International Standard

ISO 5114-1

Acoustics — Determination of uncertainties associated with sound emission measures —

Part 1:
Sound power levels determined from sound pressure measurements

Acoustique — Détermination des incertitudes associées aux mesurages de l'émission sonore —

Partie 1: Niveaux de puissance acoustique déterminés à partir des mesurages de pression acoustique

First edition
2024-06

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Foreword

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 211, *Acoustics,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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Introduction

An assessment of uncertainties that is comprehensible and close to reality is indispensable for reporting and using measured sound power levels. Uncertainties are determined following the principles of ISO/IEC Guide 98-3. This Guide specifies a detailed procedure for uncertainty evaluation that is based upon a mathematical model of the measurement. The detailedness of the model can vary from the mere analysis of the statistical spread of measured sound power levels up to an exhaustive characterisation of all relevant physical phenomena. Different such models are described by this document.

Acoustics — Determination of uncertainties associated with sound emission measures —

Part 1:
Sound power levels determined from sound pressure measurements

1 Scope

This document gives guidance on the determination of measurement uncertainties of sound power levels determined according to ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746, ISO 3747 or according to a noise test code based on one of these measurement standards.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
measurement result
value attributed to a particular quantity, obtained by following the complete set of instructions given in a measurement procedure (the measured value), together with measurement uncertainty

Note 1 to entry: The measurement result can be expressed in terms of a sound power level in octave bands, one-third octave bands or an A-weighted sound power level.

3.2
measurement uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the particular quantity subject to measurement

3.3
expanded uncertainty
U
quantity defining an interval about the result of a measurement that is expected to encompass a large fraction of the distribution of values that can reasonably be attributed to the particular quantity subject to measurement

3.4
coverage factor

k

numerical factor used as a multiplier of the measurement uncertainty in order to obtain an *expanded uncertainty* (3.3)

3.5
repeatability condition

condition of measurement that includes same measurement procedure; same observer; same measuring instrument; same location; and repetition over a short period of time

3.6
reproducibility condition

condition of measurement that includes different laboratories, operators, measuring systems, and replicate measurements on the same or similar objects

3.7
standard deviation of reproducibility of the method

σ_{R0}

standard deviation of measured values obtained under *reproducibility conditions* (3.6) using a specified method

Note 1 to entry: In statistics, it is usually distinguished between the standard deviation of the basic population σ and the empirical standard deviation derived from a sample *s*. Despite this, the symbol σ is used for all standard deviations in this document to be in line with other standards on sound emission.

3.8
standard deviation for the operating and mounting conditions

σ_{omc}

standard deviation of measured values caused by variations of operating and mounting conditions

3.9
total standard deviation

σ_{tot}

standard deviation of measured values obtained under *reproducibility conditions* (3.6)

4   General concept to describe the uncertainty of measured sound power levels

The uncertainties of sound power levels, $u(L_W)$, in decibels, determined in accordance with the International Standard used (ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746 or ISO 3747) are estimated by the total standard deviation, in decibels, given by Formula (1):

$$u(L_W) = \sigma_{\text{tot}} \tag{1}$$

This standard deviation is expressed by the standard deviation of reproducibility of the method, σ_{R0}, in decibels, and the standard deviation for the operating and mounting conditions, σ_{omc}, in decibels, describing the uncertainty due to the instability of the operating and mounting conditions of the noise source under test in accordance with Formula (2):

$$\sigma_{\text{tot}} = \sqrt{\sigma_{R0}^2 + \sigma_{\text{omc}}^2} \tag{2}$$

Formula (2) shows that variations of operating and mounting conditions expressed by σ_{omc} should be taken into account before a measurement procedure with a certain grade of accuracy (characterized by σ_{R0}) is selected for a specific machine family. The standard deviation σ_{R0} includes all uncertainty due to conditions and situations allowed by the International Standard used (different radiation characteristics of the noise source under test, different instrumentation, different implementations of the measurement procedure),

except that due to instability of the sound power of the noise source under test. The latter is considered separately by σ_{omc}.

Values for the standard deviation σ_{R0} may be derived from dedicated round robin tests (see Clause 6) or by using the mathematical modelling approach (see Clause 7). They should be given in noise test codes specific to machinery families.

NOTE 1   If different measurement procedures offered by ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746 or ISO 3747 are used, systematic numerical deviations (biases) can additionally occur.

Derived from σ_{tot}, the expanded measurement uncertainty, $U(L_W)$, in decibels, shall be calculated from Formula (3):

$$U(L_W) = k\sigma_{\text{tot}} \tag{3}$$

The expanded measurement uncertainty depends on the confidence level that is desired. For a normal distribution of measured values, there is a 95 % confidence level that the true value lies within the range $(L_W + U)$ to $(L_W - U)$. This corresponds to a coverage factor of $k = 2$. If the purpose of determining the sound power level is to compare the result with a limit value, it can be more appropriate to apply the coverage factor for a one-sided normal distribution. In that case, the coverage factor $k = 1{,}6$ corresponds to a 95 % confidence level.

NOTE 2   The expanded uncertainty, as described in this document, does not include the standard deviation of production which is used in ISO 4871[18] for the purpose of making a noise declaration for batches of machines.

5   Determination of σ_{omc}

The standard deviation for the operating and mounting conditions σ_{omc} which describes the uncertainty associated with the instability of the operating and mounting conditions for the particular noise source under test shall be taken into account when determining the measurement uncertainty. It is determined from repeated measurements carried out on the same source at the same location by the same persons, using the same measuring instruments and the same measurement position(s). To determine σ_{omc}, sound pressure level measurements are repeated either at the single microphone position associated with the highest sound pressure level, or at multiple microphone positions. These positions shall be distributed on an enveloping surface in approximated hemi-free fields or in a volume in approximated diffuse fields.

Measurements are then corrected for background noise. Background noise measurements should be taken at the same location, and as close as possible in time to the measurement when the machine is operating. Further, if background sound levels are within 10 dB of the total measured level, then the uncertainty associated with the variation in background sound level should be considered.

For each of these repeated measurements, the mounting of the machine and its operating conditions shall be readjusted. For the individual noise source under test, σ_{omc} is designated as σ'_{omc}. It is possible that a noise test code provides a value of σ_{omc} which is representative for the machine family concerned. This value should take into account all possible variations of operating and mounting conditions specified in the noise test code.

The standard deviation σ'_{omc} is calculated by Formula (4):

$$\sigma'_{\text{omc}} = \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} \left(L_{p,j} - L_{p\text{av}} \right)^2} \tag{4}$$

where

$L_{p,j}$ is the sound pressure level measured at a prescribed position or averaged over the surface or volume and corrected for background noise for the jth repetition of the prescribed operating and mounting conditions, in decibels;

$L_{p\text{av}}$ is its arithmetic mean level calculated for all these repetitions, in decibels;

N is the number of repeated measurements under variation of the prescribed operating and mounting conditions.

