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Uncertainties in Environmental Noise Assessments – ISO 1996, Effects of Instrument Class and Residual Sound

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ISO/DIS 1996-2.2 (2005) "Acoustics — Description, assessment and measurement of environmental noise — Determination of environmental noise levels" contains guidelines on assessing the uncertainties of the determined sound pressure levels. This depends on the sound source, measurement time interval, weather conditions, distance from the source, measurement method and instrumentation. Guidelines on estimating the measurement uncertainty are given. Four main sources of uncertainty (reproducibility, operating conditions, weather and ground conditions, and residual sound) are combined to determine the overall uncertainty. Reproducibility represents the influence of the operator, equipment at the same place under constant conditions. A value for IEC 61672-1 "Electroacoustics – Sound level meters – Part 1: Specifications" class 1 instrumentation is given. Operating conditions are determined from minimum 3, preferably 5, measurements under repeatable conditions and at a position where variations in meteorological conditions have little influence on results. Uncertainty due to weather and ground conditions depends upon the measurement distance and the prevailing meteorology. A method using a simplified meteo window is provided. Uncertainty due to residual sound varies depending on the difference between measured total values and the residual sound but no more specific guidelines on determining the uncertainty due to residual sound have been developed. This paper proposes a method compliant with ISO 1996 and shows initial results of investigations to determine the effects of instrumentation class. It will be shown that the choice of instrumentation greatly affects the uncertainty due to residual sound as this approaches the specific sound, and thus is an important influence on overall uncertainty.

1 Introduction – Uncertainty in ISO 1996

ISO 1996 "Acoustics — Description, assessment and measurement of environmental noise" is currently under revision. The 2nd part, ISO/DIS 1996-2.2 "Determination of environmental noise levels" [1], contains guidelines on assessing and reporting the uncertainties of the determined sound pressure levels. This depends on the sound source and the measurement time interval, the weather conditions, the distance from the source and the measurement method and instrumentation. Some guidelines on how to estimate the measurement uncertainty are given, with focus on A-weighted equivalent-continuous sound pressure levels only. Four main sources of uncertainty (reproducibility, operating conditions, weather and ground conditions, and residual sound) are used and combined to determine the overall uncertainty (see Table 1).

Reproducibility represents the influence of different operator, different equipment, same place and everything else constant. A value for instrumentation conforming with IEC 61672-1 "Electroacoustics – Sound level meters – Part 1: Specifications" [2] class 1 is given. Operating conditions are determined from at least 3, and preferably 5, measurements under repeatability conditions (the same measurement procedure, the same instruments, the same operator, the same place) and at a position where variations in meteorological conditions have little influence on the results. The uncertainty due to weather and ground conditions varies depending upon the measurement distance and the prevailing meteorology. A method using a simplified meteo window is provided. The uncertainty due to residual sound (the total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed) varies depending on the difference between measured total values and the residual sound.

2 Notes on Uncertainty in ISO 1996

With short-term assessments of the L_{Aeq} of a stable, continuous source, at close range, under favourable meteorological conditions, without noticeable residual sound, the uncertainty terms could typically be 1, 0.5, 1.5 and 0 dB respectively, giving an overall combined uncertainty of 3.0 dB, something that has proven to be realistic [3, 4].

Note that the values reproduced in Table 1 concern L_{Aeq} levels. Higher uncertainties are to be expected on maximum levels, frequency band levels and levels of tonal components in noise.

Table 1: Overview of the measurement uncertainty for L_{Aeq}

Standard deviation of reproducibility[1] in dB	**Standard uncertainty due to operating conditions[2] in dB**	**Standard uncertainty due to weather & ground conditions[3] in dB**	**Standard uncertainty due to residual sound[4] in dB**	**Combined standard uncertainty σ_t in dB**	**Expanded measurement uncertainty in dB**
1,0	X	Y	Z	$\sqrt{1{,}0^2+X^2+Y^2+Z^2}$	$\pm 2\ \sigma_t$

