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# REMARKS ON NOISE LEVELS OF LOW FREQUENCY IMPULSE SOUND FOR CORRELATION PURPOSES WITH ANNOYANCE

Karl-Wilhelm Hirsch

Institut fuer Laermschutz, Arnheimer Straße 107, D-40489 Duesseldorf, Germany

## INTRODUCTION

Much work has been done finding assessment rules for the annoyance to low frequency shooting noise in the vicinity of military installations. The general way to find these rules is to correlate measured human response ('annoyance') to predicted physical sound levels ('correlation levels'). The general results are so-called 'penalties' which have to be added to the predicted sound level to yield a rating level. This rating level is equivalent, with respect to annoyance, to the noise level of standardized steady state noise situation like traffic noise. Therefore, this procedure for finding penalties and its results and conclusions depend strongly on both the concept of annoyance and the concept of correlation levels.

Mostly, relevant investigations focus on the human response measurements, the human side of the problem which involves many uncertainties because humans provide the responses. This is an open field for sophisticated analysis and discussion.

More rarely, investigations discuss the correlation levels in principle or in detail, respectively, the physical side of the problem. The appropriate correlation level is normally said to be the sum of acoustical energy or power reaching peoples ears. This paper tries to point out that there is a need for more or even for something different than that, in order to find a good correlation partner to human response.

## REASONS FOR STATISTICS

**Is noise load a reliable correlation level?... The first reason for doing statistics.** For long term average predictions, the correlation level must trade the effects of many different sources in different locations with different numbers of events for a certain period of rating time and for a certain receiving site. From a practical or rather theoretical point of view the appropriate physical sound level should be an energy equivalent level. Only an energy equivalent measure can be added from incoherent stochastic acting sources. These levels are often termed 'noise load'.

Accepting this statement is a crucial step. In doing so, we not only define the basic level concept but also enforce the answer to a complicated question on the human side of the problem: We indirectly provide and pre-define a simple rule of how to add up annoyance. We do this because we normally want to correlate both measures linearly to get a constant penalty. So, before accepting noise load as correlation level we should test the addition rule of annoyance (equal-energy law) for low frequency impulse noise.

Some recent investigations (/1, 2, 3/) can help to decide this test. Laboratory tests in realistic free field conditions show that this concept holds for annoyance with traffic noise. With the same test conditions, so-called paired comparison tests indicate that the annoyance with high-intensive blast sounds increases approximately at twice the rate compared to the annoyance with traffic noise having the same sound energy. This means, the equal-energy-law does not seem to be true for blast noise. If we accept this statement, we can not use the concept of noise load on the physical side to provide a reliable correlation level. We must provide the level for every single event and cannot add anything on the physical side.

For long term average predictions for blast noise, this requirement leads to a rather new field on the physical side of the problem. We must analyze and provide single event levels from the level distribution ofblast noise levels at all receiver sites. This is the first reason to investigate the level statistics of blast noise.

**Even if we use noise load! ... The second reason for doing statistics.** There is a second reason for doing statistics even if noise load is used as correlation level. For low-frequency, high-energy weapon blasts, sound propagation models for noise assessment purposes normally start with a source sound level (emission level and directivity pattern), consider well known physical propagation phenomena (geometric attenuation and absorption in air) and add corrections to take into account various influences on sound propagation that are not clearly calculable (prevailing weather conditions, land surface, etc.). Normally, a fitting process to measured levels determines these corrections and their coefficients, respectively.

The sound propagation model proposed by the IfL (Institut fuer Laermschutz) and used in Germany to predict the noise load in the vicinity of military training grounds provides three of those corrections. Up to now, their coefficients are determined by a heuristic estimation. Because of this, the model predicts in most cases a higher level than measured in test series. Additionally, these tests must be performed in down wind conditions according to general rules in German acoustical standards saying that noise load values used for noise assessment ought to be values for good sound propagation conditions. If a standard will use and define this model, we also need to standardize the method for how to find the coefficients. For this purpose the level distribution also will be needed.

## STATISTICAL ANALYSIS

**How to find information about level statistics of blast noise...** Available physical models describing sound propagation of impulses are not able to yield any information about level distributions because this distribution is closely related to the statistics of weather condition. Up to now, weather data are not included in these models.

Some experimental databases of blast levels exist. However, those databases are normally archived under special test condition serving the dedicated goal of that investigation. We need to get information about the level distribution in a database that provides data under random weather condition; assorted wind speeds and wind directions, temperature gradients, etc. And this database should have as many entries as possible for the same blast source.

SCHOMER et. al. present such a database in /4/. This database holds 2940 single event levels (CSEL)for 4 distances (3.2 km, 8 km, 16 km, 24 km). It meets the major requirements mentioned above because 735 demolition tests of C4 (2.27 kg) were measured simultaneously in four directions 90° apart. This directly randomizes wind influences.

In a revised analysis of that database /5/, SCHOMER and LUZ treat all data as if they are part of two normal distributions, following a suggestion by LUZ /6/. They call these distributions ‘upwind’ and ‘downwind’ distributions. These names are for labeling purposes; not for explanation purposes. Plotting the data to a ‘normal probability’ scale, they estimate the relevant coefficient of their hypothesis of the composite of two Gaussian distributions. Their published results are encouraging.

