

# National Measurement System Acoustics Programme:

## NMS Project 2.2: Environmental Noise

Work Package 1 Progress Report No. 5 by:

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## 1.0 INTRODUCTION

- 1.1 Responsibility for delivery of WP1 falls predominantly to Bernard Berry (BFB) and Nicole Porter (NDP).
- 1.2 BFB and NDP have met three times during the past quarter to progress WP1, and in addition have progressed the work package generally through emailed correspondence. The work is described below and dates up to the beginning of August 2004. This report was originally intended to be included in the recent progress report and hence is in the format (and numbering system) of that report. However, due to the volume of material, it is being issued separately.

## 2.0 FAMILIARISATION & IDENTIFY STATE OF THE ART METHODS

2.1 This was completed in the project's second quarter, as reported in the second quarterly report, although the task will continue throughout the project in order to ensure that any new publications issued or identified within the duration of the contract are identified and reported. In particular the following publications have been identified in addition to those reported in the last progress report.

- Khan's Tonal Ratio Method for Wheel Loaders - *MS Khan and C Dickson, "Evaluation of sound quality of wheel loaders using a human subject for binaural recording", Noise Control Engineering Journal, Vol. 50, No. 4, July-August 2002.*
- Critical Band Spectrum Method to Evaluate Tonal Components - *MA Nobile, GR Bienvenue, and SG Conahan, "The Critical Band Spectrum", Inter-Noise 1992, Toronto, Canada, 1992.*
- Terhardt's Model for Pitch Saliency - *E Terhardt, G Stoll, and M Seewann, "Algorithm for extraction of pitch and pitch saliency from complex tonal signals", JASA 71(3) 1982*
- Modification Aures Model of Bandwidth Effect (In Progress) – *A Hastings and P Davies, "The Effect of Attenuation Rate and Peak Bandwidth of Tonal Components on Perceived Tonalness" ISCA 2003*
- *A Hastings, P Davies, KH Lee, and A Surprenant, "Measurement of the attributes of complex tonal components commonly found in product sound" Submitted to Noise Control Engineering Journal, April 2003.*
- Pitch Model - *Vormann M, Daniel P, Detection of tonal components with a model of spectral and virtual pitch based on the FFT, Internoise 96, p1531-34.*

2.2 An Italian Government Decree was issued by the Ministry of Environment (Decreto Ministero Ambiente 16/03/1998: tecniche di rilevamento e di misurazione dell'inquinamento acustico, G.U. n. 76 1/4/1998). According to Annex B points 8) and 9) a sound is considered impulsive when all of the below requirements are met:

- difference between LAImax (Impulse) - LASmax (Slow) greater than 6 dB;
- duration of the impulse less than 1 s, calculated for the period in which SPLFast is greater than LAFmax - 10 dB;
- the impulse is repetitive, that is at least 10 impulses per hour for the day period (06:22) and 2 per hour for the night period (22-06).

When the above requirements are met, the LAeq value of the sound referred to the measurement time is increased by 3 dB.

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### 3.0 COMPARISON OF METHODS WITH RECOMMENDATIONS

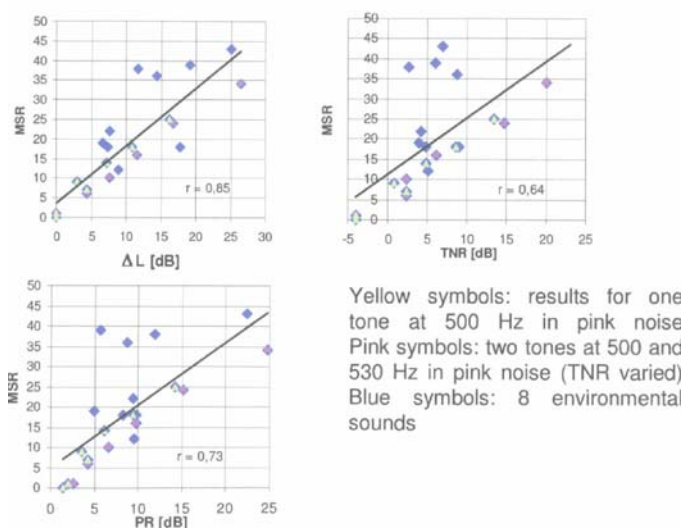
- 3.1 Evaluation of the extent of real world testing of methods and the practicality of their implementation has been the main focus for this reporting period.
  - 3.2 In the last report we examined the key stages of development of the methods i.e. showing how one method may be linked or may have led to the development of another and how the methods have developed chronologically. We developed a number of flow charts to help to highlight the origin of the fundamental principles of each method and the inter-relations between the methods, so that this information together with the information from the previous work stages on the fundamental principles could be used to categorise the methods into 'groups' for analysis. These main groupings were summarised in tables, from which we selected the initial methods that we felt were the most suitable for testing in the subsequent work. In our descriptions we gave some information on the extent of real world testing and the practicality of implementation. Because of the large number of methods, it was decided that it was neither feasible nor useful to examine extent of real world testing or practicality of implementation for all the methods identified in the previous quarterly report, but to focus our work in the selected methods.
  - 3.3 In this stage of our work, we look more in depth at the extent of real world testing and practicality of implementation, using our final listing of methods from our previous work. For the real world testing, we have reviewed previous research on intercomparison or testing of tonal and impulsive detection methods. This is reported next. For the practicality of implementation, we have investigated commercial or research implementation of the methods. This is reported after the research review described above.
  - 3.4 Finally we summarise our findings, and comment on the needs for future intercomparison exercises. We then set out our plans for the next stages of work.
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**Review of previous research on intercomparisons or testing of tonal detection methods - TNR, PR and DIN methods**