In general, the mounting and operating conditions to be used for noise emission measurements are prescribed by machinery specific noise test codes. Otherwise, these conditions shall be defined precisely and described in the test report.

Some recommendations for defining these conditions and consequences for the expected values of σ_{omc} are given hereafter.

The test conditions shall represent normal usage and conform to manufacturers' and users' recommended practice. However, even in normal usage, variations within a specified operation mode, variations in material flow, and other conditions varying between different phases of operation can occur. This uncertainty covers both the uncertainty due to variation in long-term operating conditions (e.g. from day to day) and fluctuations of noise emission measurements repeated immediately after readjusting mounting and operating conditions.

Machines that stand exclusively on soft springs or on heavy concrete floors do not normally exhibit any effect of mounting. However, there can be large discrepancies between measurements on heavy concrete floors and those made *in situ*. The uncertainty due to mounting can be highest for machinery that is connected to auxiliary equipment. Hand-held machines can also cause problems. This parameter should be investigated if movement of the machine or mounts causes changes in noise. If there is a range of possible mounting conditions to be included in a single declaration, then σ_{omc} is estimated from the standard deviation of the sound levels for these mounting conditions. If there is any known effect due to mounting, recommended mounting conditions should be documented in the relevant noise test code or manufacturers' recommended practice.

With respect to the main uncertainty quantity, σ_{tot}, investigations on σ_{omc} have a higher priority compared to those on the other uncertainty components leading to σ_{R0} [see Formula (2)]. This is because σ_{omc} can be significantly larger in practice than e.g. $\sigma_{R0} = 2\,\text{dB}$ for accuracy grade 2 measurements as given in Table 1.

If $\sigma_{\text{omc}} > \sigma_{R0}$, the application of measurement procedures with a high accuracy, i.e. a low value of σ_{R0} makes no sense economically because this is not going to result in a lower value of the total uncertainty.

NOTE   If the sound power has only a small variation with time and the measurement procedure is defined properly, a value of 0,5 dB for σ_{omc} can apply. In other cases, e.g. a large influence of the material flow into and out of the machine or material flow that varies in an unpredictable manner, a value of 2 dB is appropriate. However, in extreme cases such as strongly varying noise generated by the processed material (stone-breaking machines, metal-cutting machines and presses operating under load) a value of 4 dB results.

6   Determination of σ_{R0} by round robin tests

The standard deviation σ_{R0} includes uncertainty due to all conditions and situations allowed by ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746 and ISO 3747 (different radiation characteristics of the source under test, different instrumentation, different implementations of the measurement procedure) except that due to instability of the sound power of the source under test. The latter is considered separately by σ_{omc}.

Typical values of σ_{R0} are given in Table 1. They reflect the knowledge at the time of publication taking into consideration the great variety of machines and equipment covered by these standards (see References [2], [3], [7], [8]). In special cases or if certain requirements of the standards are not met for a machine family or

if it is anticipated that actual values of σ_{R0} for a given family of machines are smaller than those given in the standards respectively, a round robin test is recommended to obtain machine-specific values of σ_{R0}.

Table 1 — Typical values for the standard deviation of reproducibility, σ_{R0}

ISO 3741						
Frequency bandwidth		**One-third-octave**				
One-third-octave mid-band frequency Hz		100 - 160	200 - 315	400 - 5 000	6 300 - 10 000	A-weighted
Standard deviation of reproducibility, σ_{R0} dB		3,0	2,0	1,5	3,0	0,5
ISO 3743-1						
Frequency bandwidth		**Octave**				
Octave mid-band frequency Hz		125	250	500 - 5 000	8 000	A-weighted
Standard deviation of reproducibility, σ_{R0} dB		3,0	2,0	1,5	2,5	1,5
ISO 3743-2						
Frequency bandwidth		**Octave**				
Octave mid-band frequency Hz		125	250	500 - 4 000	8 000	A-weighted
Standard deviation of reproducibility, σ_{R0} dB		5,0	3,0	2,0	3,0	2,0
ISO 3744						
Frequency bandwidth		**One-third-octave**				
One-third-octave mid-band frequency Hz		100 - 160	200 - 315	400 - 5 000	6 300 - 10 000	A-weighted
Standard deviation of reproducibility, σ_{R0} dB		3,0	2,0	1,5	2,5	1,5
ISO 3745						
Frequency bandwidth	**One-third-octave**					
One-third-octave mid-band frequency Hz	50 - 80	100 - 630	800 - 5 000	6 300 - 10 000	12 500 - 20 000	A-weighted
Hemi-anechoic room						
Standard deviation of reproducibility, σ_{R0} dB	2,0	1,5	1,0	1,5	2,0	0,5
Anechoic room						
Standard deviation of reproducibility, σ_{R0} dB	2,0	1,0	0,5	1,0	2,0	0,5
ISO 3746						
						A-weighted
Standard deviation of reproducibility, σ_{R0} dB	For a noise source which emits sound without significant tones					3,0
	For a noise source which emits sound that contains predominant discrete tones					4,0
ISO 3747						
Grade of accuracy						A-weighted

Table 1 (continued)

Standard deviation of reproducibility, σ_{R0} dB	Engineering (grade 2)	$\Delta L_{fA} \geq 7$ at all microphone positions and source directivity range $\leq \pm 7$ dB	1,5
	Survey (grade 3)	$\Delta L_{fA} < 7$ or not determined and source directivity range $\leq \pm 7$ dB	4,0
	Survey (grade 3)	$\Delta L_{fA} \geq 7$ at all microphone positions and source directivity range $> \pm 7$ dB	4,0

The round robin test for determining σ_{R0} shall be carried out in accordance with ISO 5725 (all parts), where the sound power level of the noise source under test is determined under reproducibility conditions, i.e. different persons carrying out measurements at different testing locations with different measuring instruments. Such a test provides the total standard deviation σ'_{tot} relevant for the individual noise source which has been used for the round robin test.

This total standard deviation σ'_{tot}, in decibels, obtained with a round robin test includes the standard deviation σ'_{omc} and allows σ'_{R0} to be determined by using Formula (5):

$$\sigma'_{R0} = \sqrt{(\sigma'_{tot})^2 - (\sigma'_{omc})^2} \qquad (5)$$

If σ'_{R0} values obtained from many different pieces of machinery belonging to the same family deviate within a small range only, their mean value may be regarded as typical for the application of this document to this particular family and used as σ_{R0}. Whenever available, such a value should be given in the noise test code specific to the machine family concerned (together with σ_{omc}) and used in particular for the purpose of declaring noise emission values.

If no round robin test has been carried out, the existing knowledge about the sound power measurement from a particular family of machines may be used to estimate realistic values of σ_{R0}.

