EXPERIMENTAL APPROACH FOR EVALUATING UNCERTAINTIES ASSOCIATED TO VEHICLE NOISE ACCORDING TO ISO 5725

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SUMMARY

This paper propounds an approach to determine uncertainties related to the sound pressure level measurement procedure ISO 5130. This approach is based on the international standard ISO 5725 and allows estimating uncertainties with experimental data, taking into account all of the influent parameters.

INTRODUCTION

The international standard ISO 5130 is used to control stationary noise of road vehicles. Its revision is currently in progress. As mentioned in document TC43/SC1/N1458, there is a need to introduce uncertainties matters in the standard. The new procedure suggests uncertainties evaluation and values based on the GUM model.
The analysis developed in this paper is based on the use of the ISO 5725 approach which is better suited for test laboratories due to the use of the data which are available and use of the precision value issued from interlaboratories tests, as mentioned in document ISO TS 21748 recently published which shows complementary between these two approaches The aim of this paper is to show the different results obtained for the estimation of the uncertainties of measurements obtained for several situations.
Different cases were taken into account like run-to-run, day-to-day, and site-to-site situations. Measurements were also performed for different vehicles.
Uncertainties are estimated under conditions of repeatability, intermediate precision and reproducibility. These conditions are linked with the factors which are included in the model of the variance analysis. This paper is to illustrate how the influence of different parameters can be taken into account, without having to perform tests with independent variations of each parameter.

CONTEXT

European regulations for approval of motor vehicles having at least four wheels regarding to their noise emissions are the directive 1999/101/CE and the regulation 51 rev02. Two acoustical tests are required for each vehicle:

- A dynamic test which is subjected to a limit
- A stationnary test

The static test is based on the international standard ISO 5130 (Acoustics - Measurements of sound pressure level emitted by stationary road vehicles).

This sound pressure level measurement procedure has been developed to control the exhaust systems of road vehicles. The method is used to determine a reference value and to check vehicles in use (spot tests by police

or/and periodical tests by approved inspection facility). This reference value is defined for each type of vehicle during the acoustic European or national type approval tests.
The possible reasons from which can result variations of the exhaust sound pressure level between the reference value and the in use control value are:

- Degradation, modification or replacement of the exhaust system,
- Variation between the approval test sample and the mass production vehicle,
- Variation between the approval test and the in use testing conditions.

To break away from the second and third conditions, French regulation allows a 5 dB divergence between type approval and in use test values. Therefore the first condition can only be detected if the divergence between the two tests exceeds 5 dB.

DESCRIPTION OF THE SOUND PRESSURE LEVEL MEASUREMENT PROCEDURE ISO 5130 [6]

To perform the procedure, the engine speed of the vehicle must be stabilized at a reference value (3/4 of the rotational speed at maximum power, for passenger cars and commercial vehicles). After a couple seconds, the throttle is rapidly returned to the idling position.
The sound level is measured over this operating period (constant engine speed and the entire deceleration period) on FAST mode in dB(A). The test result being the maximum value given by the sound-level meter. Each measurement must be repeated three times. The final result is the mean of the 3 values.

