# Influence of a measurement threshold level on the calculation of aircraft sound exposure levels

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## Introduction

A measurement threshold is used to ensure that an aircraft noise event is clearly distinguishable from the ambient sound in automatic aircraft noise monitoring devices. Any noise below the measurement threshold level is not considered when evaluating aircraft noise events. As a consequence, the edges of the level-time curve are cut off, which leads to a different sound exposure level compared to the actual level. The lesser the maximum level exceeds the measurement threshold level, the greater the difference.

In this study, the influence of a measurement threshold level on the calculation of the sound exposure level is analyzed theoretically. In order to be able to quantify the differences to the actual levels, only calculated and not measured noise levels are used for this study.

## Evaluation of aircraft noise events

The following sections describe the background necessary for this study.

### Event detection

The international Standard ISO 20906 [1] (comparable to the German Standard DIN 45643 [2]) describes that the AS-weighted maximum sound pressure level $L_{pAS,max}$ (in the following referred to only as *maximum level*) of an aircraft noise event must be at least 5 dB above the measurement threshold level, otherwise the sound event is not taken into account in the further evaluation. Furthermore, a minimum time is specified so that short external noises are not interpreted as an event. The recommended minimum time is $t_M = 5$ s [1]. A listening time is also defined in order to separate events. If the sound pressure level falls below the measurement threshold level by this time, the event is considered to have ended. The recommended listening time is $t_H = 5$ s [1].

### Calculation of the sound exposure level $L_{pAE}$

The sound exposure level $L_{pAE}$ is calculated according to ISO 20906 [1] to

$$L_{pAE} = 10\, lg\left(\frac{1}{t_0}\int_{t_S} \frac{p_A(t)^2}{{p_0}^2}\, dt\right)$$

with $t_0 = 1$ s as the reference time, $p_0 = 2 \cdot 10^{-5}$ Pa as the reference sound pressure and $p_A(t)$ as the A-weighted sound pressure time history. The integration is performed over the so-called exceedance time $t_S$, which refers to the entire time during which the sound pressure level is above the measurement threshold level. Noise components that lie below the measurement threshold level are not considered.

### Correction of dispersed levels

For multiple measured noise events throughout a certain time period (e.g. half a year), the noise of an aircraft type is subject to a certain level dispersion, which has different causes (weather, position inaccuracy, aircraft mass, ...). For aircraft groups defined in the German „Anleitung zur Berechnung von Lärmschutzbereichen“ („Instructions for the calculation of noise protection areas“, AzB) [3] the standard deviation of the level dispersion is usually between $\sigma = 2$ dB and $\sigma = 3$ dB, whereby it can be approximately assumed that the levels are normally distributed.

Due to the measurement threshold, not all flight events are recorded with the automated measurements. The measured level frequency distribution is therefore incomplete. A calculated example of an incomplete maximum level frequency distribution for an aircraft class is shown in Figure 1. This frequency distribution was generated with 300 random values, which were determined based on a normal distribution with an expected value of 70.7 dB and a standard deviation of 2.5 dB. In this example, the measurement threshold level was set to $L_{pA,Mthr} = 65$ dB, i.e., maximum levels below 65 dB + 5 dB are not considered. This results in a detection rate of $q = 62.7$ %. Since low maximum levels are not considered, the measurement threshold inevitably results in a higher arithmetically averaged maximum level of $\overline{L_{pAS,max}}_M = 72.2$ dB and a lower standard deviation of $\sigma_M = 1.6$ dB compared to the set expected value of 70.7 dB and standard deviation of 2.5 dB.

However, assuming that the levels are normally distributed, a correction for both, the arithmetically averaged maximum level and the standard deviation, can be derived mathematically. The derivation is described in detail in [4]. In a first step, the standard deviation and the logarithmically averaged maximum level are determined from the data above the measurement threshold level in an ordinary manner (index M). In a second step, the corrected standard deviation can then be calculated as a function of the detection rate q using the formula

$$\sigma_K = \sigma_M \cdot \left(erf^{-1}(a)\,\frac{1}{\sqrt{\pi}}\,e^{-\left(erf^{-1}(a)\right)^2} + q\right)^{-1/2}$$