**Data correction.** The following sequence of figures shows the results of a more numerical method to analyze the distribution of levels using the same database. First of all, this method corrects the data with respect to non-measured values due to background noise. This procedure assumes that the probability of finding a level of 65 dB(CSEL) in the ensemble of measured levels of the database is 50 %; the probability of finding 76 dB(CSEL) is assumed to be 75%. Using these values to establish a simple exponential transition function, we can correct the entire level distribution.

Using the corrected set of data, a dedicated numerical regression process is started to find the best fit to the hypothesis. This numerical process minimizes an error sum to optimize the set of 5 parameters provided by the composite of two Gaussian distributions. These parameters are the two means and two standard deviations for the upwind and downwind distributions, respectively, and the percentage of samples belonging to one of the distributions.

As an example, fig. 1 shows the plot of the levels at a distance of 8 km with a normal probability scale. The sequence of '*' signs denotes the original data and the sequence of '+' signs denotes the corrected data, respectively. The solid lines represent sample probability distributions produced by a Gaussian random generator with the appropriate parameters.

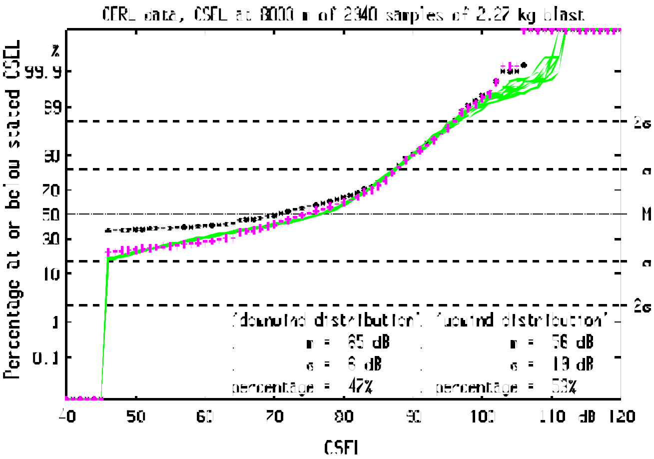


*Fig. 1 Probability distribution of 2940, 2.27 kg blast C-weighted sound exposure levels at 8000 m, measured (*), corrected (+) and hypothesis(___ )*

**Results.** Tab. 1 lists the parameter sets for each of the 4 distances. In addition, the columns of mean, standard deviation and percentage provide, in brackets, the 'figure of determination' of that parameter. In this context, this 'figure of determination' must be added to that parameter to increase the error sum by just 100 %. This figure is helpful for estimating the relative degree of certainty (or determination, or reliability) for every parameter of the minimization process. In general, the parameters of the downwind distribution are more certain than the parameters of the upwind distribution. However, the means seem to be very certain.

| Distance | Distribution | Mean (d) | Standard deviation (d) | Percentage (d) |
|---|---|---|---|---|
| [m] | | [dB] | [dB] | [%] |
| 3200 | downwind | 92,5 (0,9) | 6,8 (0,8) | 50,0 (6,0) |
| | upwind | 73,5 (1,6) | 14,5 (6,9) | 50,0 |
| 8000 | downwind | 85,0 (1,0) | 6,0 (2,2) | 47,0 (10,7) |
| | upwind | 56,0 (3,1) | 19,0 (10,7) | 53,0 |
| 16000 | downwind | 78,0 (1,5) | 6,8 (2,1) | 40,0 (12,5) |
| | upwind | 43,5 (2,0) | 22,7 (13,8) | 60,0 |
| 24000 | downwind | 77,0 (1,3) | 5,8 (1,3) | 18,0 (5,6) |
| | upwind | 35,5 (2,0) | 14,5 (7,2) | 82,0 |

*Tab. 1 Optimized parameter sets of the composite of both Gaussian distributions in each distance.*

The major goal of this analysis is to describe the dependency of the level distribution on distance. Therefore, the following figures show all five parameters versus distance. Each figure gives an approximation function to describe this dependency. The analysis yields 4 means for the 4 distances. Fig. 2 denotes these means as '*' and 'x' for the downwind and upwind distribution, respectively. In addition, the level at 250 m distance is well known to be 118.5 dB(CSEL) for the charge under consideration. The fitting function has to take this into account. So, the indicated regression lines in fig. 2 are both constrained to meet this value. It is surprising how well the data fit the straight regression lines, each having one parameter left for adjustment.

Fig. 3 shows the standard deviation for downwind (*) and upwind (o) distributions including the figure of determination. Again, the source level is included with a standard deviation of 2 dB for regression purposes.

In this case the results are adjusted to fit a power function. This serves to provide a mathematical description of the different increase with distance for each case.

