ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

SOUND IMMISSION MEASUREMENT FOR SOURCES WITH DIFFERENT TEMPORARY CONSTANT EMISSION (AIRCRAFT ENGINE) APPLYING ACCURACY MONITORED RESIDUAL SOUND SEPARATION

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Abstract

For the measurement of sound pressure levels produced at a far distant immission site by engines of airliners in maintenance during night a model of linear superposition with the local residual noise is established. Basic features of the model are the engine operation at constant power, changes of operation state accompanied by shifts of more than about 3 dB of the emission sound pressure level and positioning of a monitoring microfone close to the engine. By solution of the model equations, including the online monitored uncertainty of measurement, the engine sound impact levels, the residual noise level and the attenuation from the engine to the immission site are determined including all relevant uncertainties. An example for the feasibility test of the method at airport conditions is demonstrated.

INTRODUCTION

When engines of passenger aircrafts are to be run during night for their indispensable maintenance, some specific noise limits might not to be exceeded in the neighbourhood. Unfortunately the distance to the relevant areas of sound immission frequently is relatively great. Then, due to strong interference by residual noise, a directly evaluated measurement principally provides too high levels assigned to the specific sound source (engine) and thus lead to an erroneous statement of the exceedance of stringent noise limits, primarily at a low level. For this reason a qualified level separation principally is to be taken into account.

Fortunately for maintenance the engine usually is operated by constant power, i. e. with a constant emission level, which change from one time interval to the next due to different maintenance conditions to be examined. Additionally the information provided by a microfone installed in the engines vicinity for sound emission monitoring can be used. This is an essential for the method described here because it can give way to a very much higher resolution for the interesting final result, especially for low emission levels, than a measurement merely at the immission site alone. Taking this into account an acoustic model for the linear superposition of the source (engine) and the residual sound in the immission area can be established and operated not only on the common equivalent-continuous level L_{eq} [1] but primarily on the manyfold of the percent exceedance sound pressure levels $L_{x\%}$.

Additionally to the measurement in the common sense the actually indispensable quality control requires to monitor the unevitable uncertainties occuring within the sound measurement itself by confidence intervals for the $L_{x\%}$- and L_{eq}-type levels and also within the evaluation process. The theoretical foundations for this already are presented for example in [2] and more detailed in [3]. An example of application analogous to the method reported here is demonstrated in [4].

MODEL FOR THE SUPERPOSITION AND SEPARATION OF THE LEVELS OF SOURCE AND RESIDUAL SOUND

When the immission, coming from a dominant specific sound source, is to be separated from the residual sound, the uncertainty of the result differs only slightly from the directly measured uncertainty. In these situations a simple energy equivalent L_{eq}-difference can be rather sufficient for the sound level separation. But if on the other hand the residual sound is dominating, only the use of the relatively precise percentile levels of exceedance ratio 50 % or more and their confidence intervals can provide satisfactory low uncertainty of the separation results and therefore low resolution limits.

For the model description the following symbols are used: L: Sound pressure level, I: Sound intensity assigned to L with $I := 10^{0,1L}$ and, not confusable, also I as index for "immission", q: Percent exceedance (instead of "x"), E, S, R, 1 and 2: Indices for "emission", "source", "residual", first and second consecutive operating time interval, D: Damping (attenuation) in dB between the microfone at emission area and the immission site.

At the immission site the continuous-equivalent sound pressure level produced by the specific source (engine), denoted by L_{ISeq}, is

$$L_{ISeq} = L_{ES} - D \qquad \text{[dB]} . \qquad (1)$$

For simplicity and strongly confirmed by observation the sound emission of the aircraft engines during maintenance can be regarded as highly constant during a distinct state of operation in comparison with the range of the distribution of attenuation to the immission site and thus of the specific sound there. Also the level fluctuations of the residual sound exceed those of the engine emission. As is well known for short term conditions D is gaussian distributed with a typical standard deviation ≤ 3 dB for propagation distances of 1000 m and slightly above. Thus D in eqs. (1) and following (2) represents the difference of the L_{eq} values of the specific source between the emission microfone and the immission site. A remarkable feature and advantage of the use of a monitor microfone nearby the sound source is that due to the accessible attenuation D, caused by propagation, *all* further sound contributions of the source occurring at the immission site are known, irrespective of the level magnitude i. e. whether detectable or not at the immission site.