where

$$a = 1 - 2q$$

is the argument of the inverse error function $erf^{-1}$. Based on this corrected standard deviation, a corrected logarithmically averaged maximum level can be calculated in a third step using the formula

$$\overline{L_{pAS,max}}_{K,log} = \overline{L_{pAS,max}}_{M,log} - 10 \cdot \lg\left(\frac{1 - erf(b)}{2q}\right)$$

where

$$b = erf^{-1}(a) - \sigma_K \cdot \ln(10)/\sqrt{200}$$

is the argument of the error function $erf$. In a last step, the corrected arithmetically averaged maximum level can be determined analytically from the corrected logarithmically averaged maximum level because both refer to normally distributed levels. This analytical relation is

$$\overline{L_{pAS,max}}_{K} = \overline{L_{pAS,max}}_{K,log} - \frac{{\sigma_K}^2 \cdot ln10}{20}$$

The correction is applied to the example in Figure 1, which results in a corrected arithmetically averaged maximum level of $\overline{L_{pAS,max}}_{K} = 70.9$ dB and a corrected standard deviation of $\sigma_K = 2.3$ dB. Both deviate only by 0.2 dB from the initially set values of 70.7 dB and 2.5 dB, respectively. The probability density functions (PDF) based on the mean values and standard deviations are shown in Figure 1 as blue (uncorrected values) and red (corrected values) lines.

It is noteworthy at this point that the correction gives adequate results even though the distribution of the values in Figure 1 do seem to differ from a normal distribution. Additional tests, which are out of scope for this study, even show that the correction of the averaged maximum level works comparably well if the same example is repeated with non-normal distributed values (e.g. equal distribution).

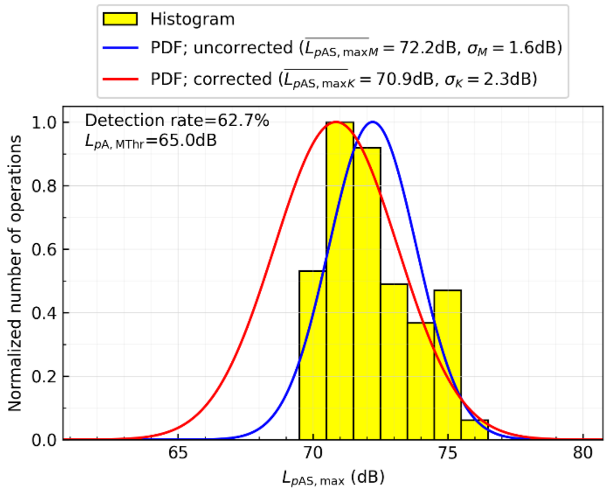


**Figure 1:** Example of a maximum level frequency distribution (histogram) with measurement threshold. Also shown are the probability density functions (PDF) without (blue line) and with (red line) correction according to [3].

The above correction methodology can only be applied to maximum levels. Due to a missing termination criterion, it cannot be used for the correction of exposure levels. Instead, as described in [4], the corrected arithmetically averaged maximum level $\overline{L_{pAS,max}}_{K}$ can be used to determine an associated corrected arithmetically averaged exposure level $\overline{L_{pAE}}_{K}$ by regression analysis of the measured $L_{pAS,max}$- and $L_{pAE}$-values. The corrected standard deviation of the maximum level is used for the standard deviation of the exposure level as well. Similar to the maximum level, the corrected logarithmically averaged exposure level can be analytically calculated as[1]

$$\overline{L_{pAE}}_{K,log} = \overline{L_{pAE}}_{K} + \frac{{\sigma_K}^2 \cdot ln10}{20}$$

However, the logarithmically averaged exposure level is not considered further in this study.

In the procedure for correcting the exposure level, it is important to bear in mind that the error due to a short exceedance time is not corrected.

## Simulation setup

In order to be able to investigate the influence of a measurement threshold level on the exposure level, this study is based on the AzB-method [3]. The AzB-method is implemented in the DLR software framework AIRNAF (Aircraft Noise Analyses Framework). In contrast to the AzB, AIRNAF discretizes the flight path in constant time steps. In [5] it was shown that a discretization with $\Delta t = 1$ s provides comparable results to the segmentation method of the AzB. In order to reduce numerical errors in this study, the temporal discretization of the flight path was set to a very low value of $\Delta t = 0.05$ s.

