Uncertainties in Applied Acoustics – Determination and Handling

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Introduction

A lot of attention has been paid to the issue of uncertainties in applied acoustics, recently. One reason for this is the publication of the Guide to the expression of uncertainty in measurements (GUM, [1]). This document provides a method for an uncertainty determination, and the aim is that this method is used consistently all over the world. So, in many scientific fields and also in applied acoustics, efforts were undertaken to determine uncertainties in accordance with GUM. Other reasons for the interest in uncertainties are that the knowledge of uncertainties is inevitable for

- fair trade,
- comparability of quantities,
- health protection,
- environmental control,
- market surveillance,
- accreditation of laboratories,
- conformity assessments and
- declaration of product properties.

All these processes have become more important in the past years thus increasing the attention paid to uncertainties.

Before discussing the determination and handling of uncertainties, it is necessary to define it. According to [2], the uncertainty is a parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand. The parameter may be, for example, a standard deviation, or the half-width of an interval having a stated level of confidence.

In applied acoustics, different kinds of quantities are to be distinguished. The first are quantities which can be measured directly. These are the field quantities of the fluid-borne or structure-borne sound field like an airborne sound pressure or the acceleration on the surface of a vibrating body. From these measured quantities, other quantities are derived, like a sound power or a sound insulation. Such quantities are usually determined by an integration over a field region. They will therefore be called integral quantities. The majority of measurements in applied acoustics finally aim at the determination of such integral quantities.

The transformation from a field quantity to an integral quantity very often requires certain assumptions on the nature of the sound field, e.g. diffuse or free-field. Unfortunately, the degree of fulfilment of these assumptions is very difficult to check. Hence, the determination of uncertainties associated with the transformation from (measurable) field quantities to integral quantities is a very challenging task.

Another important aspect is that many decisions in applied acoustics are based on a comparison between predicted values and legal requirements. The prediction of an immission level may decide whether a new enterprise, railroad or motorway is built or not. The prediction of the sound insulation in a building leads to decisions on the building products and thus on the costs of the building. The uncertainty of predictions is therefore a very important task to be addressed.

After a short introduction into the basic methods to determine uncertainties, some examples will be used to illustrate the current knowledge on the uncertainty determination in applied acoustics. These examples include measurable quantities as well as integral quantities. Afterwards, it will be discussed how uncertainties may be handled.

Uncertainty determination

GUM approach

Starting point for an uncertainty analysis according to the GUM [1] is the definition of the measurand. From this definition, a model function is established describing the relation between the measurand Y and the various input quantities X_i. This is expressed formally by a function f

$$Y = f(X_i) \cdot \qquad (1)$$

The measurand and the input quantities are considered to be random variables following certain distributions. The best estimate or the expected value of the measurand y is now determined by the best estimates of the input quantities x_1, x_2, ..., and the combined uncertainty of the measurand can be calculated by

$$u_c(y) = \sqrt{\sum_{i=1}^{n} [c_i \; u(x_i)]^2} \qquad (2)$$

where $u(x_i)$ are the standard uncertainties of the input quantities. The sensitivity coefficients c_i are calculated from the partial derivatives of the function f with respect to the input quantity X_i

$$c_i = \left. \frac{\partial f}{X_i} \right|_{x_i} \qquad (3)$$

Correlation between input quantities is neglected in eq. (2).

Round robin approach

The application of the GUM requires a mathematical model of the measurement process which must contain the main effects influencing the result. Especially for quantities which can’t be measured directly, such models are very difficult to establish. Therefore, uncertainties of these quantities are often determined in another way.

Starting point is that the measurand is implicitly defined by a procedure, e.g. a standard. It follows from this definition that all results obtained according to the prescribed procedure are valid realisations of the measurand. The uncertainty of the measurand is usually determined by round robins according to ISO 5725 [3], [4]. For this purpose, test objects are distributed to the participating laboratories. All laboratories apply the prescribed procedure to obtain results in accordance with the definition of the measurand. The standard deviation of reproducibility σ_R is then calculated from the results from all laboratories. This value is considered to be an estimate for the combined uncertainty of results obtained according to the prescribed procedure for any test specimen

$$u_c \approx \sigma_R \,. \tag{4}$$

The determination of uncertainties by round robins involves several difficulties. One main problem is the proper choice of test specimens for the round robin. Besides some practical aspects, they must cover the complete field of application of the method. Otherwise it is questionable whether eq. (4) can be applied for all test objects. Furthermore, different procedures for the determination of the same quantity may lead to different results. Naturally, these differences will not be covered if the uncertainties of the single procedures are all determined separately according to eq. (4). A way out of this problem is the definition of a reference procedure and the determination of systematic deviations between results from other measurement procedures and the reference procedure.