*Study of Dreesen and Weber 1995 (ref 1)- later analysed by Daniel, Vormann and Mundt 2002 (ref 2).*

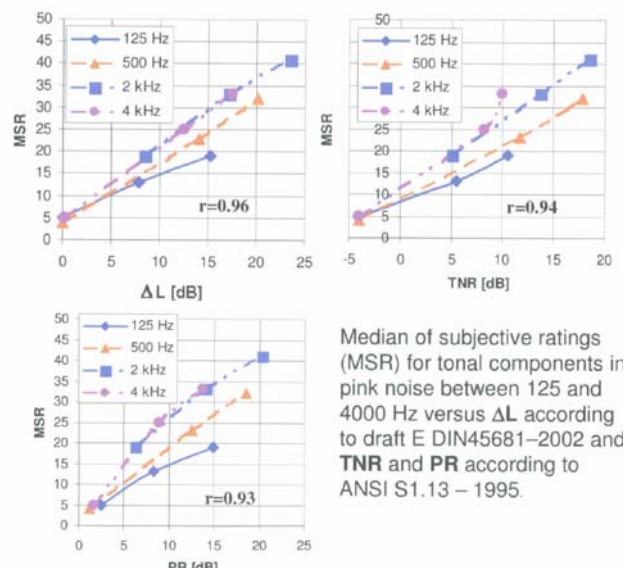
- 3.5 Two experiments were conducted in this study. Experiment 1 used 15 subjects and investigated the influence of one and two tones in pink noise, with increasing TNRs (between 7 and 33 dB) and of 8 environmental sounds (ranging between subjective judgments of not to very prominent).
- 3.6 Daniel, Vormann and Mundt used the data from this work to compare the later standard E DIN 45681- 2002 with the TNR and PR methods of ANSI S1.13 – 1995. They showed the findings in terms of the mean subjective ratings for a sound against the objective measures of Delta L (from E DIN 45681 – 2002), TNR and PR. These findings are shown in the next set of figures, taken from reference of P Daniel at al.
- 3.7 The later analysis work using Dreesen and Weber’s findings showed that all 3 methods predict the prominence of the synthetic sounds fairly well, but the prominence of the 2 tone complexes was shown to be slightly overestimated for all three methods. The DIN standard appears to rate the environmental sounds better than for TNR and PR.

Application to Environmental Acoustics: Results for experiment 1 of Dreesen and Weber (1994)



- 3.8 Experiment 2 investigated the influence of frequency on prominence using 10 subjects. Dreesen and Weber varied the frequency of the tonal components in pink noise between 66 to 8000 Hz, having TNRs between 0 and 25 dB. Subjective ratings of prominence ranged 11.5 to 15 category units, depending on the frequency of the signal.
- 3.9 Again, Daniel, Vormann and Mundt analysed the findings. These findings are shown in the next set of figures.

Frequency dependence: Results for experiment 2 of Dreesen and Weber (1995)

