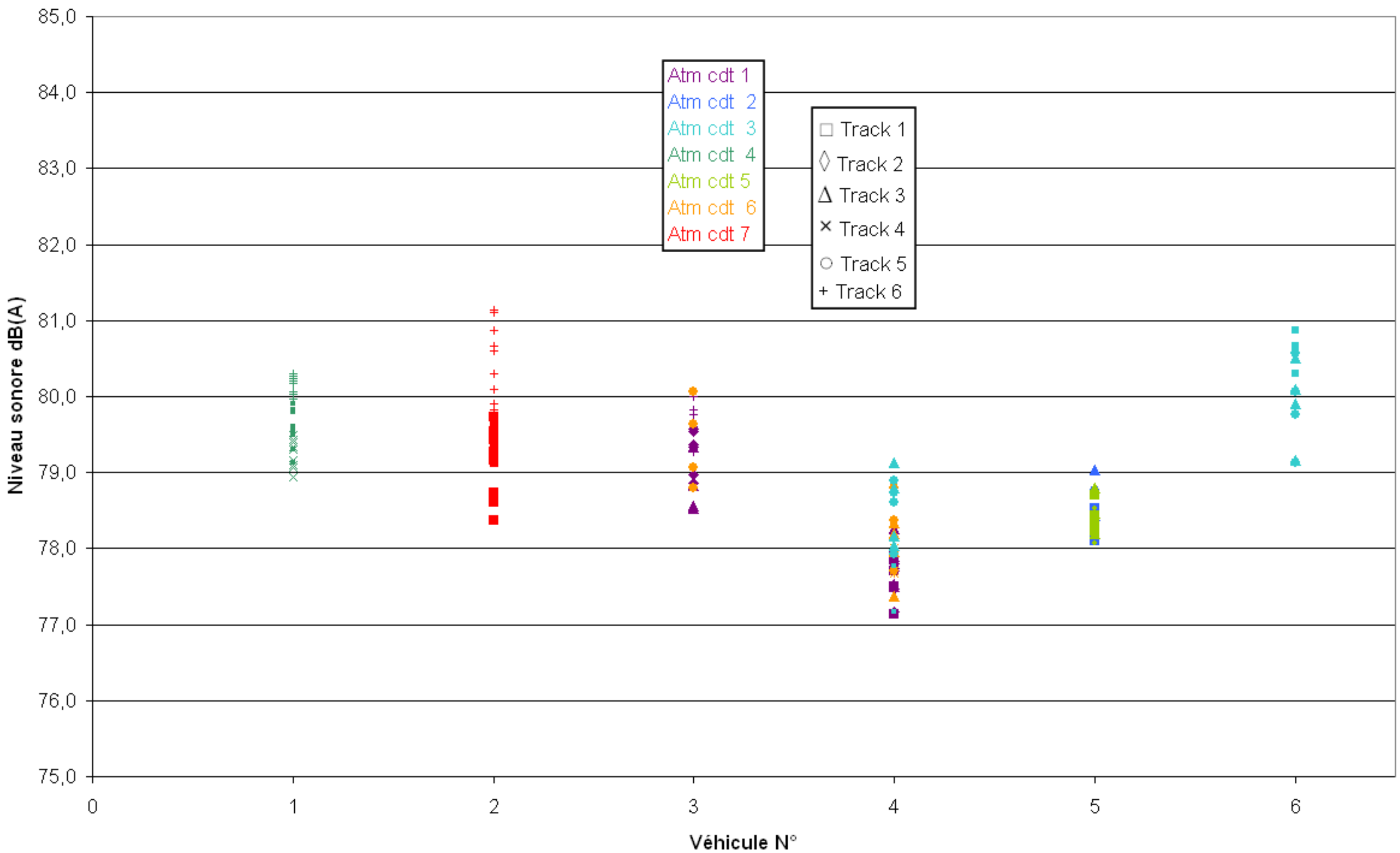
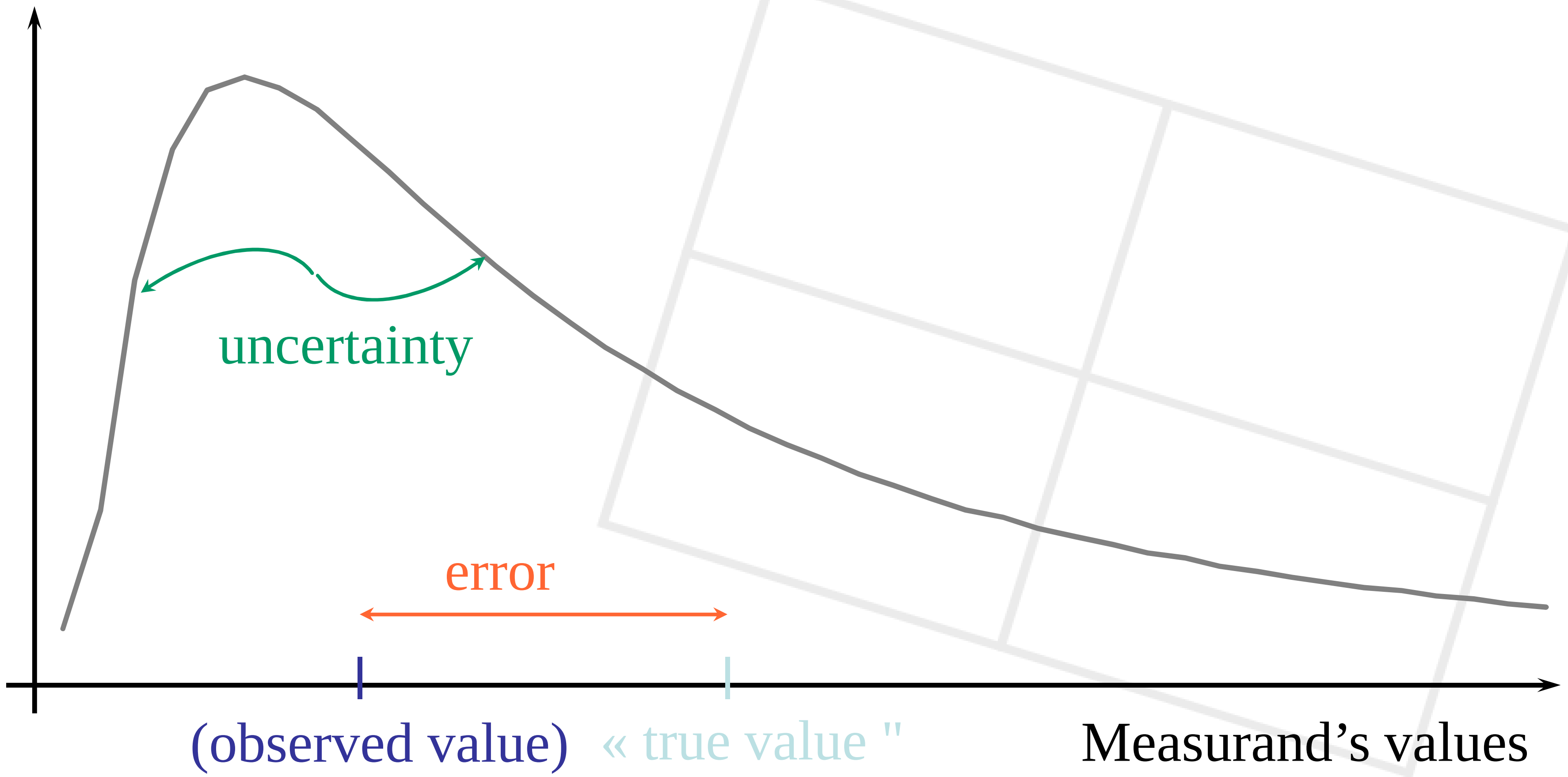