Despite these difficulties, a determination of uncertainties by round robins is still the preferred method for many quantities in applied acoustics. Very often, the GUM does not provide a realistic alternative due to the lack of a mathematical model for the complete measurement process.

Directly measured quantities

One-third octave band sound pressure levels

As a very first example, a simple laboratory setup is considered ([5], Figure 1). A flush mounted speaker is placed in the floor of a hemianechoic room. It is excited by broadband and multi-sine signals with one tone at each one-third octave midband frequency. The sound pressure level is measured in 13 field points by 5 completely different measurement chains, each consisting of a microphone, a preamplifier, a cable, a one-third octave band analyser and a calibrator. To control the stability of the emission, a reference microphone is additionally placed in the hemianechoic chamber.

The first step for the determination of the measurement uncertainty is the definition of the measurand. For the experiment described above, the measurand is simply the sound pressure level at the described room positions as measured by a ½''-microphone at a given angle of sound incidence. Since environmental conditions remained constant, air absorption effects as well as changes of the microphone sensitivity due to environmental conditions can be neglected.

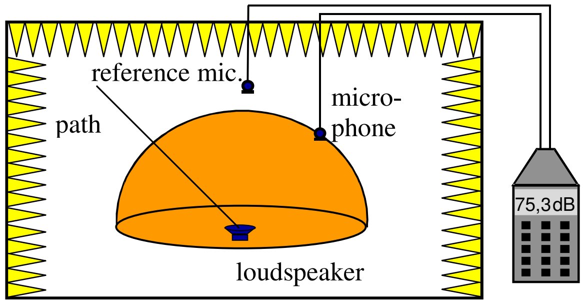

Figure 1 Laboratory setup for the measurement of one-third octave band sound pressure levels

The measurand is determined from the indicated value L'_p and corrections for the frequency response of the microphones K_{mic}, for the filter properties K_{fil}, for the display resolution K_{dis}, for the time averaging K_{av}, for the angle of sound incidence K_{ang}, for the calibration K_{cal}, for the positioning of the microphone in the sound field K_{pos}, for the influence of the background noise K_1 and for changes in the sound emission from the source K_{em}

$$\begin{aligned} L_p = L_p^{'} - K_{\text{mic}} - K_{\text{fil}} - K_{\text{dis}} - K_{\text{av}} \\ - K_{\text{ang}} - K_{\text{cal}} - K_{\text{pos}} - K_1 - K_{\text{em}} \end{aligned} \,. \tag{5}$$

All corrections can be considered to be independent of each other in the investigated situation. Even though some of the expected values of the corrections are 0 dB, their uncertainties do not vanish. The combined uncertainty of the measurand therefore is

$$u_c\left(L_p\right) = \sqrt{\left[u^2\left(K_{\text{mic}}\right) + ... + u^2\left(K_{\text{em}}\right)\right]} \,. \tag{6}$$

A detailed analysis of all the single components [5] finally leads to the complete uncertainty budget (Figure 2). The most important uncertainty components at the low and medium frequencies are the calibration and the filter properties followed by the frequency response of the microphone. At high frequencies, the positioning of the microphone (due to remaining standing waves in the hemianechoic room) and the angle-dependent sensitivity of the microphone play a major role. The combined uncertainty has a value of 0.4 dB at low and medium frequencies and increases considerably towards higher frequencies.

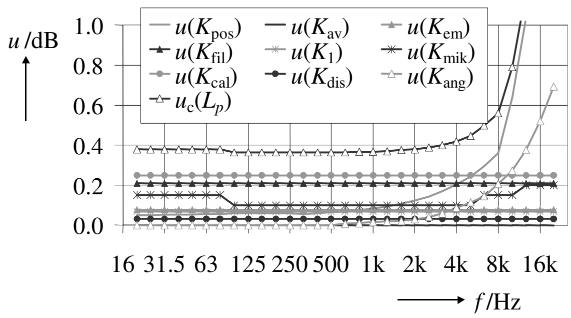

Figure 2 Combined uncertainty and uncertainty components for sine signals

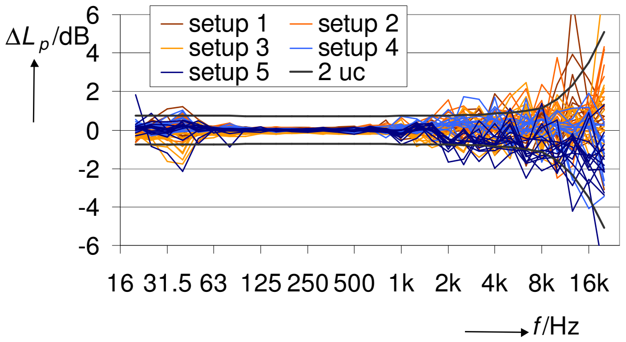

Figure 3 Expanded combined uncertainty (2 uc) and measured sound pressure deviations for sine signals, all measurement positions