1) Different operator, different equipment, same place and everything else constant, see ISO 5725. If class 2 sound level meters or directional microphones are used the value will be larger.
2) To be determined from at least 3, and preferably 5 measurements under repeatability conditions (the same measurement procedure, the same instruments, the same operator, the same place) and at a position where variations in meteorological conditions have little influence on the results. For long-term measurements more measurements will be required to determine the repeatability standard deviation. For road traffic noise some guidance on the value of X is given in 6.2.
3) The value will vary depending upon the measurement distance and the prevailing meteorology. A method using a simplified meteo window is provided in Annex A (in this case $Y = \sigma_m$). For long-term measurements different weather categories will have to be dealt with separately and then combined together. For short-term measurements variations in ground conditions will be small. However, for long-term measurements, these variations may add considerably to the measurement uncertainty.
4) The value will vary depending on the difference between measured total values and the residual sound.

Table 2: Determining the uncertainty of short term measurements due to using IEC 61672 class 1 & 2 instrumentation

	IEC 61672 Class 1		**IEC 61672 Class 2**		
Factor	**Spec-ifications minus test**	**Expected effect on short-term L_{Aeq} measurements**	**Spec-ifications minus test**	**Expected effect on short-term L_{Aeq} measurements**	**Notes**
Directional response	1,0	0,7	2,0	1,7	Estimated from different tolerences
Frequency weighting	1,0	1,0	1,8	1,8	Estimated from different tolerences
Level linearity	0,8	0,5	1,1	0,8	Estimated from different tolerences
Toneburst response	0,5	0,5	1,0	1,0	Long tones
Power supply voltage	0,1	0,1	0,2	0,2	From IEC 61672
Static pressure	0,7	0,0	1,0	0,0	Included in weather influence
Air temperature	0,8	0,0	1,3	0,0	Included in weather influence
Humidity	0,8	0,0	1,3	0,0	Included in weather influence
A.C. and Radio Frequency fields	1,3	0,0	2,3	0,0	Except near power systems
Calibrator	0,25	0,3	0,4	0,4	From calibrator standard
Windscreen	0,7	0,7	0,7	0,7	Estimated from different tolerences
Expanded Uncertainty (2σ)	**2,6**	**1,6**	**4,5**	**2,9**	
Combined Uncertainty (σ)	**1,3**	**0,8**	**2,2**	**1,5**	

The method assumes arithmetic averaging and Gaussian distribution. Discussion of this is outside the scope of this paper.

In addition, the values reproduced in Table 1 concern the use of Class 1 instrumentation. However, the standard permits the use of instrumentation systems, including the microphone, cable and recorders if any, that conform to the requirements for a class 1 or class 2 instrument laid down in IEC 61672-1. If class 2 sound level meters or directional microphones are used the value will be larger.

ISO TC42/SC1 Working Group 45 (WG45), who is responsible for the development of the standard, has spent much time discussing the guidelines regarding the various sources of uncertainty and the requirements to instrumentation. However, WG45 has not developed more specific guidelines on determining the uncertainty due to residual sound (the total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed). This is the challenge that is taken up by the authors.

2.1 Instrumentation Used

The value reproduced in Table 1 for the standard deviation of reproducibility when using Class 1 instrumentation was determined through a variety of procedures. Brüel & Kjær confirmed the figure by investigating the expected effect on short-term measurements of the different factors that are tested for in the IEC 61672 Class 1 specifications. The factors were investigated for typical sources expected to be investigated in ISO 1996. The tolerances were adjusted to those that must be used by sound level meter manufacturers to allow type approval and periodic compliance tests at various test houses. In several cases, the overall effect had to be estimated due to the frequency dependent tolerances.

The above does not include the effects of self-generating noise. This is covered in the uncertainty due to residual noise (see below). In addition, the above may underestimate the uncertainty due to the directional response of the instrumentation if the source under investigation covers a wide angle. The overall combined uncertainty has been estimated to 1.1 dB. Thus, 1.0 dB is used in ISO 1996.

If class 2 sound level meters or directional microphones are used the value will be larger. Studies carried out at Brüel & Kjær have shown these to be double those of Class 1 instrumentation (see Table 2).