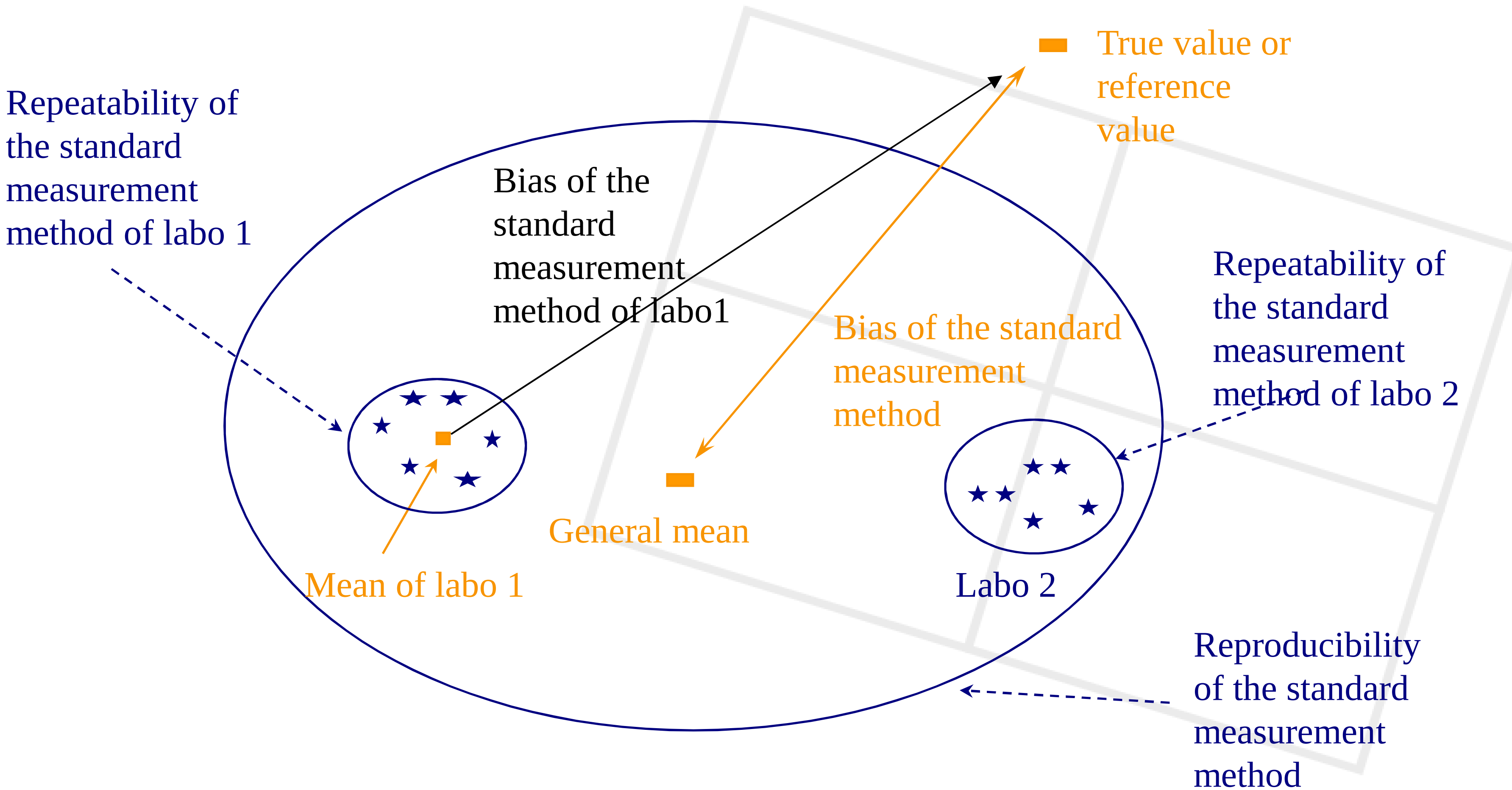
Experimental results



Measurand, Error, Uncertainty



ISO 5725 approach (3)



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