For the case of sine excitation, deviations between measured individual sound pressure levels and the mean value are presented for all field positions in Figure 3. The graph also includes a 95% tolerance range calculated by $2 \cdot u_c$ according to eq. (6). Observed deviations are mainly covered by the tolerance range. Only at the very low and high frequencies, single measurement results leave the tolerance range. In the central frequency range, the combined uncertainty is much larger than the deviations. This means that one or more uncertainty components have been overestimated.

The results for the broadband excitation are very similar [5]. Only at the high frequencies, the effect of the positioning and the angle influence are less pronounced due to the averaging over the bandwidth.

It is now interesting to compare these findings to a result obtained from comparison measurements which are regularly held at PTB. Different teams come to PTB and, among other things, measure a single point sound pressure in the receiving room of a building acoustic test facility. The ceiling of the room is excited by an ISO tapping machine, and the measured sound pressure levels are compared to the levels indicated by a PTB-reference equipment. The differences between these results are well within the calculated tolerance range (Figure 4). So, a combined uncertainty of about 0.4 dB seems to be a realistic estimate for single-point sound pressure levels measured in one-third octave bands.

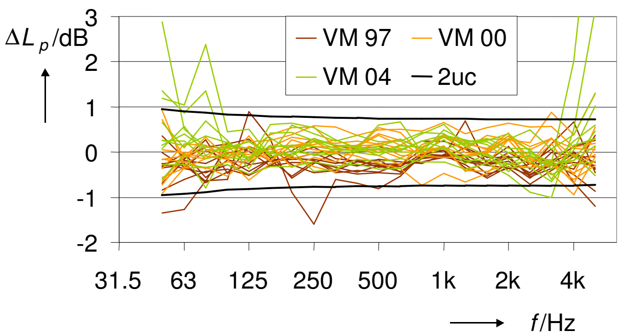

Figure 4 Expanded combined uncertainty (2 uc) and measured sound pressure deviations for comparison measurements held at PTB in 1997, 2000 and 2004

Occupational noise exposure

A very good example for the determination of an uncertainty is contained in ISO 9612 [6]. This standard describes several methods for the determination of occupational noise exposure. We will focus here on the task-based method. A working day with an overall duration T_0 is divided into M individual tasks. Each task is characterised by a duration T_m and an equivalent A-weighted sound pressure level $L_{p,A,,eq,Tm}$. The noise exposure is calculated by

$$L_{\mathrm{Ex},8h} = 10 \lg \left[\sum_{m=1}^{M} \frac{T_m}{T_0} 10^{\left(L_{p,A,eq,Tm} + C_2 + C_3\right)/10} \right] \mathrm{dB} \qquad (7)$$

where C_2 and C_3 are corrections for the measurement equipment and for the position of the measurement device in the sound field. The expected values for these corrections vanish whereas their uncertainties do not vanish. It is now to be noticed that eq. (7) is valid without any further assumptions. It is especially valid for all kinds of sound fields since the noise exposure includes the nature of the sound field by definition. Therefore, eq. (7) serves as the mathematical model for the measurement process. It can be treated according to GUM easily.

Let's consider an example (Figure 5). A worker has two different tasks. The first is the planning and preparation of the work which takes about 3 h, and 5 hours are spent for the working process. The equivalent A-weighted sound pressure levels are 70.0 and 82.0 dB, respectively.