With use of eq. (1) and if the residual noise dominates the immission from the source, the sound intensity components are superimposed at the immission site according to the linear equation

$$I_{ES} \cdot 10^{-0,1D} + I_{Rq} = I_{Iq} \quad . \tag{2}$$

The optimal working region of parameter q for the separation procedure is about $50\ \% < q < 70\ \%$ exceedance. In eq. (2) are known the directly measured levels L_{ES} and L_{Iq}, respectively the assigned intensities I_{ES} and I_{Iq}. Quantities to be evaluated are the damping parameter D and the exceedance level L_{Rq} of the residual sound, respectively the assigned intensity I_{Rq}. Hence a second equation of this kind is

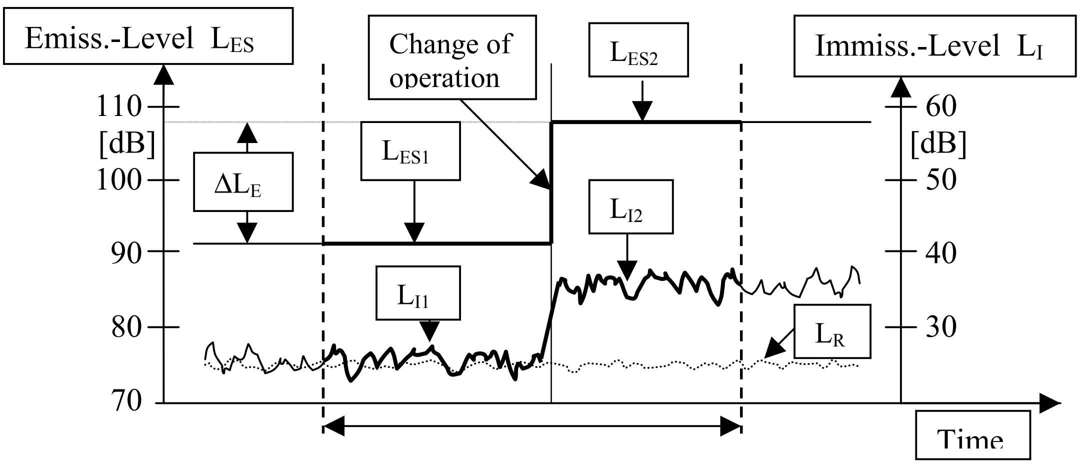

Figure 1 - Time window ↔ around an operation change of the specific sound source (engine) with input levels, their notations and residual level L_R (schematically)

necessary, based on a significant different state of engine operation, say with level difference $L_{ES2} - L_{ES1} := \Delta L_E$ dB (see Figure 1) relative to the foregoing state. So we get the starting couple of equations for further evaluation:

$$I_{ES\,1}\cdot 10^{-0,1D} + I_{Rq} = I_{Iq\,1} \quad . \tag{3}$$

$$I_{ES\,2}\cdot 10^{-0,1D} + I_{Rq} = I_{Iq\,2} \quad . \tag{4}$$

For the validity of these equations is precondition, at least within an adequately short time region around the transition to a a new engine operation state, that neither D nor the residual sound parameters change beyond the uncertainties which are effective anyway. If there is evidence that at least during one of the consecutive operation states the immission part of the source dominates the residual sound the choice of "eq" instead of "q" in eqs. (3) and (4) provides a consistent solution in every case.

In the first solution step from eqs. (3) and (4) we get the damping parameter

$$D = 10\cdot\log[(I_{ES2} - I_{ES1})/(I_{Iq2} - I_{Iq1})] \qquad \text{dB]} \tag{5}$$

and from this by eq. (1) immeadetely the equivalent-continuous immission levels L_{ISeq1} and L_{ISeq2} for the two operating states of the engine. The q-percent exceedance or L_{eq} level respectively of the residual sound is determined by

$$L_{Rq} = 10\cdot\log\,[(I_{ES2}\cdot I_{Iq1} - I_{ES1}\cdot I_{Iq2})/(I_{ES2} - I_{ES1})] \quad [\text{dB}]\ . \tag{6}$$

CONFIDENCE INTERVALS AND RESOLUTION LIMITS

A precondition for a meaningful evaluation of the final results for D, L_{ISeq1}, L_{ISeq2} and (optional) L_{Rq} is, that the uncertainty of the measured sound pressure level descriptors, primary the percent exceedance level, is known and sufficiently low. The uncertainty of the primary measurement results can be monitored in real time with the mutual half distance of the confidence limits ("confidence half interval", c.h.i.) as for $L_{q\%}$ as for L_{eq} . The basic features of this procedure, including hints to a versatile evaluation software ("NOISY"), measurement examples and some possible fields of application, are presented for example in [2] and [3].