For certain applications, the effort involved in a round robin test may be reduced by omitting measurements for different locations, e.g. if machines under test are usually installed under conditions with a small background noise correction K_1 or if the noise emission of a machine is rechecked at the same location. Results of such delimited tests should be denoted by $\sigma_{R0,DL}$, and this designation should also be used for tests on large machines being not movable in space.

Values for $\sigma_{R0,DL}$ can be expected to be lower than those given in in ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746 and ISO 3747.

The determination of σ_{R0} using Formula (5) is imprecise if σ_{tot} is only slightly higher than σ_{omc}. In this case, Formula (5) provides a small value of σ_{R0} but with a low accuracy. To limit this inaccuracy, σ_{omc} should not exceed $\sigma_{tot}/\sqrt{2}$.

It is advised to develop a detailed uncertainty budget (see Clause 7) for the design of a new round robin to ensure that the main uncertainty components are covered by the round robin test.

7 Detailed uncertainty budget to determine σ_{R0}

Generally σ_{R0}, in decibels, is dependent upon several partial uncertainty components, $c_i u_i$, associated with the different measurement parameters such as uncertainties of instruments, environmental corrections,

and microphone positions. Using the modelling approach presented in ISO/IEC Guide 98-3, σ_{R0} can be described by Formula (6):

$$\sigma_{R0} \approx \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + \ldots + (c_n u_n)^2 + 2 \sum_{i=1}^{N-1} \sum_{j=j+1}^{N} c_i c_j u(x_i, x_j)} \tag{6}$$

where $u(x_i, x_j)$ is the covariance associated with the ith and j^{th} uncertainty components.

If the contributions in Formula (6) are assumed to be not correlated, σ_{R0} can be given by Formula (7):

$$\sigma_{R0} \approx \sqrt{(c_1 u_1)^2 + (c_2 u_2)^2 + \ldots + (c_n u_n)^2} \tag{7}$$

For consistency with Formula (5), in Formulae (6) and (7) the uncertainty components due to the instability of the sound emission of the source are not included. These components are covered by σ_{omc}.

NOTE   The modelling approach requires detailed knowledge to determine the individual terms in Formulae (6) and (7).

By contrast, the estimation of σ_{R0} based on a round robin test does not require assumptions about possible correlations between the individual terms of Formulae (6) and (7). A round robin test is currently more realistic than determining possible correlations between the single terms of Formulae (6) and (7) and their dependencies on all other influencing parameters using the modelling approach. However, round robin tests are not always possible and are often replaced by experience from earlier measurements.

The modelling approach, however, implies both statistically independent components c_i, u_i and especially the existence of Formulae which allow assessment of these uncertainty components by considering either measurement parameters and environmental conditions or a reasonably large body of practical experience. However, relevant well-founded data for this part of this document were not available at the time of publication. However, Annex A, Annex B and Annex C give a rough outline of the relevant quantities without being definitive. It is recommended to validate the results from detailed uncertainty budgets by round robin testing (see Clause 6).

8   Determination of σ_{tot}

The total standard deviation and the expanded measurement uncertainty shall be determined using Formula (2) and Formula (3), respectively. Examples are given in Table 2.

Table 2 — Examples of calculated total standard deviations σ_{tot} for three different cases

Standard deviation of reproducibility of the method, σ_{R0}, dB	Operating and mounting conditions		
	stable	unstable	very unstable
	Standard deviation, σ_{omc}, dB		
	0,5	2,0	4,0
	Total standard deviation, σ_{tot}, dB		
0,5 (Accuracy grade 1)	0,7	2,1	4,0
1,5 (Accuracy grade 2)	2,1	2,8	4,5
3 (Accuracy grade 3)	3,0	3,6	5,0

The examples show that it might be superfluous to extend the measuring effort to ensure a measurement of accuracy grade 1 if the uncertainty associated with the mounting and operating conditions is large.

Furthermore $\sigma_{\text{omc}} > \sigma_{R0}$ might create substantial misunderstandings with respect to the true relevant total standard deviation, σ_{tot}, because the different grades of accuracy are, at the time of publication, specified by the value of σ_{R0} only.

Annex A
(informative)

Detailed uncertainty budget for sound power determinations in (approximated) free fields according to the direct enveloping method

A.1 Model formula

Preliminary estimations show that when corrected for meteorological conditions, the sound power level, L_W, determined in (approximated) free field according to ISO 3744, ISO 3745 or ISO 3746, is a function of a number of parameters, indicated by Formula (A.1) (see ISO/IEC Guide 98-3[20]):

$$L_W = \overline{L'_{p(\mathrm{ST})}} + 10\lg\left(\frac{S}{S_0}\right)\mathrm{dB} - K_1 - K_2 + C_1 + C_2 + C_3 + \delta_{\mathrm{angle}} + \delta_{\mathrm{mic}} + \delta_{\mathrm{slm}} + \delta_{\mathrm{tone}} + \delta_{\mathrm{method}} + \delta_{\mathrm{omc}} \quad (\text{A.1})$$

Formula (A.1) is a general formulation for all direct free-field methods. Not all quantities are explicitly mentioned in all standardised procedures, e.g. K_2 is omitted in ISO 3745, and C_3 is omitted in ISO 3744 and ISO 3746.

The parameters included in Formula (A.1) are explained in Table A.1.

Table A.1 — Explanation for quantities used in Formula (A.1)

$\overline{L'_{p(\mathrm{ST})}}$	is the mean (in octave band or one-third-octave band) sound pressure level of the noise source under test, before background corrections are applied, in decibels;
S	is the total surface area, in square metres, of the measurement surface;
S_0	$= 1$ m^2;
K_1	is the background noise correction, in decibels;
K_2	is the environmental correction, in decibels;
C_1	is a meteorological correction to account for the different decibel reference quantities used in sound pressure level and in sound power level, in decibels $$C_1 = -10\lg\frac{p_s}{p_{s,0}}\mathrm{dB} + 5\lg\left[\frac{273,15 + \theta\,/\,{}^\circ\mathrm{C}}{\theta_0\,/\,\mathrm{K}}\right]\mathrm{dB};$$
C_2	is a source order correction to account for changes in sound power with temperature and pressure, the value shall be obtained from the appropriate noise test code. In the absence of a noise test code, the following formula may be used. It is valid for a monopole source and also a mean value for other sources (see References [1] and [4]) $$C_2 = -10\lg\frac{p_s}{p_{s,0}}\mathrm{dB} + 15\lg\left[\frac{273,15 + \theta\,/\,{}^\circ\mathrm{C}}{\theta_1\,/\,\mathrm{K}}\right]\mathrm{dB};$$
C_3	is the correction for air absorption, in decibels (see Reference [5]);
p_s	is the ambient pressure, in pascals, at the time of test;
$p_{s,0}$	is the reference ambient pressure, 101,325 kPa;
θ	is the air temperature, in degrees Celsius, at the time of test;
θ_0	$= 314$ K;
θ_1	$= 296$ K;
δ_{angle}	is an input quantity to account for any difference of angle between the direction in which the sound is emitted by the source and the normal to the measurement surface, in decibels;

Table A.1 *(continued)*

δ_{mic}	is an input quantity to allow for any uncertainty due to the finite number of microphone positions, in decibels;
δ_{slm}	is an input quantity to allow for any uncertainty in the measuring instrumentation, in decibels;
δ_{tone}	is an input quantity to allow for any uncertainty due to spectral shape and the presence of tones, in decibels;
δ_{method}	is an input quantity to allow for any uncertainty due to the measurement method applied including the derivation of results and associated uncertainties, in decibels;
δ_{omc}	is an input quantity to allow for any uncertainty due to operating and mounting conditions, in decibels — this quantity is not included in the calculation of σ_{R0} [see Formula (2)].