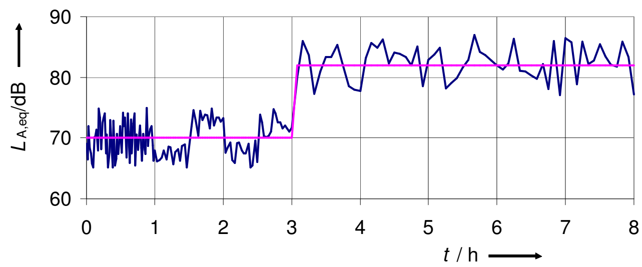

Figure 5 A-weighted equivalent sound pressure level for an 8h working day

Under the assumption of Gaussian distributions for all quantities, an uncertainty budget can be compiled (Table 1, eqs. (2), (3)). The proposal from ISO 9612 is adopted here with respect to the uncertainty of the measuring device of 1.0 dB (class 2 sound level meter according to IEC 61672, [7]) and of the positioning of 1.0 dB. The uncertainty of the A-levels can be determined from n repeated measurements according to the usual statistical approach

$$u\left(L_{p,\mathrm{A,eq},T1}\right) = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} \left(L_{p,\mathrm{A,eq},T1,i} - \overline{L_{p,\mathrm{A,eq},T1}}\right)^2} \quad . \qquad (8)$$

The calculation yields a noise exposure level of 80.1 dB with a combined uncertainty of 2.2 dB. The last column of Table 1 reveals that the uncertainty contribution from the A-level of task 2 is by far the largest. So, if the uncertainty is to be reduced, this component is the first to be dealt with. It is furthermore interesting to notice that the combined uncertainty of the result is smaller than the uncertainty of the A-level of task 1. This is due to the nature of the measurand.

It is basically a weighted sum, where the single uncertainty components are multiplied with a sensitivity coefficient smaller than one. This example clearly shows the potential of the GUM approach. The calculation is transparent, the most important uncertainty contributions are detected and the uncertainty reflects the exact situation.

Table 1: Uncertainty budget for a noise exposure

Quantity	Estimate	u	c	$(c\ u)^2$
$L_{p,\mathrm{A,eq,T1}}$	70.0 dB	3.0 dB	0.04	0.01 dB^2
$L_{p,\mathrm{A,eq,T2}}$	82.0 dB	1.5 dB	0.96	2.09 dB^2
T_1	3 h	1.0 h	0.05 dB/h	0.00 dB^2
T_2	5 h	1.0 h	0.84 dB/h	0.70 dB^2
$C_{2,1}$	0 dB	1.0 dB	-0.04	0.00 dB^2
$C_{2,2}$	0 dB	1.0 dB	-0.96	0.93 dB^2
$C_{3,1}$	0 dB	1.0 dB	-0.04	0.00 dB^2
$C_{3,2}$	0 dB	1.0 dB	-0.96	0.93 dB^2
			Sum:	4.66 dB^2

$L_{\mathrm{ex,8h}}$	80.1 dB
u_c	2.2 dB

Integral quantities

Sound power

There are different methods for the determination of airborne sound power levels. Here, we restrict ourselves to the sound pressure method on an enveloping surface (ISO 3744 [7]). The basic problem is now that the method has several presumptions, e.g. measurement positions should be in the free and far field. In ordinary rooms as well as in anechoic rooms, these assumptions are only partly fullfilled. So far, no quantitative relation between a measurable parameter describing the sound field and a sound power uncertainty could be established. It has therefore not been possible yet to derive a full model of the measurement.

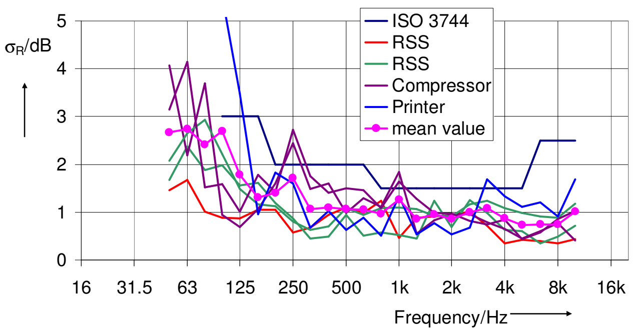

Figure 6 Standard deviation of reproducibility for sound power determinations in approximated free fields (ISO 3744)

Thus uncertainties are derived from round robin tests. Figure 6 shows standard deviations of reproducibility as derived from different round robin tests. To be on the safe side, the values given in ISO 3744 are larger than the mean value from the different round robins.