In addition, the above may underestimate the uncertainty due to the directional response of the instrumentation if the source under investigation covers a wide angle, causing an increase in the overall combined uncertainty to 2.2 dB. It should be noted that the above covers a smaller range of meteorological conditions than for Class 1 instrumentation. In addition, it also does not include the effects of self-generating noise. As it is twice the value of Class 1 uncertainty, and as ISO 1996 uses 1.0 dB for Class 1, an uncertainty of 2 dB is used for Class 2 instrumentation in the following study.

Using the same assessment example for Class 2 instrumentation, short-term assessments of the L_{Aeq} of a stable, continuous source, at close range, under favourable meteorological conditions, without noticeable residual sound, the uncertainty terms could typically be 2, 0.5, 1.5 and 0 dB respectively, giving an overall combined uncertainty of 4.0 dB.

3 Determining Uncertainty due to Residual Sound

The uncertainty due to residual sound is dependent on the following primary factors:

- The parameter measured
- The difference between measured total values and the residual sound
- The uncertainty of the assessments of the total values and the residual sound

The uncertainty due to residual sound varies depending on the difference between measured total values and the residual sound. The authors felt that it was important to investigate the influence of instrument class on reproducibility and the residual sound. For this investigation, the chosen parameter is L_{Aeq}.

3.1 The Difference between Measured Total Values and the Residual Sound

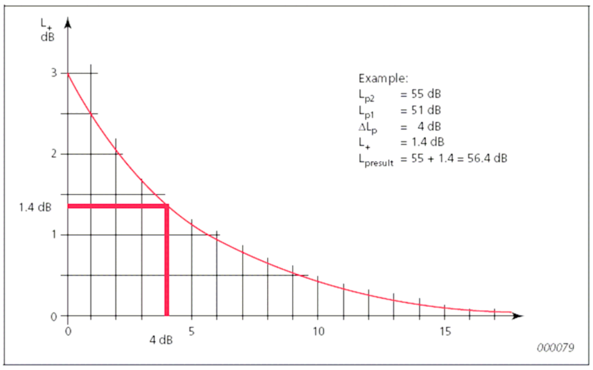

Figure 1: The effect of residual sound level on measuring specific sound level

The uncertainty due to residual sound varies depending on the difference between measured total values and the residual sound (including self-generating noise in the instrumentation). It is well-known how the residual sound level influences measurement of the specific sound level. At 10dB below, the influence has traditionally been accepted to be insignificant (it is, in fact 0.5 dB – see Figure 1).

Later we will show how this factor influences the uncertainty and the determination of the uncertainty of the assessment.

Table 3: Overview of the measurement uncertainty for residual sound L_{Aeq}

Standard deviation of reproducibility[1)] in dB	**Standard uncertainty due to operating conditions[2)] in dB**	**Standard uncertainty due to weather and ground conditions[3)] in dB**	**Combined standard uncertainty σ_t in dB**	**Expanded measurement uncertainty in dB**
1,0	X	Y	$\sqrt{1{,}0^2 + X^2 + Y^2}$	$\pm 2\,\sigma_t$

1) Different operator, different equipment, same place and everything else constant, see ISO 5725. If class 2 sound level meters or directional microphones are used the value will be larger.
2) To be determined from at least 3, and preferably 5 measurements under repeatability conditions (the same measurement procedure, the same instruments, the same operator, the same place) and at a position where variations in meteorological conditions have little influence on the results.
3) The value will vary depending upon the measurement distance and the prevailing meteorology. A method using a simplified meteo window is provided in Annex A (in this case $Y = \sigma_m$).

3.2 The Uncertainty of Assessments of Total Values and the Residual Sound

It is relatively simple to determine the residual sound level and how the uncertainty attached to the assessment of residual sound level should be determined. One can regard them as “specific” sound levels (i.e. the one under investigation) and use the method described in ISO 1996 to determine both the level and the uncertainty associated with the assessment of this level. Thus, with no residual sound level to deal with, Table 1 can be converted into Table 3 for the assessment of the uncertainty of the assessment of residual sound level.