The access to the uncertainty of the final results is performable by use of the c.h.i. for the the exceedance levels L_{Iq1} and L_{Iq2} as the input elements for an in principle conventional algorithmic error processing. This is to be performed within the sound intensity variable space due to the physical additivity of sound intensity. This procedure is completely corresponding to the European DIN V ENV 13 005, the "GUM" [5]. After the retransformation into the level space the uncertainty of the final result in terms of confidence limits can be expressed and evaluated. For the quantities interesting here this is performed as follows. For the immission levels L_{Iq1} and L_{Iq2}, extracted separately from consecutive engine operation states the simultaneously measured c.h.i. are denoted by V_{Iq1} and V_{Iq2} respectively, both in the unit dB(A).

Decisive for the uncertainty in the evaluation of damping D is the spread of the difference I_{Iq2} - I_{Iq1} in eq. (5). The c.h.i. of an intensity quantity I is $V_{int} = (0,1\cdot\ln 10)\cdot I\cdot V_{level}$ [4]. Thus the upper confidence limit D_u of damping D calculates as

$$D_u \;=\; D - 10 \cdot \log\left(1 - V^{(D)}_{\text{int},tot} \,/\left|I_{Iq2} - I_{Iq1}\right|\right) \quad [\text{dB}] \;, \qquad (7)$$

where

$$V^{(D)}_{\text{int},tot} \;:=\; (0{,}1 \cdot \ln 10)\,\sqrt{I^2_{Iq1} \cdot V^2_{Iq1} + I^2_{Iq2} \cdot V^2_{Iq2}} \quad . \qquad (8)$$

The lower confidence limit D_l evidently calculates by setting 1+V ... in the bracket of eq. (7). D can have a meanigful outcome only if $\mid I_{Iq2}\text{-}I_{Iq1} \mid \geq V^{(D)}_{\text{int,tot}}$. Taking equality this yields the resolution limit D_g for D according to

$$D_g \;:=\; 10 \cdot \log\;\left(\left|I_{ES2} - I_{ES1}\right| / V^{(D)}_{\text{int},tot}\right) \quad [\text{dB}] \;. \qquad (9)$$

In eqs. (7) and (9) the influence of uncertainty related to the emission is neglected because the level fluctuations of emission here are one order of magnitude less than of immission. From the parameter D is evident that for each kind of quantity to be evaluated here we get a set of four mutual assigned values: The value of the quantity itself, the upper and lower c.h.i. and the resolution limit. As L_E in eq. (1) is practically constant we get for the confidence and resolution limits of the immission level of the source (indices 1 and 2 for the operation states here omitted):

$$L_{u,ISeq} = L_{ES} - D_l \quad [\text{dB}], \qquad (10) \qquad\qquad L_{l,ISeq} = L_{ES} - D_u \quad [\text{dB}] \qquad (11)$$

and

$$L_{g,ISeq} \;=\; L_{ES} - D_g \;[\text{dB}] \;. \qquad (12)$$

Remarkable is that once D and its confidence limits are determined, the contribution to immission also from arbitrarily low emission states are accessible with the same accuracy as for a high level operating state.

For the residual sound, eq. (6), the upper confidence limit calculates as

$$L_{u,Rq} \;=\; L_{Rq} + 10 \cdot \log\left(1 + V^{(R)}_{\text{int},tot} \,/\left|I_{ES2} \cdot I_{Iq1} - I_{ES1} \cdot I_{Iq2}\right|\right) \;[\text{dB}]\;, (13)$$

where

$$V^{(R)}_{\text{int},tot} \;:=\; (0{,}1 \cdot \ln 10)\sqrt{I^2_{ES2} I^2_{Iq1} \cdot V^2_{Iq1} + I^2_{ES1} I^2_{Iq2} \cdot V^2_{Iq2}} \quad [\text{dB}] \;. \;\; 14)$$

The lower confidence limit $L_{l,Rq}$ is determined by setting 1-V ... in the bracket of eq. (13). The resolution limit $L_{g,Rq}$ for the evaluation of the residual sound pressure level is given by

$$L_{g,Rq} \;=\; 10 \cdot \log\left(V^{(R)}_{\text{int},tot} \,/\left|I_{ES2} - I_{ES1}\right|\right) \quad [\text{dB}] \;. \qquad (15)$$

From eqs. (9) and (15) it is evident that the difference between the emission state levels strongly influence the resolution limits of the evaluated immission parameters, as of the source (engine) as of the residual sound. Already from eqs. (3) and (4) and directly from (5) and (6) is evident that, for sake of sufficiently meaningful results, the emission levels of the two states of operation must have at least a certain minimum difference, denoted here by ΔL_{Eg} (definition of ΔL_E see Figure 1). For this a criterion can be stated as follows: It should be $D_g > D + \Delta D$ (16). By use of eqs. (9) and (1) this criterion is transformed into

$$10^{\,0,1\Delta L_{Eg}} \;=\; 1 \;+\; 10^{\,0,1\Delta D} \cdot V_{\mathrm{int},tot}^{(D)} \;/\; I_{ISq1} \quad . \tag{17}$$