In a next step it was investigated whether the uncertainty of A-weighted sound power levels can be calculated from the uncertainty of the one-third octave band levels. The usual equation for the calculation of A-weighted sound power levels L_{WA} is

$$L_{WA} = 10\,\lg\left[\sum_i 10^{\left(L_{W,i}+A_i\right)/10\mathrm{dB}}\right]\mathrm{dB} \tag{9}$$

where $L_{W,i}$ are the one-third octave band levels and A_i are values of the A-weighting at frequency band i. The uncertainty of the A-weighted levels can be calculated under the assumption of no correlation between the one-third octave bands from

$$u^2(L_{WA}) = \sum_i \left[\frac{10^{\left(L_{W,i}+A_i\right)/10\mathrm{dB}}}{\sum_i 10^{\left(L_{W,i}+A_i\right)/10\mathrm{dB}}}\,u\left(L_{W,i}\right)\right]^2 \tag{10}$$

with the uncertainty of the one-third octave band levels $u(L_{W,i})$. For full correlation between one-third octave band levels, uncertainties are added to or subtracted from the band levels. An A-level is calculated from both resulting spectra according to

$$L_{WA\pm} = 10\,\lg\left[\sum_i 10^{\left(L_{W,i}\pm u\left(L_{W,i}\right)+A_i\right)/10\,\mathrm{dB}}\right]\mathrm{dB} \quad . \tag{11}$$

The uncertainty is then calculated from these two values by

$$u(L_{WA}) = 0{,}5\,\left(L_{WA+} - L_{WA-}\right) \quad . \tag{12}$$

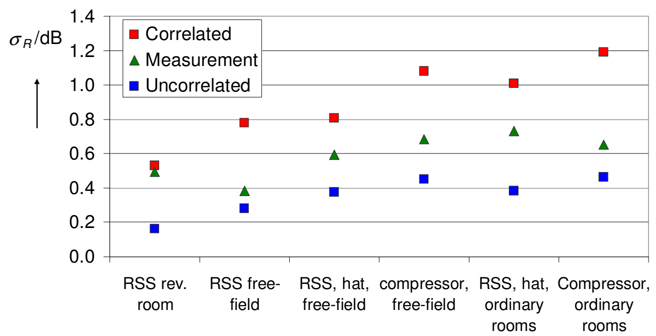

Figure 7 Standard deviation of reproducibility for A-weighted sound power levels under the assumption of full and of no correlation and measured results, reference sound source (RSS) and compressor in different environments

Uncertainties of A-weighted sound power levels from different round robins are displayed in Figure 7. As expected, the assumption of full correlation between one-third octave bands leads to the largest uncertainties. Much smaller uncertainties are obtained by an uncorrelated superposition of the spectral uncertainties. The standard deviation of the A-weighted levels from the different participants of the round robin is additionally shown. It is always between the correlated and uncorrelated case, but the degree of correlation can't be predicted. It is thus necessary to derive the uncertainty of A-weighted sound power levels from round robins as well.

Airborne sound insulation

Another important quantity in applied acoustics is the airborne sound insulation *R*. It is defined by

$$R = 10\,\lg\left(\frac{P_1}{P_2}\right)\text{dB} \qquad (13)$$

with the transmitted sound power P_2 and the incoming sound power P_1. For the measurement, the test specimen is usually mounted between two rooms. One room is excited by a loudspeaker, and the sound pressure level difference and the absorption in the receiving room are measured. Under the assumption of diffuse fields in both rooms, the airborne sound insulation can be determined from the measured quantities. Again, it has not been possible to derive a full model for the measurement yet, even though some basic considerations already exist [12]. So, uncertainties are determined by round robins.

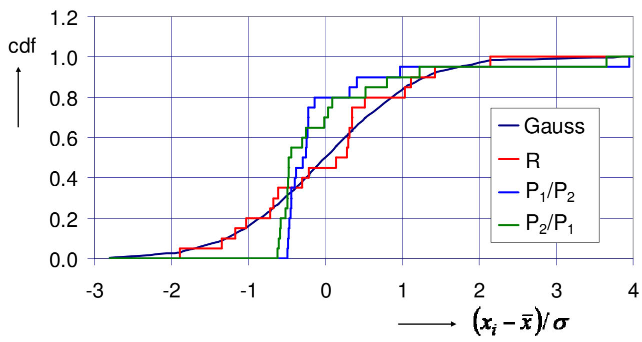

Figure 8 Cumulative distribution function for the sound reduction index R, for the argument of the lg-function (P_1/P_2) and for the transmission coefficient (P_2/P_1) in comparison to a Gaussian distribution

A very first question to be dealt with is the distribution of the quantities. Figure 8 shows cumulative distribution functions (cdf) of a set of measured data. The airborne sound insulation in dB follows much better a Gaussian distribution than the argument of the lg – function in eq. (13) and the transmission coefficient P_2/P_1. Since this is valid for nearly all analysed measurement results, a data analysis on the dB scale is much more reasonable than in physical units.