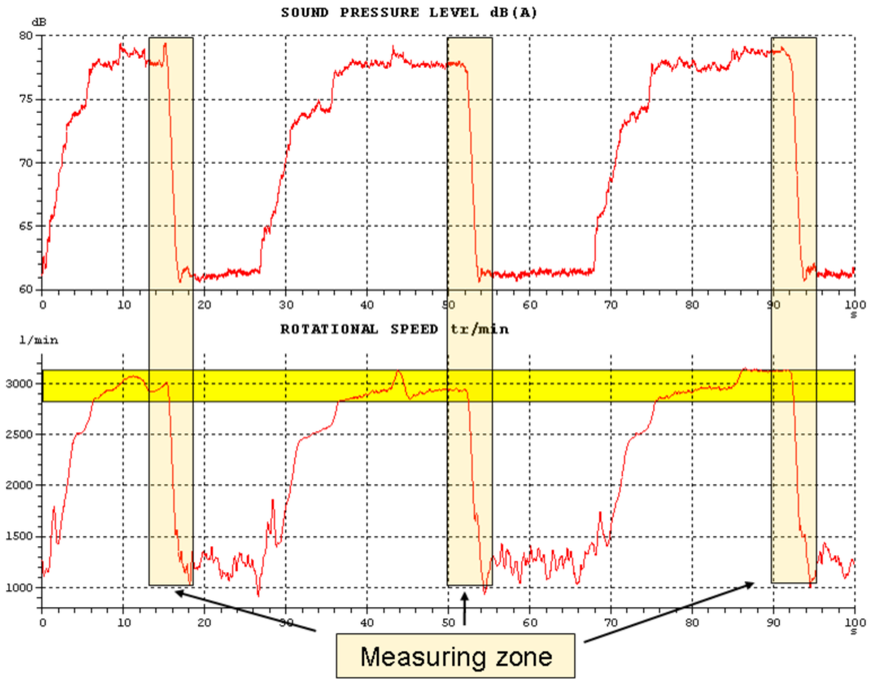

Figure 1: Example of one measure

The microphone is located as described in figure 2. Its maximum sensitivity axis must be parallel to the track surface at the height of the exhaust outlet pipe.

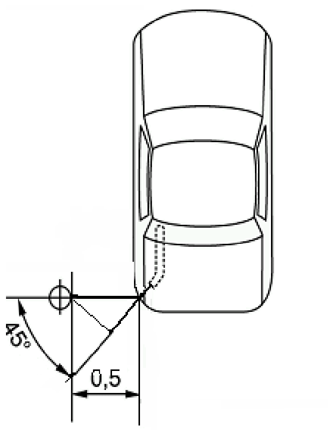

Figure 2: Position of the microphone

For the test to be valid, outdoor conditions must be respected:

- The test site has to be made out of a level concrete, dense asphalt or a similar hard material flat surface.
- Measurements must not be made in poor atmospheric conditions. It must be ensured that the results are not affected by gusts of wind.

On the other hand the procedure allows a large range of surfaces and atmospheric conditions which can introduce measurement uncertainties.

DESCRIPTION OF THE UNCERTAINTIES STUDY

The test was carried out on 6 identical diesel light vehicle with mileage going from 1000 to 100000 km. The reference value defined during the type approval test was taken as the true value.

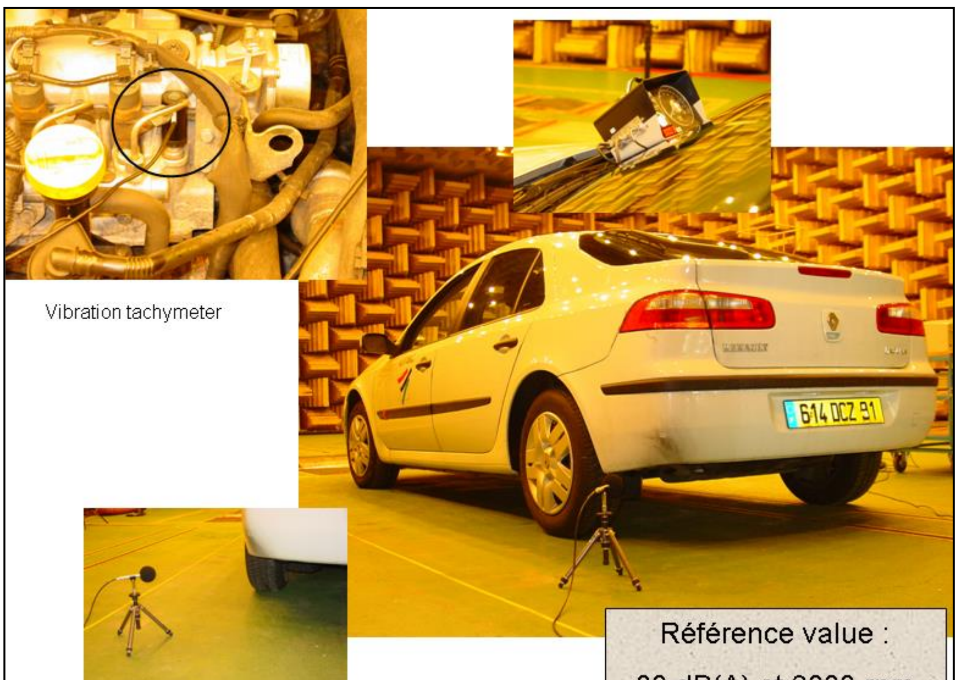

Figure 3: Test configuration

The test was performed on 6 different surfaces (ISO 10844 surface, bitumen asphalt surface, concrete asphalt surface or simple concrete surface) and at 7 different atmospheric conditions from 5°C to 25°C.

For this study, 4 variables are considered as influent:

- vehicle,
- atmospheric conditions,
- test surface,
- operator.