NOTE 1   The input quantities included in Formula (A.1) to allow for uncertainties are those thought to be applicable at the state of knowledge current at the time of publication of this document, but further research could reveal that there are others.

NOTE 2   Similar expressions as Formula (A.1) apply with respect to sound power levels determined in frequency bands and with A-weighting applied.

NOTE 3   A similar expression as Formula (A.1) applies to sound energy levels.

A probability distribution (normal, rectangular, Student-*t*, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty.

The uncertainty components related to mounting and operating conditions are already covered by σ_{omc} whereas σ_{R0} includes the remaining uncertainty components.

NOTE 4   In case of specific families of noise sources, e. g. for a certain type of machinery, the values in this annex can be explicitly checked. Smaller values can be expected. For purposes where the sound power levels are compared with limit values, the measured variation in δ_{angle} can be reduced when the noise test code specifies a single measurement surface shape and a measurement distance related to the source dimensions. In practice, this allows a smaller value of the total standard deviation σ_{tot} to be declared.

The standard uncertainties from some contributions remain to be established by research.

A.2   Explanation and numerical example for the uncertainty parameters

An explanation and numerical example for the uncertainty parameters are given in Table A.2. Formulae to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

Table A.2 — Uncertainty budget for determination of σ_{R0} for sound power level using the direct method

Quantity		Estimate dB	Standard uncertainty, u_i	Probability distribution	Sensitivity coefficient, c_i
$\overline{L'_{p(\text{ST})}}$	mean sound pressure level	$\overline{L'_{p(\text{ST})}}$	$\dfrac{u_{\overline{L'_{p(\text{ST})}}}}{\sqrt{N}}$	Normal	$1 + \dfrac{1}{10^{0,1\Delta L_p/\text{dB}}-1}$
$10\lg\left(\dfrac{S}{S_0}\right)$	measurement surface area	$10\lg\left(\dfrac{S}{S_0}\right)$	$8,7\dfrac{\Delta r}{\sqrt{3}\,r}\text{dB}$	Rectangular	1
K_1	background noise correction	K_1	$s_{L_{p(\text{B})}}$	Normal	$\dfrac{1}{10^{0,1\Delta L_p/\text{dB}}-1}$
K_2	environmental correction	K_2	$\sqrt{u^2\left(L_W^*\right)+u^2\left[L_{W(\text{RSS})}\right]}$	Normal	1
C_1	decibel reference correction	C_1	0	Triangular	1

Table A.2 *(continued)*

Quantity		Estimate dB	Standard uncertainty, u_i	Probability distribution	Sensitivity coefficient, c_i
C_2	source order correction	C_2	0,2 dB	Triangular	1
C_3	air absorption correction	C_3	0,1 C_3 to 0,3 C_3	Rectangular	1
δ_{angle}	angle	0	Box: $0,05\,\mathrm{dB}+0,6\lg\left(\dfrac{S}{d^2}\right)\mathrm{dB}$ Hemisphere: $\dfrac{-1,1\,\mathrm{dB}}{1-1,3\left(\dfrac{r}{d_0}\right)^2}$	Rectangular	1
δ_{mic}	sampling	0	$\dfrac{u_{L'_{p(\mathrm{ST})}}}{\sqrt{N_M}}$	Normal	1
δ_{slm}	sound level meter	0	Class 1: 0,3 dB Class 2: 1,0 dB	Normal	1
δ_{tone}	spectral shape	0	Audible tones: 3 dB Otherwise: 0	Normal	1
δ_{method}	method	0	0,3 dB	Normal	1

A.3 Uncertainty of the mean sound pressure level

The uncertainty of the mean sound pressure level may be obtained from the standard deviation of repeatability, using N measurements of the decibel sound pressure levels at a single microphone position (without correction for background noise), as given in Formula (A.2):

$$u_{\overline{L'_{p(\mathrm{ST})}}} = \frac{1}{\sqrt{N}}\sqrt{\sum_{j=1}^{N}\frac{\left[L'_{p(\mathrm{ST}),j}-L'_{p(\mathrm{ST})\mathrm{av}}\right]^2}{N-1}} \tag{A.2}$$

These measurements are made under repeatability conditions.

Measurement repeatability can also be strongly influenced by averaging time. High background noise level can cause high values of $u_{L'_{p(\mathrm{ST})}}$ due solely to the fluctuations in background noise. If the averaging time does not cover a sufficient number of machinery cycles, the total uncertainty can be unacceptably large for any grade standard. This component of uncertainty can often be made negligible with a sufficiently long averaging time consisting of an integer number of work cycles. For extremely low noise sources, reduction of background noise can reduce the sensitivity coefficient and hence total uncertainty by up to a factor of 2.

The sensitivity coefficient is given by Formula (A.3):

$$c_{L'_{p(\mathrm{ST})}} = 1 + \frac{1}{10^{0,1\Delta L_p/\mathrm{dB}}-1} \tag{A.3}$$

A.4 Uncertainty of the measurement surface area, S

For a hemispherical measurement surface, the estimate for $S = 2\pi r^2$ is calculated for a given value of the radius of the hemisphere. The standard uncertainty depends on the uncertainty of the realisation of the defined microphone positions on this surface. If the uncertainty in the measurement surface dimensions is

assumed to have a rectangular distribution with a range of $\pm\Delta r$, the standard deviation results in Formula (A.4):

$$u_S = \Delta r \big/ \sqrt{3} \tag{A.4}$$

Similar results apply for a box surface. If the uncertainty in the measurement surface dimensions is assumed to have a rectangular distribution with a range of $\pm\Delta d$, the standard deviation is given by Formula (A.5):

$$u_S = \Delta d \big/ \sqrt{3} \tag{A.5}$$

where d is the distance from the reference box to a parallelepiped measurement surface.

The sensitivity coefficient, c_S, is obtained from the derivative of L_W from Formula (A.1) with respect to r. After substitution for the surface area $S = 2\pi r^2$, the sensitivity coefficient is $c_S = 8{,}7\,\text{dB}/r$ for a hemisphere or $c_S = 8{,}7\,\text{dB}/d_0$ for a box surface, where d_0 is the characteristic source dimension.