The standard dealing with uncertainties in building acoustics is ISO 140-2 [13]. The current version of this document contains standard deviations which are derived from round robin tests. Included test conditions are repeatability conditions (same staff, same equipment, same site, short time interval) and reproducibility conditions (different staff, different equipment, different site). It is proposed to include an important intermediate case in the revision of ISO 140-2 which was called in-situ conditions (different staff, different equipment, same site), since these conditions are very often met in practice e.g. when different consultants measure in the same building situation.

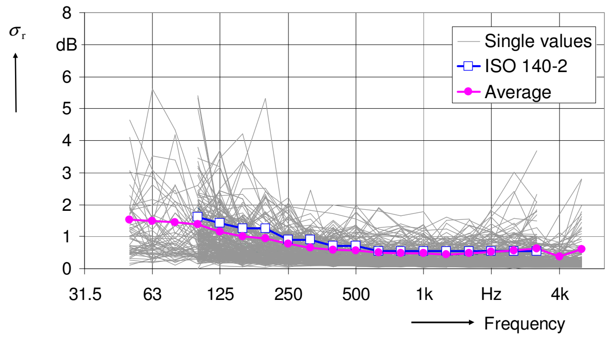

Figure 9 Standard deviation of repeatability of airborne sound insulation from round robin testing and average value in comparison to the value from ISO 140-2

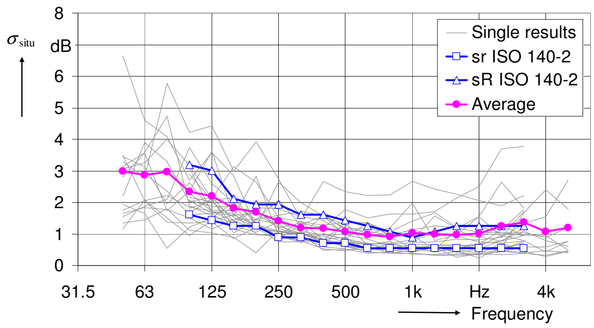

Figure 10 In-situ standard deviations of airborne sound insulation from round robin testing and average value in comparison to the standard deviations of repeatability sr and of reproducibility sR from ISO 140-2

For the revision of ISO 140-2, a large data base was established at PTB containing data from many round robins. The standard deviation of repeatability calculated from the round robins shows a considerable spread (Figure 9). But the mean value is very close to the value given in the current version of ISO 140-2. The averaged in-situ standard deviation assumes values which are between the currently standardised values for the repeatability standard deviation and the reproducibility standard deviation (Figure 10). The averaged standard deviation of reproducibility calculated from the new data base is considerably larger than the value from the current ISO 140-2 (Figure 11). The main reason is that the distinction between in-situ and reproducibility conditions was not made in the past. The collective average from both data sets was assigned to the standard deviation of reproducibility which naturally leads to smaller values.

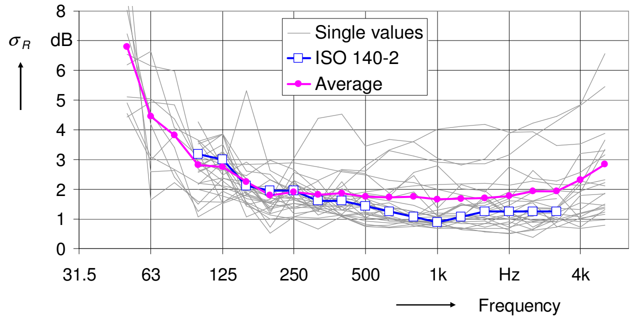

Figure 11 Standard deviation of reproducibility of airborne sound insulation from round robin testing and average value in comparison to the value from the current ISO 140-2

For communication purposes, planning procedures and the formulation of requirements, rated single-number values according to ISO 717-1 are used. They are calculated from the one-third octave band sound insulations. As for the calculation of A-weighted sound powers and their uncertainties, correlation effects play a major role for the uncertainties of single-number ratings [15]. It is therefore proposed to use average values for the different standard deviations which are derived from the round robin tests (Figure 12). For the weighted sound reduction index, averaged standard deviations are 1.2, 0.8 and 0.4 dB for reproducibility, in-situ and repeatability conditions, respectively.