If ΔL_E is relatively small, then

$$V_{\mathrm{int},\,tot}^{(D)} \;\approx\; (0{,}1 \cdot \ln 10) \cdot \sqrt{2} \cdot I_{ISq\,1} \cdot V_{Iq} \qquad [\mathrm{dB}] \quad . \tag{18}$$

Thus

$$10^{\,0,1\Delta L_{Eg}} \;\approx\; 1 \;+\; 0{,}33 \cdot 10^{\,0,1\Delta D} \cdot V_{Iq} \quad . \tag{19}$$

For $\Delta D = 10$ dB as a convention and $V_{Iq} \geq 0{,}3$ dB from the observations outdoor eq. (19) yields the emission condition

$$\left| L_{ES\,2} - L_{ES1} \right| \;\geq\; \Delta L_{Eg} \;\approx\; 3\; dB \quad . \tag{20}$$

EXAMPLE

To demonstrate, in which order of magnitude the results from the application of this method, eqs. (5 - (15), can be, an example is given as follows. Figure 2a shows the sound pressure level over time at immission site around the moment when the source, the aircraft engine in maintenance, changed into a new operation state. The situation is highly stationary besides the nonrepresentative first peak at the beginning of the second subinterval coming from the engine itself and the following 3 peaks from cars passing by in a medium distance.

This diagram is divided into the two parts corresponding to the distinct operation states and then evaluated separately over each subwindow. The nonrepresentative engine sound peak is cut out.

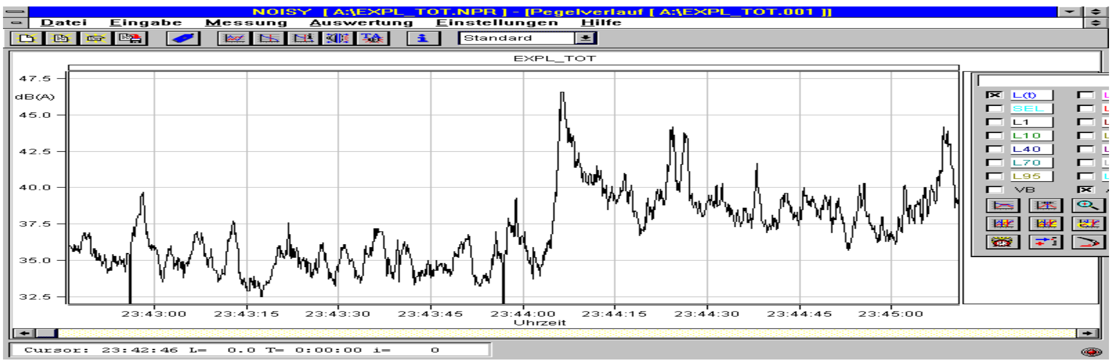

Figure 2a - Sound pressure level over time at immission site (1300 m distance to testing site). Transition into a new aircraft engine operation state at 23:44:05. Preceding this and after 23:44:10: Constant sound emission of the engine (not shown here) at different levels.

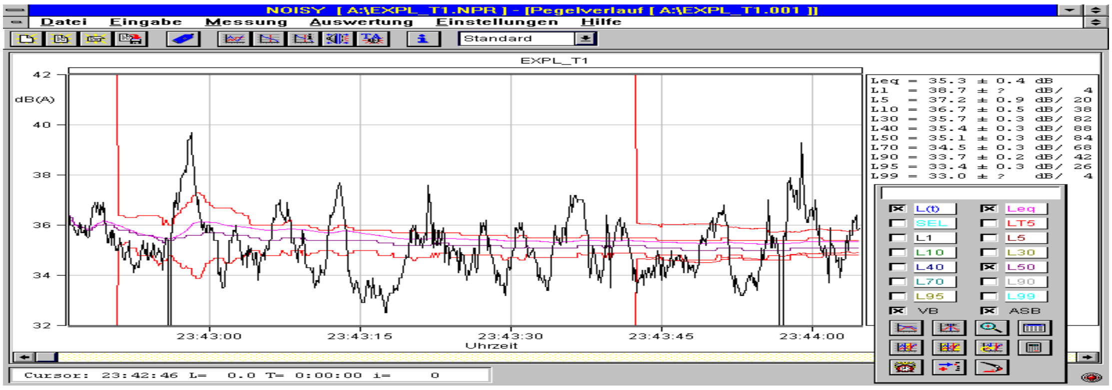

Figure 2b - Evaluation of the first sub time interval.
By choice edited in the graph are L_{eq} and $L_{50\%}$ over time. In the table on the right above distinct level values and their confidence half intervals are edited for this time interval. The last column indicates twice the number of stochastic periods which occurred.