For this study, a single departure of the aircraft class S3_M130_T2_N7-SB [5] and a single microphone are considered. The departure profile and the position of the selected microphone directly below the flight path are shown in Figure 2.

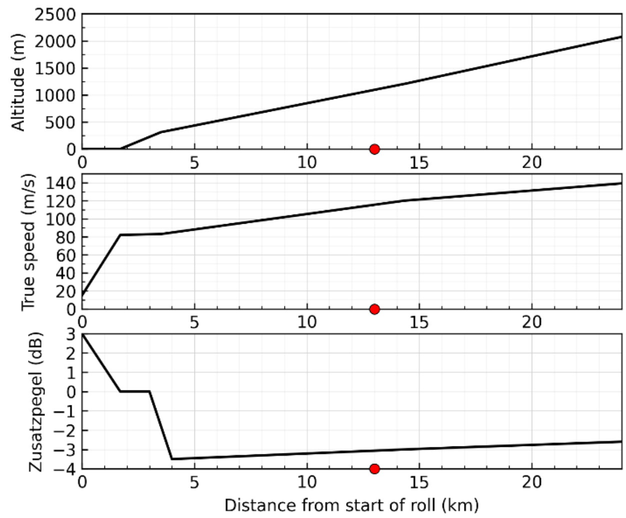


**Figure 2:** Take-off profiles of the class S3_M130_T2_N7- SB. The position of the microphone used in this study directly below the flight path is marked as a red dot.

## Evaluation

In the following, the difference that arises due to a finite exceedance time is examined in a first step. In a second step,

[1]In [3], the correction value of the arithmetically averaged exposure level is also applied to the averaged exposure level.

the effect of this difference on a level frequency distribution is examined.

**Error due to finite exceedance time**

First, a single overflight is considered. The level-time curve for the case described in the simulation setup is shown in Figure 3. The red shaded area indicates levels below the measurement threshold level $L_{pA,Mthr}$ and the gray shaded area indicates levels below $L_{pA,Mthr} + 5$ dB. As previously described, cases where the maximum level is less than $L_{pA,Mthr} + 5$ dB are disregarded in the evaluation. Furthermore, when calculating the sound exposure level, only the curve above $L_{pA,Mthr}$ is considered, which leads to a difference compared to the actual value (i.e., of the fully recorded noise).

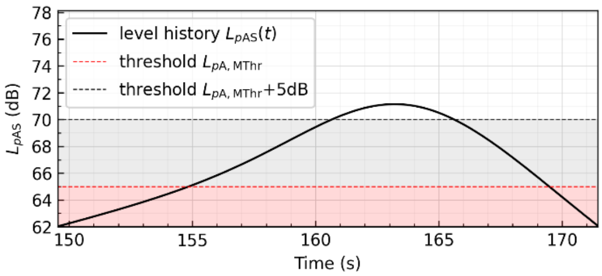


**Figure 3:** Level-time curve for the microphone position shown in Figure 2. The area highlighted in red indicates levels below the measurement threshold level $L_{pA,Mthr}$ and the gray shaded area indicates levels below $L_{pA,Mthr} + 5$ dB.

To demonstrate how the measurement threshold affects the difference between calculated sound exposure level and actual value, the level-time curve of Figure 3 is shifted to higher and lower noise levels. Each time the difference to the actual value is determined. The resulting differences are shown in Figure 4 as a function of the distance of the maximum level to the measurement threshold level. The greatest difference is about -1.5 dB in the case where the maximum level is only 5 dB above the measurement threshold level. But even if the maximum level is about 10 dB above the measurement threshold, the difference is still -0.5 dB.

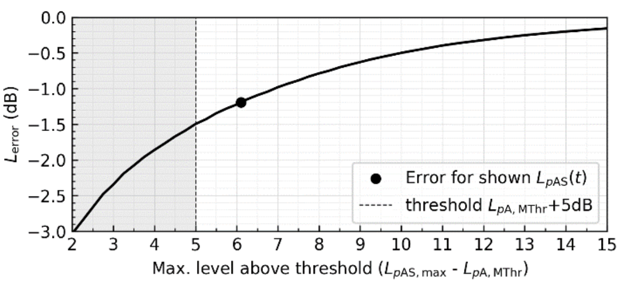


**Figure 4:** Difference in the $L_{pAE}$ in the presence of a measurement threshold as a function of the distance of the maximum level to the measurement threshold level (based on shifted level-time curves shown in Figure 3). The black dot shows the value for the level-time curve from Figure 3.