In an extreme scenario, the range for Δr is 7 % of r, resulting in an uncertainty contribution, $c_S u_s$ of 0,4 dB. Typically, an uncertainty contribution of 0,1 dB is achievable with very careful microphone positioning.

A.5 Uncertainty of the background noise correction, K_1

The uncertainty, u_{K_1}, due to the background noise correction, K_1, is obtained from the standard deviation, $s_{L_{p(\text{B})}}$, of the decibel values from repeated measurements of background noise at a single microphone position.

The sensitivity coefficient, c_{K_1}, due to the background noise level, $\overline{L_{p(\text{B})}}$, is obtained from the derivative of L_W from Formula (A.1) with respect to $\overline{L_{p(\text{B})}}$. The parameters in L_W that are related to the source measurement are given by $\overline{L_{p(\text{ST})}} = \overline{L'_{p(\text{ST})}} + 10\lg\left(1 - 10^{-0{,}1\Delta L_p}\right)\text{dB}$, where $\Delta L_p = \overline{L'_{p(\text{ST})}} - \overline{L_{p(\text{B})}}$. In this example, the sign of the sensitivity coefficient is unimportant, and reduces to Formula (A.6):

$$\left| c_{K_1} \right| = \frac{1}{10^{0{,}1\Delta L_p/\text{dB}} - 1} \tag{A.6}$$

Lowering the fluctuations in background noise can reduce this uncertainty component. Significant reductions in the sensitivity coefficient are obtained by reducing background noise by systematically tracking down and blocking and/or absorbing noise from unwanted sources (through proper grounding, lead wrapping, vibration isolation, adding mass, adding absorptive materials, etc., as appropriate). Furthermore, the uncertainty, u_{K_1}, is typically halved each time the averaging time is increased by a factor of four. In large rooms, the sound pressure caused by the noise source under test is higher near noise sources, and background noise can be reduced by measuring closer to the noise source under test. The influence of background noise is reduced by 3 dB when the measurement surface area is reduced by a factor of 2 for enveloping surfaces methods.

A.6 Uncertainty of the environmental correction, K_2

For the absolute comparison test, the uncertainty of the environmental correction, K_2, is given by Formula (A.7).

$$u(K_2) = \sqrt{u^2\left(L_W^*\right) + u^2\left[L_{W(\mathrm{RSS})}\right]} \tag{A.7}$$

where $u\left(L_W^*\right)$ is the uncertainty of the measured sound power level of the reference sound source without applying the environmental correction ($K_2 = 0$) and $u\left[L_{W(\mathrm{RSS})}\right]$ is the uncertainty of the sound power level of the reference sound source calculated from the calibrated sound power level and the meteorological conditions at calibration and at the measurements providing the input for Formula (A.6).

For a K_2-determination based on the equivalent absorption area, A, the uncertainty of the environmental correction depends on how the equivalent absorption area is determined. When it is determined by measurement of reverberation time, T, the uncertainty of the environmental correction is given by Formula (A.8):

$$u(K_2) = \frac{10}{\ln(10)}\left(1 - 10^{-0,1K_2/\mathrm{dB}}\right)\frac{u(T)}{T}\,\mathrm{dB} \tag{A.8}$$

where $u(T)$ is the uncertainty of the reverberation time.

When the equivalent absorption area is determined by the two-surface method with averaged sound pressure levels $\overline{L_{p,1}}$ measured on the smaller surface and $\overline{L_{p,2}}$ measured on the larger surface, the uncertainty of the environmental correction is given by Formula (A.9):

$$u(K_2) = \sqrt{\left[\frac{10\,\mathrm{dB}}{\ln(10)}\frac{u(S_1/S_2)}{1 - S_1/S_2}\right]^2 + \left[\frac{u\left(\overline{L_{p,1}} - \overline{L_{p,2}}\right)}{10^{0,1\left(\overline{L_{p,1}} - \overline{L_{p,2}}\right)/\mathrm{dB}} - 1}\right]^2} \tag{A.9}$$

where $u\left(\overline{L_{p,1}} - \overline{L_{p,2}}\right)$ is the uncertainty of the sound pressure level difference and in the case that $u(S_1)/S_1$ and $u(S_2)/S_2$ are equal and independent, Formula (A.10) applies:

$$u(S_1/S_2) = \sqrt{2}\,\frac{S_1}{S_2}\frac{u(S_1)}{S_1} \tag{A.10}$$

When the equivalent absorption area is determined by a reference sound source, the uncertainty of the environmental correction is given by Formula (A.11):

$$u(K_2) = \sqrt{u^2\left(\overline{L_{p,\mathrm{in\,situ}}}\right) + u^2\left[L_{W(\mathrm{RSS})}\right]} \tag{A.11}$$

where $u\left(\overline{L_{p,\mathrm{in\,situ}}}\right)$ is the uncertainty of the mean sound pressure level of the reference sound source mounted near to the noise source under test, corrected for background noise but not for the influence of the environment and $u\left[L_{W(\mathrm{RSS})}\right]$ is the uncertainty of the sound power level of the calibrated reference sound source under the meteorological conditions of the test.

Formulas (A.8), (A.9), (A.10) are derived under the assumption, that uncertainties due to surface areas and room volumes can be neglected.

The corresponding sensitivity coefficient is given by $c_{K_2} = 1$.

A smaller uncertainty contribution could be obtained by reducing the measurement distance, or reduction of K_2 by changing rooms, adding absorption in the room, or opening large doors and windows, or making

measurements outdoors. This uncertainty component could be made very small in an outdoor measurement or by measurement in a hemi-anechoic room.

NOTE   Air contributes a substantial amount to the absorption of high frequency sound.

A.7 Uncertainty of the meteorological corrections C_1, C_2 and C_3

The decibel reference correction is associated with a negligible uncertainty when temperature and static pressure are measured with a relative uncertainty of 1 % or better, i.e. $u_{C_1} = 0\,\text{dB}$. The correction has a direct effect on the measurement, so that $c_{C_1} = 1$, and the total uncertainty contribution is 0 dB.

A typical uncertainty, u_{C_2}, remaining after the correction for the source order is $u_{C_2} = 0,2\,\text{dB}$. This correction has a direct effect on the measurement so that $c_{C_2} = 1$ and the total uncertainty contribution is 0,2 dB. A lower uncertainty contribution can be obtained by measuring under the reference conditions of 101,325 kPa absolute pressure (i.e. at sea level) and 23 °C, by measuring in a different location, or by applying the appropriate correction depending on the source type.