However, it must be noted that the ability to determine the primary source of residual noise levels will determine the ability to determine *Y*, the standard uncertainty due to weather and ground conditions. However, it may not be possible to fulfill the requirement in note 2 regarding meteorological conditions at the same time as assessing the residual sound level without the presence of the specific sound source. The user must make the best efforts possible. If it is not possible, to separately determine *Y*, then *X*, the standard uncertainty due to operating conditions, and *Y* must then be combined in one single, inseparable factor, determined by sound level measurement.

As an example, a short-term assessment of the L_{Aeq} of stable, continuous residual sound from a nearby primary source, under favourable meteorological conditions, could give typical uncertainty terms of 1, 0.5 and 1.5 dB respectively, giving an overall combined uncertainty of 3.0 dB. However, this is **not** the parameter Z. Determining parameter Z and the overall, combined uncertainty require further steps.

So, now we have a specific sound level (i.e. the overall sound level corrected for the residual sound level), and we have an uncertainty for the residual sound level. We also have a preliminary uncertainty for the specific sound level that does not yet account for the effects of residual sound. We will typically have 3 to 5 measurements of the overall sound level and 3 to 5 measurements of the residual sound level from which we will determine the uncertainty of the specific sound level.

3.3 Determining Overall, Combined Uncertainty and Parameter Z

In order to determine the uncertainty for the specific sound level, σ_S, the actual measured overall and residual sound levels are combined. In the example shown in Table 2, this resulted in 15 specific sound levels. From these, the uncertainty for the specific sound level, σ_S, can easily be calculated (in Table 4, resulting in 3.3 dB). The standard uncertainty due to residual sound, Z, can be calculated in accordance with equation 1:

$$Z = \sqrt{\sigma_S^{\;2} - \sigma_O^{\;2}} \tag{1}$$

In the example in Table 2, this results in Z = 1.3 dB. This can then be reported in accordance with ISO 1996.

Table 4: Determining the uncertainties for the specific sound level (σ_S) and due to residual sound, Z, for overall sound levels with uncertainty σ_O, residual sound levels with uncertainty σ_R, with a residual sound level 10 dB lower than the overall sound level and Class 1 instrumentation

Class 1		**Residual**			**Z**
	Specific	**57,0**	**60,0**	**63,0**	1,30
Overall	**66,4**	65,9	65,3	63,7	
	67,8	67,4	67,0	66,0	
	70,0	69,8	69,5	69,0	
	72,3	72,1	72,0	71,7	
	73,6	73,5	73,4	73,2	
Uncertainty (σO)	3,00			Uncertainty (σS)	3,27

Table 5: Determining the uncertainties for the specific sound level (σ_S) and due to residual sound, Z, for overall sound levels with uncertainty σ_O, residual sound levels with uncertainty σ_R, with a residual sound level 5 dB lower than the overall sound level and Class 1 instrumentation

Class 1		**Residual**			**Z**
	Specific	**62,0**	**65,0**	**68,0**	6,84
Overall	**66,4**	64,4	60,8	50	
	67,8	66,4	64,5	50	
	70,0	69,3	68,3	65,7	
	72,3	71,8	71,3	70,2	
	73,6	73,3	73	72,2	
Uncertainty (σO)	3,00			Uncertainty (σS)	7,47

Table 6: Determining the uncertainties for the specific sound level (σ_S) and due to residual sound, Z, for overall sound levels with uncertainty σ_O, residual sound levels with uncertainty σ_R, with a residual sound level 10 dB lower than the overall sound level and Class 2 instrumentation

Class 2		**Residual**			**Z**
	Specific	**56,0**	**60,0**	**64,0**	2,68
Overall	**65,2**	64,6	63,6	59,0	
	67,0	66,6	66,0	64,0	
	70,0	69,8	69,5	68,7	
	73,0	72,9	72,8	72,4	
	74,8	74,7	74,7	74,4	
Uncertainty (σO)	4,00			Uncertainty (σS)	4,81

Table 7: Determining the uncertainties for the specific sound level (σ_S) and due to residual sound, Z, for overall sound levels with uncertainty σ_O, residual sound levels with uncertainty σ_R, with a residual sound level 5 dB lower than the overall sound level and Class 2 instrumentation