**Influence on a level frequency distribution**

As stated earlier, multiple flyovers of the same aircraft lead to dispersed levels on the ground. For the following analysis, it is assumed that the maximum levels are normally distributed. To simulate a normally distributed level dispersion, the level-time history from Figure 3 is shifted in the range of -20 dB to +20 dB in steps of 0.005 dB. For each step size, the frequency is determined according to the AzB-class-specific level dispersion of $\sigma = 2.5$ dB. Furthermore, a measurement threshold level of $L_{pA,Mthr} = 65$ dB is assumed. The simulation results in the maximum level frequency distribution shown in Figure 5. The light-yellow bars represent the frequencies of occurring maximum levels that are not recorded (i.e., detected) due to the measurement threshold. Accordingly, the rich yellow bars represent the frequencies of maximum levels that are recorded even with a measurement threshold.

It can be clearly seen in Figure 5 that the frequency distribution is "cut off" at $L_{pA,Mthr} + 5$ dB. The resulting overall detection rate is 67.7 %. From the mean value and standard deviation of the detected movements, a probability density function (PDF) can be formed which is shown as blue line. Clearly, the arithmetically averaged maximum level of 72.5 dB and the standard deviation of 1.8 dB deviate from the actual value of 71.1 dB and 2.5 dB, respectively. Applying the previously described correction method leads to the probability density function shown as a red line. It can be seen that the corrected probability density function is almost identical to the probability density function resulting from the frequencies without a measurement threshold (gray line). Under ideal conditions, it can therefore be concluded that the arithmetically averaged maximum level and standard deviation of measured maximum levels can be corrected well.

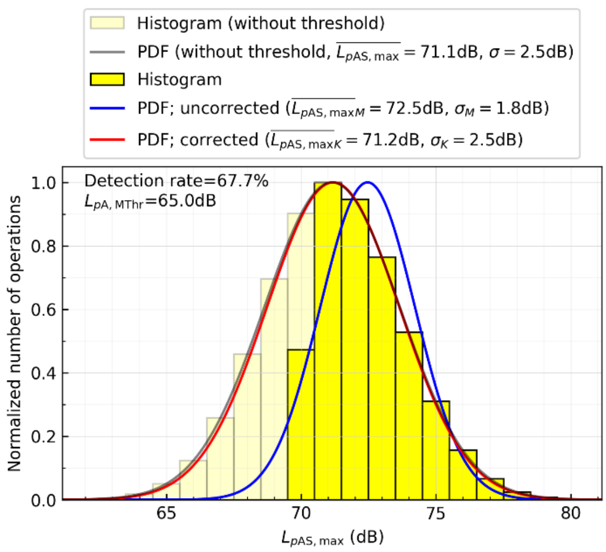


**Figure 5:** Histograms of the $L_{pAS,max}$ without and with consideration of a measurement threshold level. Also shown are the probability density functions (PDF) based on the level values without consideration of a measurement threshold level (gray line) and with consideration of a measurement threshold level without correction (blue line) and with (red lines) correction according to [4].

Figure 6 shows the frequency distribution of the $L_{pAE}$-values according to the same scheme. As before, the distribution is also "cut off" at lower levels. However, it can also be seen that the overall frequency distribution is skewed towards lower values. The reason, as explained in Figure 4, is due to the short exceeding times. Similar to the maximum level frequency distribution, the arithmetical mean value is too high and the standard deviation is too low. In contrast to the maximum level frequency distribution, however, the correction in this case does not lead to a better agreement with the actual values. In this specific case, the corrected mean value is calculated 1.2 dB too low, which is even worse than the uncorrected value.