The contribution to the uncertainty in the sound power level, L_W, due to the correction for air absorption is $c_{C_3} u_{C_3} = 0,1 C_3$, provided the attenuation coefficient $\alpha(f)$ is obtained from ISO 9613-1[9]. Otherwise, if C_3 is estimated using the approximation in ISO 3745:2012, 9.4.4.1, NOTE 2, the uncertainty contribution is $c_{C_3} u_{C_3} = 0,3 C_3$. Typically, this uncertainty contribution is negligible at 1 000 Hz for a 2 m radius measurement, but can rise to 0,5 dB at 10 kHz with an 8 m radius measurement. These results were obtained assuming C_3 is given by $C_3 \approx \alpha_0 r(f/10\,000)$, where $\alpha_0 = 0,2\,\text{dB/m}$ and $u_{\alpha_0} = 0,1/\sqrt{3}\,\text{dB/m}$ (the denominator is based on an assumed rectangular distribution for α_0). The associated sensitivity coefficient is $c_{\alpha_0} = r(f/10\,000)$. The dominant contribution to uncertainty in C_3 is due to α_0 and uncertainty components due to f and r can be ignored.

A.8 Uncertainty due to the angle, δ_{angle}

The uncertainty due to the incident angle of the sound wave is denoted u_{angle}. The use of sound pressure to approximate the sound intensity basically leads to an overestimate of the sound power. The magnitude of this overestimation depends on the sound source, its directional characteristics and the measurement distance. No generally valid relationships either for an approximate estimate or for its standard uncertainty can be given. The derivation of a value for a reasonable standard uncertainty by investigating different sound sources using different methods (i.e. sound pressure versus sound intensity measurements) is recommended.

For a box shaped measurement surface the overestimate ranges between 0 dB and $1,4\lg\left(S/d^2\right)\,\text{dB}$, depending on the angle of the incident sound. The magnitude of the correction depends on the source and shall be specified in a noise test code. The largest overestimate occurs when sound is produced from a localized position near the centre of the bottom edge of the measurement surface, an example would be a reference sound source positioned near a very large machine. For a given box shaped measurement surface, the standard uncertainty is approximately as given by Formula (A.12) (see Reference [6]):

$$u_{\text{angle}} = 0,05\,\text{dB} + 0,6\lg\left(\frac{S}{d^2}\right)\text{dB} \tag{A.12}$$

where

    d is the distance to the measurement surface, in metres;

    S is the measurement surface area, in square metres;

For a hemispherical measurement surface, the overestimate depends on the angle of the incident sound, (i.e. the intensity and coherence of sound produced by different parts of the source). The overestimate ranges between 0 dB and $\left\{-2/\left[1-1{,}3(r/d_0)^2\right]\right\}\text{dB}$, where d_0 is the characteristic dimension of the noise source. The largest overestimate can occur when sound is produced from localized position(s) near the top corner(s) of the source. For a hemispherical measurement surface in a free field above a reflecting plane, the standard deviation is given by Formula (A.13):

$$u_{\text{angle}} = \frac{-1{,}1}{1-1{,}3(r/d_0)^2}\ \text{dB} \tag{A.13}$$

In individual frequency bands, the uncertainty u_{angle} is affected by the microphone directivity. Using a 1/2" microphone below 4 kHz, Formula (A.12) is appropriate. At higher frequencies, this uncertainty is gradually reduced and the ±30° directional response starts to approximate that of an intensity probe. At 10 kHz, $u_{\text{angle}} = 0\,\text{dB}$, and at higher frequencies the microphone shall be pointed at the source of sound radiation to avoid underestimating levels.

Furthermore, the uncertainty due to the incident angle is influenced by the environmental correction K_2. The corresponding sensitivity coefficient is given by $c_{\text{angle}} = 10^{-K_2/\text{dB}}$. The angle error only affects the direct sound field from the source. The sensitivity coefficient c_{angle} is obtained from the derivative of $\partial \overline{L_p}\,/\,\partial \overline{L_{p(\text{direct})}}$ using Formula (A.14):

$$L_p = 10\lg\left(10^{0{,}1\,\overline{L_{p(\text{direct})}}\,/\text{dB}} + 10^{0{,}1\,\overline{L_{p(\text{reverb})}}\,/\text{dB}}\right)\text{dB} \tag{A.14}$$

where

$\overline{L_{p(\text{direct})}}$ is the sound pressure level from the direct field of the source, in decibels;

$\overline{L_{p(\text{reverb})}}$ is the level of the sound pressure contribution from the reverberant sound, in decibels;

The derivative is simplified by assuming $K_2 = L_p - \overline{L_{p(\text{direct})}}$. For a worst-case scenario, assume a cubic measurement surface located very close to a large noise source under test. For example, a source with typical height, width and depth of 8 m, with a measurement distance of 1 m would have $u_{\text{angle}} = 1{,}6\,\text{dB}$ (ISO 3744:2024, Annex C, also indicates that at such a close measurement distance over 100 measurement points would be required). The sensitivity coefficient has a maximum value $c_{\text{angle}} = 1$ when $K_2 = 0\,\text{dB}$ dB (i.e. outdoors). More typically, a measurement surface with nine points, would reduce to 1,0 dB, with $K_2 = 2\,\text{dB}$, the sensitivity coefficient $c_{\text{angle}} = 0{,}6\,\text{dB}$, and the total contribution to uncertainty $c_{\text{angle}}u_{\text{angle}} = 0{,}6\,\text{dB}$. For a given measurement surface the uncertainty contribution, $c_{\text{angle}}u_{\text{angle}}$, is reduced for a larger K_2. The uncertainty contribution could be reduced by increasing the measurement distance. For large measurement distances, a hemispherical measurement surface according to ISO 3744 can reduce this uncertainty contribution below 0,25 dB.

In ISO 3745, the smallest r is $2d_0$, so the worst case $u_{\text{angle}} = 0{,}26\,\text{dB}$. In many cases, the measurement radius is larger than the minimum, so the typical total contribution to uncertainty $c_{\text{angle}}u_{\text{angle}} = 0{,}1\,\text{dB}$. This uncertainty contribution can be reduced using a larger measurement radius or by correction for the bias component of u_{angle}. However, the magnitude of the bias correction is unique to each source and shall be specified in a noise test code.

A.9 Uncertainty due to sampling, δ_{mic}

The uncertainty of the surface averaged sound pressure level due to a finite number of microphone positions, u_{mic}, is given by:

$$u_{\text{mic}} = \frac{u_{L'_{p(\text{ST})}}}{\sqrt{N_M}} = \frac{1}{\sqrt{N_M}} \sqrt{\sum_{i=1}^{N_M} \frac{\left[L'_{p(\text{ST}),i} - L'_{p(\text{ST})\text{av}} \right]^2}{N_M - 1}} \tag{A.15}$$

where

$L'_{p(\text{ST}),i}$ is the sound pressure level, uncorrected for background noise, measured at position i, in decibels;

$L'_{p(\text{ST})\text{av}}$ is its arithmetic mean level calculated for all microphone positions, in decibels;

N_M is the number of microphone positions;

The sampling has a direct effect on the measurement result so the sensitivity coefficient, $c_{\text{mic}} = 1$.