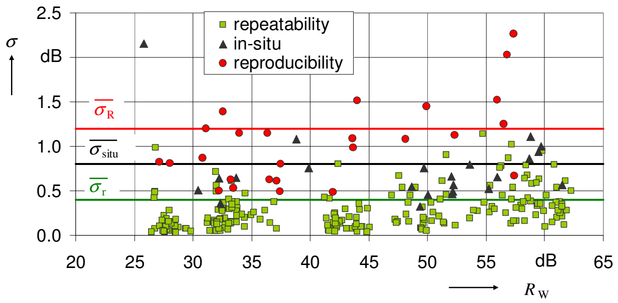

Figure 12 Standard deviations for the weighted sound reduction index and proposed values for ISO 140-2

Handling of uncertainties

Expanded uncertainty

The basic assumption is that the result of a measurement is a distribution of values and not a single value. It is therefore straightforward to calculate an expanded uncertainty U encompassing a fraction of the distribution with a certain level of confidence ([1], Figure 13).

$$U = k\, u_c \tag{14}$$

The coverage factor k depends on the shape of the distribution associated to the measurand. In applied acoustics, Gaussian distributions are usually assumed. The coverage factor then assumes values between 1 and 3 for levels of confidence between 68 and 99.75 % for two-sided tests (Table 2).

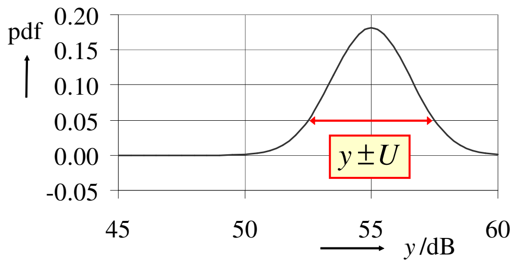

Figure 13 Probability density function (pdf) associated to the measurand y and the expanded uncertainty U

Table 2: Coverage factors for Gaussian distributions

	Level of confidence	
k	two-sided test	one-sided test
1.00	68 %	84 %
1.65	90 %	95 %
1.96	95 %	97.5 %
2.58	99 %	99.5 %
3.00	99.75 %	99.87 %

Airborne sound insulation

In the following, the handling of uncertainties is demonstrated for airborne sound insulations between dwellings. Starting point is the requirement $R'_{W,req}$. In Germany, the apparent sound reduction index must be larger than 53 dB.

$$R'_{W,req} = 53 \text{ dB} \tag{15}$$

The conformity with this requirement can be proved by predictions according to EN 12354-1 [16]. With this method, the performance of the building is analytically calculated from the properties of the building elements. It is thus possible to apply the propagation of uncertainties according to GUM [1] to the prediction procedure [17]. The combined uncertainties of the apparent sound reduction index turned out to be between 1.5 and 2.1 dB for solid buildings, depending on the building situation [17]. The planner can now choose a level of confidence and thus a coverage factor k for the one-sided test in order to fulfil the requirement. The equation for the comparison of the predicted apparent sound insulation $R'_{W,pred}$ and the requirement is:

$$R'_{W,pred} - k\, u_c \geq R'_{W,req} \tag{16}$$

The implications of such a procedure are demonstrated in Figure 14. An 84 % level of confidence requires an expected value of the prediction of 55.0 dB if the combined uncertainty is assumed to be 2.0 dB. Higher levels of confidence lead to larger expected values of the prediction. An expected value of 57.0 dB is necessary to reach a level of confidence of 97.5 %. Thus, the planner can adjust the level of confidence to the current situation.

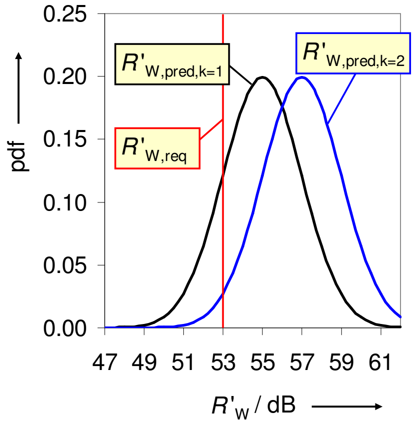

Figure 14 Required apparent sound reduction index and probability density functions of the predicted sound reduction indices with combined uncertainties of 2.0 dB

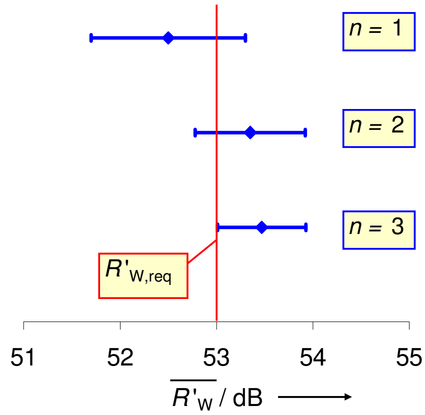

Figure 15 Evolution of mean values and associated uncertainties for the example of Table 3