Class 2		**Residual**			**Z**
	Specific	**61,0**	**65,0**	**69,0**	7,74
Overall	**65,2**	63,1	51,7	50	
	67,0	65,7	62,7	50	
	70,0	69,4	68,3	63,1	
	73,0	72,7	72,3	70,8	
	74,8	74,6	74,3	73,5	
Uncertainty (σO)	4,00			Uncertainty (σS)	8,72

The above example was for well-controlled measurements with relatively insignificant residual sound levels. In another example shown in Table 3, the residual sound level is only 5 dB below the overall sound level. In this case, some residual sound levels are above the overall sound level and the overall sound level cannot be determined. Default overall sound levels 20dB below the reported overall sound level are entered for these combinations (the 50dB entries in Table 5). This gives a more realistic uncertainty value. If set blank, the results may not be included in the spreadsheet’s uncertainty calculation and the uncertainty figure decreases. 20 dB is chosen as this is the level at which results to 1 decimal place do not change visibly. Here, the uncertainty for the specific sound level, σ_S, is calculated as 7.5 dB, resulting in a standard uncertainty due to residual sound, Z, of 6.8 dB.

3.4 The Influence of Instrumentation Class on Uncertainty

When Class 1 instrumentation is replaced by Class 2 instrumentation, the uncertainties for overall sound levels, σ_O, and for residual sound levels, $\sigma_{R,}$, increase from 3.0dB to 4.0 dB, as described earlier. The uncertainty for the specific sound level, σ_S, is calculated as 4.8 dB, resulting in a standard uncertainty due to residual sound, Z, of 2.7 dB (Table 6).

We now change the residual sound level to 5 dB below the overall sound level while still using Class 2 instrumentation. The uncertainty for the specific sound level, σ_S, is then calculated as 8.7 dB, resulting in a standard uncertainty due to residual sound, Z, of 7.7 dB (Table 7).

The influence of the instrumentation on the 2 cases is shown in Table 8. As it can be seen, there is a significant improvement in the uncertainty with the use of Class 1 instrumentation when residual sound levels are to be taken into account.

Table 8: The effect on uncertainty (σ_S) for the specific sound level and the standard uncertainty due to residual sound, Z, of using Class 1 and Class 2 instrumentation, and the effect on the expanded measurement uncertainty

	Overall-Residual (dB)			
	5		**10**	
Class	$\boldsymbol{\sigma_S}$	**Z**	$\boldsymbol{\sigma_S}$	**Z**
1	7,5	6,8	3,3	1,3
2	8,7	7,7	4,8	2,7
Difference	-1,2	-0,9	-1,5	-1,4
Expanded	-2,4		-3,0	

4 An ISO 1996 Compliant Procedure for Determining Uncertainty due to Residual Sound

This paper describes a method to determine the uncertainty due to residual sound that is compliant with ISO 1996. It involves the following steps:

1. Put the overall and the residual sound levels in a table and calculate the specific sound level for each overall-residual sound level result pair. **Note:** If the overall level is below the residual sound level, then set specific sound level to 20 dB below the arithmetic average of the overall sound levels
2. Calculate the uncertainty of the matrix of the results (σ_S)
3. Calculate the residual noise uncertainty (Z) by taking the square root of the difference between the square of the uncertainty of the matrix of the results (σ_S) and the square of the uncertainty of the overall sound level (σ_O).

The paper shows the initial results of investigations to determine the effects of choice of instrumentation class. It can be seen that the choice of instrumentation class greatly affects the uncertainty due to residual sound, and thus is an important influence on the overall uncertainty.

References

[1] ISO/DIS 1996-2.2 - “Acoustics — Description, assessment and measurement of environmental noise” (2005)

[2] IEC 61672-1 “Electroacoustics – Sound level meters – Part 1: Specifications” (2002)

[3] R. Tyler “Measuring Noise Outdoors”, *IOA Acoustics Bulletin*, p.40-41 March/April 2000 (2000)

[4] Private correspondence with IOA Measuring Noise Outdoors Seminar 2000 participants