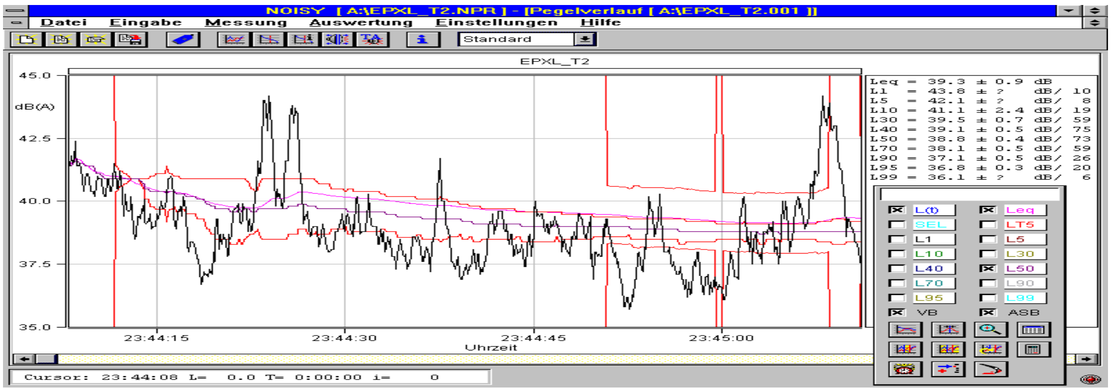

Figure 2c - Evaluation of the second sub time interval.
The uncertainty of L_{eq} within this time window now is clearly higher due to the three emerging accentuated peaks from cars passed by.

Table 1 - Evaluation of the measurement example, Figures (2a) - (2c)

<table>
<tr><th colspan="2">Input [dB(A)]
from measurement</th><th></th><th colspan="6">Results [dB(A)]
by eqs. (5)-(15)</th></tr>
<tr><td>Para-meter</td><td>Value</td><td></td><td>Para-meter</td><td>Value</td><td>Upper confid. limit</td><td>Lower confid. limit</td><td>Confid. half interval</td><td>Reso-lution limit</td></tr>
<tr><td>L_{ES1}</td><td>84</td><td></td><td>D</td><td>54,2</td><td>56</td><td>52,9</td><td rowspan="3">1,6</td><td>58,7</td></tr>
<tr><td>L_{ES2}</td><td>92</td><td></td><td>L_{ISeq1}</td><td>29,8</td><td>31,1</td><td>28</td><td>25,3</td></tr>
<tr><td>L_{Iq1}</td><td>35,3</td><td></td><td>L_{ISeq2}</td><td>37,8</td><td>39,1</td><td>36</td><td>33,3</td></tr>
<tr><td>V_{Iq1}</td><td>0,4</td><td></td><td>L_{Rq}</td><td>33,8</td><td>34,7</td><td>32,8</td><td>0,9</td><td>27</td></tr>
<tr><td>L_{Iq2}</td><td>39,2</td><td></td><td colspan="6" rowspan="2"></td></tr>
<tr><td>V_{Iq2}</td><td>0,9</td><td></td></tr>
</table>

In the evaluation table 1, for the input levels L_{Iq} the L_{Ieq}-values are used because in the second time interval the sound from the source (engine) is dominant. On the other hand this has the disadvantage of a relatively extended primary confidence half interval of ± 0,9 dB(A). Nontheless the quality of the final results is quite acceptable: The damping is determined with a relative uncertainty of only ± 3 %, confidence half intervals of ± 1,6 dB(A) are still acceptable and evidently also ± 0,9 dB(A) for the level (L_{eq}) residual sound.

CONCLUSION

The model presented principally provides a tool to determine the contributions to sound immission corresponding to known different constant emission states of a distant sound source. The procedure including quality monitoring in real time simultaneously provides the separation of the residual sound level component.

It is to be emphasized that in the environment a great variety of distinct situations as level height configurations, the dynamics of level drifts, structured sound events etc. occurs. Thus the situations which are to be assessed are to be selected thoroughly. But this must not be a disadvantage for instance for a long term and quality controlled statistical monitoring of the contribution of immission related to the specific sound source of interest.

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