Figure 4 describes the structure of the study

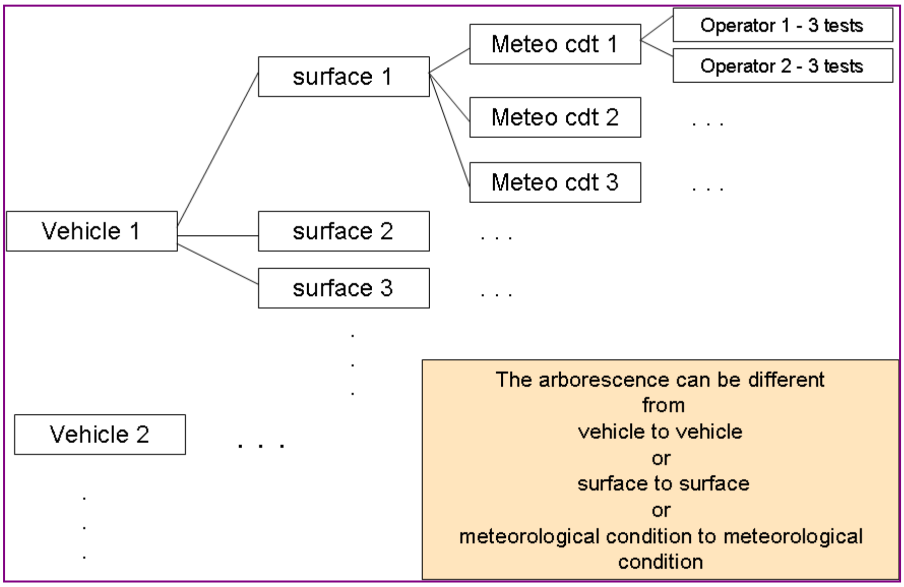

Figure 4: Experimental approach

The results shown in the following figure are used for the estimation of uncertainties.

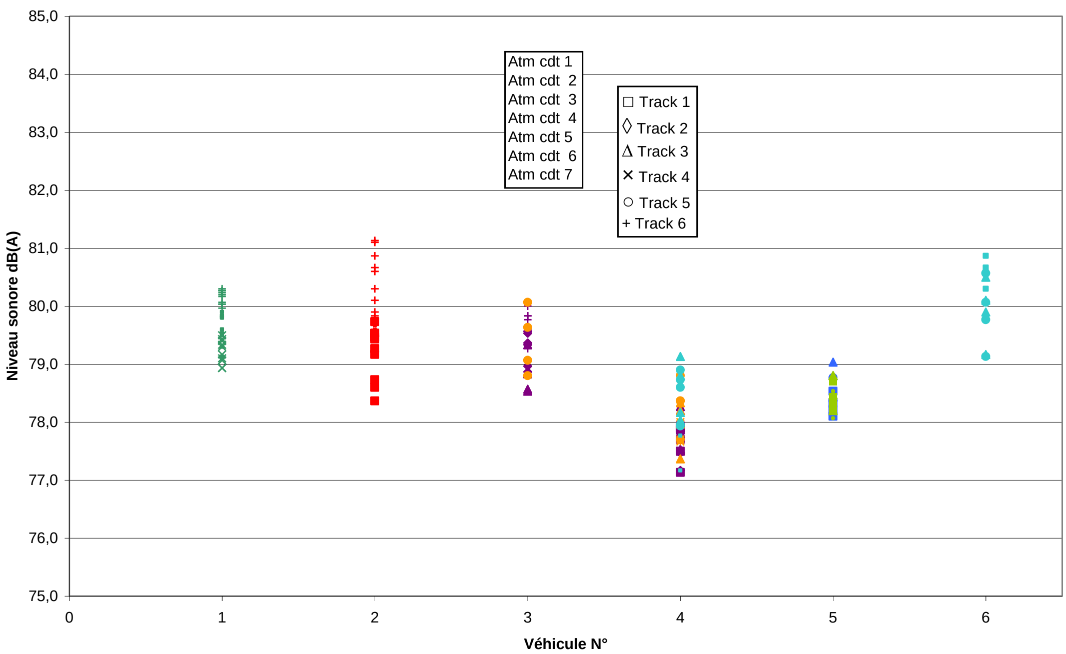

Figure 5: Results

EVALUATION OF THE UNCERTAINTY IN MEASUREMENT

Definition of the data

The aim is to determine the uncertainty of the measurement results on the stationary noise variable expressed in decibels. The influential factors are:

the vehicle, with 6 levels,
the atmospheric conditions, with 7 levels,
the test surface, with 6 levels,
the operator, with 6 levels.