A.10 Uncertainty due to the sound level meter, δ_{slm}

The estimate of δ_{slm} is zero and the corresponding sensitivity coefficient is 1. The standard uncertainty u_{slm} due to performance deviations of the measuring instrumentation from nominal performance depends on the class of instrumentation in accordance with IEC 61672-1[10] and on frequency and other characteristics of the noise to be measured.

For sound power measurements the uncertainty in the measuring instrumentation, u_{slm}, for a class 1 instrument is $u_{\text{slm}} = 0,3\,\text{dB}$. This figure is consistent with variations found by experience between national laboratories.

Uncertainties in the sound level meter directly affect measured levels, so that $c_{\text{slm}} = 1$.

Additional details regarding parameters affecting the uncertainty of sound level meters can be found in IEC 61672-1[10].

A.11 Uncertainty due to the spectral shape, δ_{tone}

When the sound pressure in the considered frequency band is dominated by one tone, a limited number of microphone positions can increase uncertainty related to interference effects. In such a case, experience suggests that $u_{\text{tone}} = 3\,\text{dB}$. Typically, in cases where there are no tones, or when measurements are made with enough microphone positions, $u_{\text{tone}} = 0\,\text{dB}$. The sensitivity coefficient $c_{\text{mic}} = 1$. When tones are present, the uncertainty contribution can be reduced by increasing the number of measurement positions.

A.12 Uncertainty due to the measurement method, δ_{method}

The uncertainty due to the measurement method applied, u_{method}, is due to the fact, that Formula (A.1) is valid only for perfectly free fields or for the superposition of an ideal free field with an ideal diffuse field. If these conditions are not fully met, the relation between the sound power level emitted by the source and the sound pressure level on an enveloping surface can be different from Formula (A.1). The closeness between underlying assumptions and real measurement situations cannot be described by a mathematical model at the time when this standard is written.

Nevertheless, experience shows that a realistic estimate is $u_{\text{method}} \approx 0,3\,\text{dB}$.

The measurement method has a direct effect on the measurement result so the sensitivity coefficient, $c_{\text{method}} = 1$.

Annex B
(informative)

Detailed uncertainty budget for sound power determinations in (approximated) diffuse fields according to the direct method

B.1 Model formula

Preliminary estimations show that when corrected for meteorological conditions, the sound power level, L_W, determined in a (approximated) diffuse field according to ISO 3741 is a function of a number of parameters, indicated by Formula (B.1) (see ISO/IEC Guide 98-3[20]):

$$L_W = \overline{L'_{p(\text{ST})}} + 10\lg\left(\frac{A}{A_0}\right)\text{dB} + 4,34\left(\frac{A}{S}\right)\text{dB} + 10\lg\left(1 + \frac{S\,c}{8\,f\,V}\right)\text{dB} - K_1 + C_1 + C_2 + \delta_{\text{mic}} + \delta_{\text{slm}} + \tag{B.1}$$

$$\delta_{\text{tone}} + \delta_{\text{method}} + \delta_{\text{omc}} - 6\ \text{dB}$$

The parameters included in Formula (B.1) are explained in Table B.1.

Table B.1 — Explanation for quantities used in Formula (B.1)

$\overline{L'_{p(\text{ST})}}$	is the mean (in octave band or one-third-octave band) sound pressure level of the noise source under test, before background corrections are applied, in decibels;
A	is the equivalent absorption area, in square metres, of the room;
A_0	=1 m^2;
S	is the total surface area, in square metres, of the measurement room;
c	is the speed of sound, in metres per second, at the temperature, θ, in degrees Celsius, of the air in the test room at the time of test; $c = 20,05\sqrt{273,15 + \theta\,/\,^\circ\text{C}}$ m/s;
V	is the volume, in cubic metres, of the measurement room;
f	is the mid-band frequency, in Hertz, of the measurement(s);
K_1	is the background noise correction, in decibels;
C_1	is a meteorological correction to account for the different decibel reference quantities used in sound pressure level and in sound power level, in decibels $C_1 = -10\lg\frac{p_{\text{S}}}{p_{\text{S},0}}\text{dB} + 5\lg\left[\frac{273,15 + \theta\,/\,^\circ\text{C}}{\theta_0\,/\,\text{K}}\right]\text{dB}$;
C_2	is a source order correction to account for changes in sound power with temperature and pressure, the value shall be obtained from the appropriate noise test code. In the absence of a noise test code, the following formula may be used. It is valid for a monopole source and also a mean value for other sources (see References [1] and [4]) $C_2 = -10\lg\frac{p_{\text{S}}}{p_{\text{S},0}}\text{dB} + 15\lg\left[\frac{273,15 + \theta\,/\,^\circ\text{C}}{\theta_1\,/\,\text{K}}\right]\text{dB}$;
p_{S}	is the ambient pressure, in pascals, at the time of test;
$p_{\text{S},0}$	is the reference ambient pressure, 101,325 kPa;
θ	is the air temperature, in degrees Celsius, at the time of test;
θ_0	= 314 K;
θ_1	= 296 K;

Table B.1 (continued)

δ_{mic}	is an input quantity to allow for any uncertainty due to the finite number of microphone positions, in decibels;
δ_{slm}	is an input quantity to allow for any uncertainty in the measuring instrumentation, in decibels;
δ_{tone}	is an input quantity to allow for any uncertainty due to spectral shape and the presence of tones, in decibels;
δ_{method}	is an input quantity to allow for any uncertainty due to the measurement method applied including the derivation of results and associated uncertainties, in decibels;
δ_{omc}	is an input quantity to allow for any uncertainty due to operating and mounting conditions, in decibels — this quantity is not included in the calculation of σ_{R0} [see Formula (2)].

NOTE 1   The input quantities included in Formula (B.1) to allow for uncertainties are those thought to be applicable at the state of knowledge current at the time of publication of this document, but further research could reveal that there are others.

NOTE 2   Similar expressions as Formula (B.1) apply with respect to sound power levels determined in frequency bands and with A-weighting applied.

NOTE 3   A similar expression to that of Formula (B.1) applies to sound energy levels.

A probability distribution (normal, rectangular, Student-t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty.

The uncertainty components related to mounting and operating conditions are already covered by σ_{omc} whereas σ_{R0} includes the remaining uncertainty components.

NOTE 3   In case of specific families of noise sources, e. g. for a certain type of machinery, the values in this annex can be explicitly checked. Smaller values can be expected.

The standard uncertainties from some contributions remain to be established by research.

B.2   Explanation and numerical example for the uncertainty parameters

An explanation and numerical example for the uncertainty parameters are given in Table B.2. Formulae to calculate uncertainties are given with examples to show the expected range of measurement uncertainties.