Fig. 4 shows the percentage of events assigned to the downwind distribution. There are some reasons why the data should fit to a transition function from 50% to 0%. Very close to the source, the percentage has to be 50% because it is said that wind does not influence sound propagation in that range. For larger distances the probability for sound to find good propagation condition

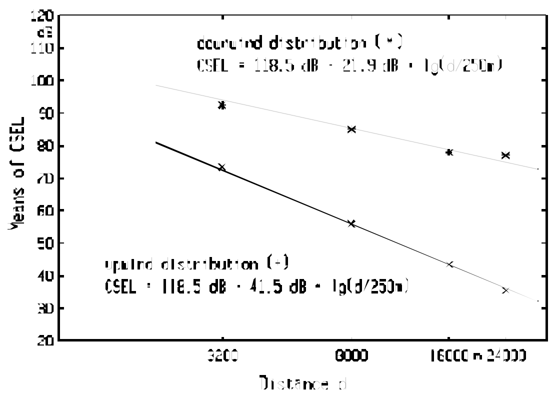


*Fig. 2 Means of downwind (*) and upwind (x) distributions versus distance.*

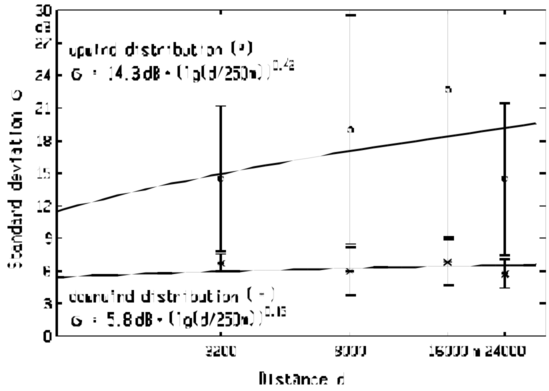

*Fig. 3* *Standard deviation of downwind (*) and upwind (o) distributions versus distance.*

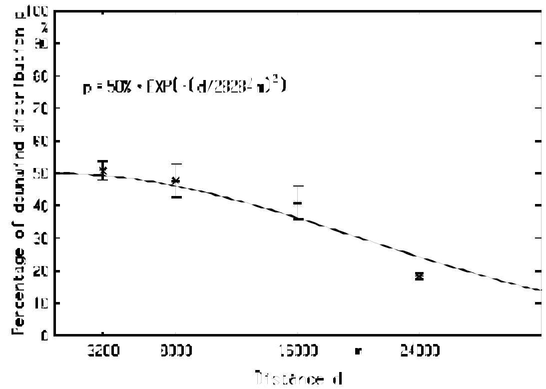

*Fig. 4* *Percentage of levels belonging to the downwind distributions versus distance.*

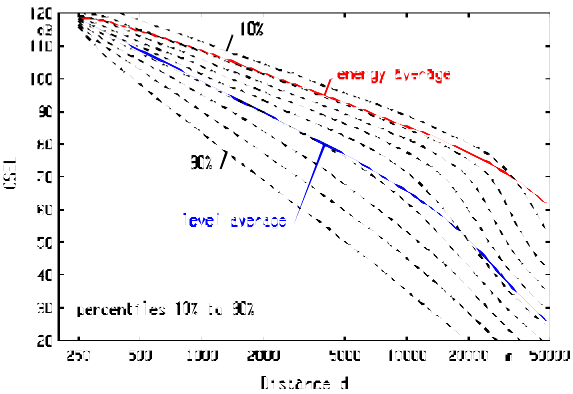


*Fig. 5* *Field of level percentiles versus distance including energy and level average.*

along its path decreases and tends to zero, eventually. These conclusions are not really fair because we only label the distributions using wind conditions, but never prooved that there is any correlation. However, there is no simpler function, actually, that makes more sense. A straight line, for example, does not make sense.

**The major goal...** Using the approximation functions for all parameters describing the variation with distance, fig. 5 presents the desired goal, the level distribution versus distance. Fig. 5 shows the set of percentiles from 10% to 90% as dashed lines, the energy average level and the level average as solid lines. The first interesting result that comes out of this presentation is that the energy average follows the 20 % percentile at closer distances. For larger distances, all lines and especially the higher percentiles go down rapidly compared to the logarithm of distance. This is interesting because it supports the heuristic model proposed by IfL.

## CONCLUSION

The description of the level statistics using a composite of two Gaussian distributions is reasonable for the database under consideration. If further experiments, which have to be made, support this hypothesis, the physical side of the problem will take an important step forward.

**For the first reason for doing statistics:** On the basis of this hypothesis it is possible to provide an statistical single event level. Using an appropriate parameter set (appropriate according to number of single events for every source, the type of source, etc.) it is possible to predict a reasonable ensemble of single event levels for calculating annoyance equivalent single event rating levels. The sum of this rating for a certain receiver site is a measure which could correlate to long term average annoyance which is measured in field surveys.

**For the second reason for doing statistics is:** If we can show that the parameters of the hypothesis do not depend on the directivity pattern with respect to height of different sources, this resulting distribution can help to interpret test series in an objective way using the correlation between the 20 % percentile, the energy and level average. It helps to understand that it is necessary to measure levels in downwind, upwind and neutral conditions to find a reliable prediction for 'good' sound propagation conditions in accordance with German assessment rules.

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