There are other possible factors, but these are linked to the measurement method.
108 tests were performed. The number of test repetitions is not the same for all of the levels.

Used method

The standard ISO 5725 [1] allows evaluating the accuracy of the results and methods of measurement. The term accuracy involves two concepts:

precision: the closeness of agreement between independent test results obtained under stipulated conditions ISO 3534 [2],

trueness: the closeness of agreement between the average value obtained from a large series of test results and an accepted value of reference [2].

The documentation booklet FD X 07-021 [3] makes it possible to establish the connection between the values of precision and the values of uncertainty. For reminder: the uncertainty of measurement is the parameter associated with the results of a measurement that characterizes the dispersion of the value that could reasonably be attributed to the measurand [4].

Writing of the model

The model is a nested model, which is written according to [1], with the potentially influential factors:

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

y_{ijklm} represents the value of the studied characteristic of the m^{th} repetition for the l^{th} operator of k^{th} test surface j^{th} atmospheric condition of i^{th} vehicle,

μ a general effect,

V_i the effect due to i^{th} 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 j^{th} atmospheric condition of i^{th} vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_{AC}^2

$TS_k(AC_j(V_i))$ effect due to k^{th} test surface j^{th} atmospheric condition of i^{th} vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_{TS}^2

$O_l(TS_k(AC_j(V_i)))$ effect due to the l^{th} operator of k^{th} test surface j^{th} atmospheric condition of i^{th} vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_O^2

ε_{ijklm} residue of the m[th] repetition for the l[th] operator of k[th] test surface j[th] atmospheric condition of i[th] vehicle, presumed distributed according to a Laplace-Gauss distribution with mean 0 and variance σ_ε^2

Standard deviations of the measurement method precision (standard deviation of repeatability s_r, standard deviation of intermediate precision and standard deviation of reproducibility s_R) are estimated from this model.

Estimate of the combined standard uncertainty

According to [3], the combined standard uncertainty $u_c(y)$ comes from the values of precision:

$u_c(y) = s_r$ in conditions of repeatability,
$u_c(y) = s_{fi}$ in conditions of intermediate precision,
$u_c(y) = s_R$ in conditions of reproducibility.

Definition of expanded uncertainty

The expanded uncertainty U is obtained by multiplying the combined standard uncertainty $u_c(y)$ by a coverage factor k:

$U = k \times u_c(y)$ with coverage factor k equal to 2, the level of confidence is 95 percent.

EXPRESSION AND ANALYSIS OF THE NUMERICAL RESULTS

The results of the table are deducted from the variance of repeatability, the variance of intermediate precision and the variance of reproducibility.

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**

These calculations provide an interval of uncertainty [- U, +U].
The result is written under the form:

Characteristic (Y) = value observed y_{ijklm} of characteristic ± expanded uncertainty (U).

Here, as in the majority of cases, the data are corrected upstream and the interval of uncertainty is positioned suitably.

CONCLUSION

By its global aspect the approach using [1] offers the possibility of modeling and testing the influence of several factors with an adequate model of variance analysis. Moreover, if a factor is left out, it is necessarily included in the residue.
The user can take values of precision published and resulting from a former interlaboratory test, as long as it can be proved that the testing method is similar to that used during the interlaboratory test. This is convenient for test laboratories.
Eventually it can be pointed out that in practice in certain situations, it can be useful to associate the GUM approach [5] and the use of the standard ISO5725 [1]; the most often it is a question of estimating variances of input quantities according to the standard [1] and to use the estimate according to [5] in the law of propagation of uncertainty.

REFERENCE

[1] ISO 5725, part 1 to 6 Accuracy (trueness and precision) of measurement methods and results, 1994.
[2] ISO 3534-1 Statistics-Vocabulary and symbols-Part1 Probability and general statistical terms, 1993.
[3] FD X 07-021 Metrology and application of the statistics. Help to the process for the estimation and the use of the measurement and test results uncertainty 1999
[4] NFX 07-001, "International Vocabulary of basic and general terms in metrology ", 1994.
[5] NF ENV 13005 Guide to the expression of uncertainty in measurement 1999.
[6] ISO Committee Draft — 5130:2005 — Acoustics - Measurements of sound pressure level emitted by stationary road vehicles