Table B.2 — Uncertainty budget for determination of σ_{R0} for sound power level using the direct method, valid for measurements of a source with a relatively flat frequency spectrum

Quantity		Estimate dB	Standard uncertainty, u_i	Probability distribution	Sensitivity coefficient, c_i
$\overline{L'_{p(\text{ST})}}$	mean sound pressure level	$\overline{L'_{p(\text{ST})}}$	$\dfrac{u_{\overline{L'_{p(\text{ST})}}}}{\sqrt{N}}$	Normal	$1 + \dfrac{1}{10^{0,1\Delta L_p/\text{dB}} - 1}$
A	equivalent absorption area	A	$u_A \approx 0,1\,A$	Normal	$4,3\left(\dfrac{1}{A} + \dfrac{1}{S}\right)\text{dB}$
S	room surface area	s	$u_S \approx 0,05\,S$	Normal	$4,3\left(\dfrac{A}{S^2} + \dfrac{c}{8\,f\,V + S\,c}\right)\text{dB}$
V	room volume	V	$u_V \approx 0,05\,V$	Normal	$\dfrac{4,3}{V}\dfrac{S\,c}{8\,f\,V + S\,c}\text{dB}$
K_1	background noise correction	K_1	$s_{L_{p(\text{B})}}$	Normal	$\dfrac{1}{10^{0,1\Delta L_p/\text{dB}} - 1}$
C_1	decibel reference correction	C_1	0	Triangular	1

Table B.2 *(continued)*

	Quantity	Estimate dB	Standard uncertainty, u_i	Probability distribution	Sensitivity coefficient, c_i
C_2	source order correction	C_2	0,2 dB	Triangular	1
δ_{mic}	sampling	0	$\dfrac{u_{L'_{p(ST)}}}{\sqrt{N_M N_S}}$	Normal	1
δ_{slm}	sound level meter	0	Class 1: 0,3 dB Class 2: 1,0 dB	Normal	1
δ_{tone}	spectral shape	0	Audible tones: 3 dB Otherwise: 0	Normal	1
δ_{method}	method	0	0,3 dB	Normal	1

B.3 Uncertainty due to the equivalent absorption area, A

The equivalent absorption area, A, is determined from Formula (B.2):

$$A = \frac{55,26}{c}\left(\frac{V}{T_r}\right) \tag{B.2}$$

where

T_r is the reverberation time, in seconds, of the test room at the midband frequency of the measurement(s);

V is the test room volume, in cubic meters;

c is the speed of sound, in m/s;

Experience shows, that the uncertainty of the equivalent absorption area is dominated by the uncertainty of the reverberation time measurement. The contributions from the room volume and from the speed of sound can be neglected. A realistic estimate can be given by $u_A \approx 0,1\,A$. At low and very high frequencies, this value can be exceeded whereas it can be lower at medium frequencies.

The sensitivity coefficient, c_A, due to the equivalent absorption area, A, is obtained from the derivative of L_W from Formula (B.1) with respect to A. This gives Formula (B.3):

$$c_A = 4,3\left(\frac{1}{A}+\frac{1}{S}\right)\text{dB} \tag{B.3}$$

The equivalent absorption area in a room depends also on humidity and temperature. It is therefore recommended to keep humidity and temperature constant during sound pressure and reverberation time measurement. If this cannot be ensured, additional uncertainty components are to be considered, especially at high frequencies.

With the given estimates, the uncertainty contribution from the equivalent absorption area is about 0,4 dB.

B.4 Uncertainty due to the room surface area S

The uncertainty, u_S, due to the room surface area, S, depends on the uncertainty of the measurement of the room geometry. With modern equipment, an uncertainty of $u_S \approx 0,05\,S$ can easily be obtained.

The sensitivity coefficient, c_S, due to the room surface area S is obtained from the derivative of L_W from Formula (B.1) with respect to S. This gives Formula (B.4):

$$c_S = 4{,}3 \left(\frac{A}{S^2} + \frac{c}{8\,f\,V + S\,c} \right) \text{dB} \tag{B.4}$$

The uncertainty contribution of room surface area is for normal test room dimensions and equivalent absorption areas less than 0,1 dB.

B.5   Uncertainty due to the room volume V

The uncertainty, u_V, due to the room volume, V, depends on the uncertainty of the measurement of the room geometry. With modern equipment, an uncertainty of $u_V \approx 0{,}05\,V$ can easily be obtained.

The sensitivity coefficient, C_V, due to the room volume, V, is obtained from the derivative of L_W from Formula (B.1) with respect to V. This gives Formula (B.5):

$$c_V = \frac{4{,}3}{V} \frac{S\,c}{8\,f\,V + S\,c} \text{dB} \tag{B.5}$$

The uncertainty contribution of room volume is for normal test room dimensions less than 0,1 dB.

B.6   Uncertainty due to sampling, δ_{mic}

The uncertainty due to a limited number of source and microphone positions may be obtained from the standard deviation of measured levels at different source and microphone positions given by Formula (B.6):

$$u_{L'_{p(\text{ST})}} = \frac{u_{L'_{p(\text{ST})}}}{\sqrt{N_M N_S}} = \frac{1}{\sqrt{N_M N_S}} \sqrt{\sum_{j=1}^{N_S} \sum_{i=1}^{N_M} \frac{\left\{ \left[L'_{p(\text{ST}),i} \right]_j - L'_{p(\text{ST})\text{av}} \right\}^2}{N_M N_S - 1}} \tag{B.6}$$

where

$\left[L'_{p(\text{ST}),i} \right]_j$ is the sound pressure level, uncorrected for background noise, measured at the ith microphone position for the jth source position, in decibels;

$L'_{p(\text{ST})\text{av}}$ is the arithmetic mean level calculated for all the microphone and source positions, in decibels;

N_M is the number of microphone positions;

N_S is the number of source positions;

The sampling has a direct effect on the measurement result so the sensitivity coefficient, $c_{\text{mic}} = 1$.

B.7   Uncertainty due to the measurement method, δ_{method}

The uncertainty due to the measurement method applied, u_{method}, is due to the fact, that Formula (B.1) is valid only for an ideal diffuse field. If this is not the case, the relation between the sound power level emitted by the source and the sound pressure level in the room can be different from Formula (B.1). The closeness between underlying assumptions and real measurement situations cannot be described by a mathematical model at the time when this standard is written.

Nevertheless, experience shows that a realistic estimate is $u_{\text{method}} \approx 0{,}3\,\text{dB}$.

The measurement method has a direct effect on the measurement result so the sensitivity coefficient, $c_{\text{method}} = 1$.

B.8   Uncertainty of the mean sound pressure level, the background noise correction K_1, decibel reference correction C_1, source order correction C_2, sound level meter δ_{slm} and spectral shape δ_{tone}

The uncertainty of the mean sound pressure level, the background noise correction K_1, decibel reference correction C_1, source order correction C_2, sound level meter δ_{slm} and spectral shape δ_{tone}, are identical for the (approximated) diffuse and free field methods. Details on these uncertainty components are given in A.3, A.5, A.7, A.10 and A.11.