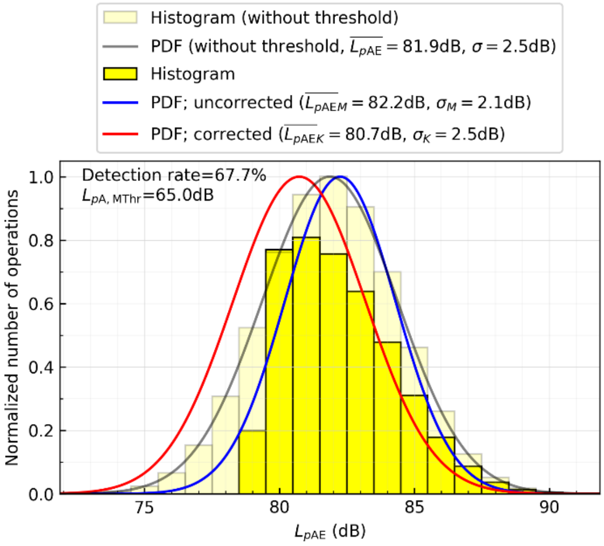


**Figure 6:** Histograms of the $L_{pAE}$ without and with consideration of a measurement threshold level. Also shown are the probability density functions (PDF) based on the level values without consideration of a measurement threshold level (gray line) and with consideration of a measurement threshold level without correction (blue line) and with (red line) correction according to [4].

In order to quantify the influence of different measurement threshold levels, the calculation case presented in Figure 6 is repeated for different measurement threshold levels ranging from 55 dB to 69 dB. For each measurement threshold level, the difference to the actual value for $\overline{L_{pAS,max}}$ and $\overline{L_{pAE}}$ is quantified. Figure 7 shows this difference for $\overline{L_{pAS,max}}$ (solid line) and $\overline{L_{pAE}}$ (dashed line) for uncorrected (blue) and corrected levels (red). As can be seen from this figure, the arithmetically averaged maximum levels can be corrected well, i.e., with a remaining difference less than 0.5 dB, in all cases. However, the correction method for the sound exposure level does not give better results than without correction. Instead, the differences are almost always greater than without correction. The remaining difference results from the short exceedance time which is not corrected with the described method. This would need to be corrected by other means. Note, that the shown differences only apply to the level-time history shown in Figure 3.

## Summary

This study uses calculated noise levels to demonstrate the influence of a measurement threshold level on the calculation of the exposure level. Due to shorter exceedance times, the level-time history used in this study results in differences compared to the actual value of up to -1.5 dB.

For dispersed levels resulting from multiple flyovers, the measurement threshold level results in a frequency distribution which is “cut off” at lower levels. This results in different arithmetically averaged values and standard deviations for both, the maximum level and the exposure level, compared to complete frequency distributions.

In the ideal case of normally distributed levels, the arithmetically averaged maximum level as well as the standard deviation can be corrected well with the described method. A similar correction can also be applied to the exposure levels. However, the correction of the exposure levels does not provide better results because an error still remains due to the finite exceedance time, which would need to be corrected by other means.

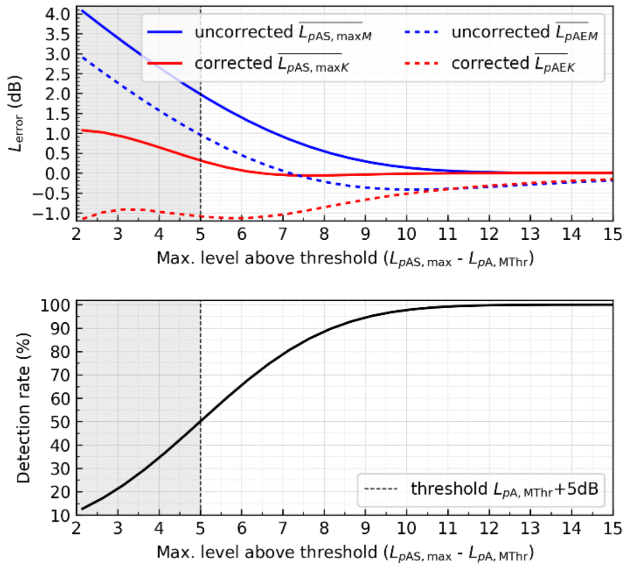


**Figure 7:** Difference in the $\overline{L_{pAE}}$ and $\overline{L_{pAS,max}}$ without and with correction according to [4] in the presence of a measurement threshold (upper figure) and detection rate (lower figure) as a function of the distance of the maximum level to the measurement threshold level.

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