When the building is erected, it can happen that the airborne sound insulation is determined in-situ. The combined uncertainty for the weighted sound reduction index is 0.8 dB (Figure 12). If a first measurement result is 52.5 dB, it can't be decided whether the requirement is fulfilled or not (Figure 15, Table 3) for a coverage factor of k = 1. Thus, a second independent measurement is initiated. Independent means in this context, that different equipment is used by different staff according to the in-situ conditions mentioned above. It is assumed that this second measurement yields an apparent weighted sound reduction index of 54.2 dB. It is now advisable to use the mean apparent sound reduction index from both measurements and calculate the combined uncertainty associated to this value by

$$u_c\left(\overline{R'_W}\right) = \frac{u_c\left(R'_W\right)}{\sqrt{n}} \qquad (17)$$

where n is the number of measurements. Unfortunately, no clear decision can be made on the base of the two measurements. Therefore, a third measurement is carried out leading to the decision that the requirement is fulfilled (Figure 15, Table 3).

This example demonstrates that clear decisions may require a larger measurement effort. On the other hand, the effort can be adjusted to the specific situation by choosing the number of independent measurements.

Table 3: Example for in-situ measurements

No.	R'_W dB	$u_c\left(R'_W\right)$ dB	$\overline{R'_W}$ dB	$u_c\left(\overline{R'_W}\right)$ dB
1	52.5	0.8	52.5	0.8
2	54.2	0.8	53.35	0.57
3	53.7	0.8	53.47	0.46

Conclusion

Whenever possible, uncertainties should be determined according to GUM [1]. One advantage is that the method is standardised and accepted all over the world. The calculation procedure is transparent and results are reliable. Furthermore, the uncertainties reflect the exact situation during each individual measurement. The greatest disadvantage in the context of applied acoustics is, that an application of GUM requires a mathematical model which must contain all relevant effects. Such models can be established for field quantities which are directly measured (e.g. sound pressure level). Models for integral quantities like sound power levels or sound insulations are more difficult to obtain, if at all.

Besides these difficulties, an application of GUM in applied acoustics is often prevented by the basic problem that physical effects depend on frequency. Therefore, quantities and their uncertainties also depend on frequency. But the final results we are interested in are mostly averaged or summed over frequency for instance A-levels or weighted sound reduction indices. Legal or other requirements usually refer to such quantities. The averaging or summation of frequency contributions requires the knowledge on the correlation between frequency bands. It has been shown that correlation effects are of crucial importance for sound power levels and for airborne sound insulations. Thus, the elaboration of sophisticated frequency dependent model equations must aim at separating these correlation effects. Otherwise, the models would be useless for the final results averaged or summed over frequencies.

Due to these aspects, round robins are widely used in applied acoustics. The basic advantage is that the quantity is implicitly defined by the measurement procedure. There is no explicit model required. Another advantage is that frequency summed or averaged values can be handled in exactly the same way as frequency band values. Correlation effects are therefore automatically included.

An uncertainty determination by round robins involves also some disadvantages. One is that different methods for the same quantity may lead to different results. This could be overcome by defining a reference procedure and including corrections in the other procedures. Another disadvantage is that round robins should cover the complete field of application in order to give realistic estimates of the combined uncertainty. Since many measurement procedures have a very broad scope, this is nearly impossible. Nevertheless, round robin results still provide the best estimates of the combined uncertainty for the majority of measurands in applied acoustics.

Acknowlegdements

This contribution was initiated by the author's reception of the Lothar Cremer award of the Deutsche Gesellschaft für Akustik (DEGA - German Acoustical Society). On that occasion I would like to express my deep gratitude to all the staff members of the Applied Acoustics division at the Physikalisch-Technische Bundesanstalt (PTB) and especially to the working group Building Acoustics. In particular, I thank Prof. W. Scholl, the head of the Applied Acoustics division, who supported and still supports me in all respects. I would furthermore like to thank all those persons who contributed to my education in acoustics, namely the staff members of the Institute for Technical Acoustics at TU Dresden under the leadership of Prof. W. Wöhle and Prof. P. Költzsch, and Prof. Gerhard Hübner from Stuttgart University, who initiated and supervised my PhD-Thesis.

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