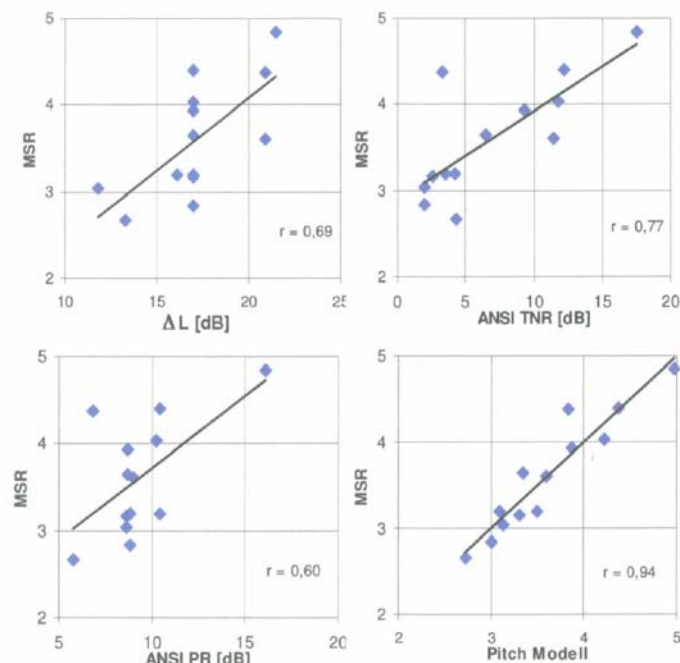


3.10 They found that overall correlation between the subjective and objective ratings was best for the DIN standard with TNR and PR having similar correlations to each other. The findings also clearly showed that the prominence of the low frequencies was overestimated by all three methods. However, for frequencies above 500 Hz, the use of the masking index  $a_v$  of the DIN standard reduced the frequency effect compared to the results for NR and PR.

*Daniel, Ellermeier and Leclerc 1998 (ref 3) - later analysed by Daniel, Vormann and Mundt 2002 (ref 2).*

3.11 Listening tests were conducted using tyre sounds as background noise with pure tones added with TNR values of 3, 6, 9, 12, 18 dB, and with narrow band noises (NBN) added which were centred around 500 Hz having bandwidths of 10, 50, 100 and 200 Hz. All the sounds were rated by 25 listeners using a 6 point category scale ranging from 'not tonal' to 'very tonal'. The findings are shown in the next set of figures, which also include a then proposed 'Pitch Model', not previously identified or described in these reports. The authors concluded that the correct estimation of tonal components should take into account the time and frequency resolution as well as the masking properties of the human ear. In the pitch model, it is recognised that prominence is closely related to the sensation of spectral pitches, which is dependent on sensation level, bandwidth, duration, and frequency of the tonal components present. From an auditory analysis, candidates for tonal components are derived in the frequency domain. In the time domain, components lasting long enough to be detected by the human listener are connected to form tracks out of which the prominence is calculated. This model must be added to overall summary of groups for subsequent testing.

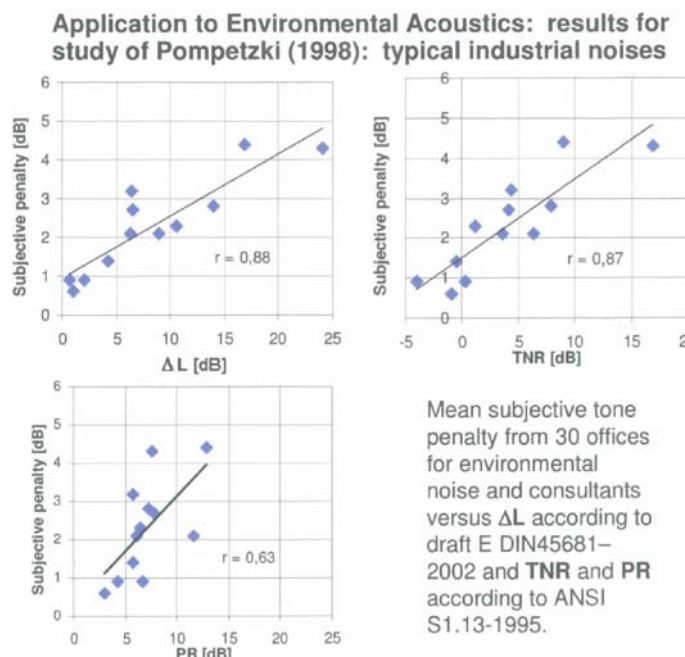
Application to the sound quality of tire noises  
Results for experiments of Daniel&Ellermeier 1998



- 3.12 The reanalysis of the findings showed that perceived prominence of the inserted tonal components was rated as rather low, due to spectral masking by the background tyre noise. All three methods - DIN, TNR and PR - were shown to overestimate the perceived low prominence of components around 500 Hz since the spectral masking is not taken into account, and furthermore do not take into account the perceived differences in prominence for the added NBN. The Pitch Model showed much higher correlations between the subjective and objective measures and Daniel et al suggested that this model provides a useful method to measure tonalness of non-time varying as well as time varying sounds.

*Pompetzki 1998 (ref 4) - later analysed by Daniel, Vormann and Mundt 2002 (ref 2).*

- 3.13 14 examples of typical industrial noises were recorded and sent on CD to 30 offices for environmental noise and consultants, for subjective evaluation by 114 experts. The tonal penalties for the noises were also calculated, using the draft standard procedure for the new EDIN 45681. Pompetzki derived some modifications for the revised standard.
- 3.14 Again Daniel, Vormann and Mundt used the data from this work to compare the later standard E DIN 45681- 2002 with the TNR and PR methods of ANSI S1.13 - 1995. These findings are shown in the next set of figures which shows that the DIN method fared better than the TNR method, which fared better than the PR method for this selection of stimuli.



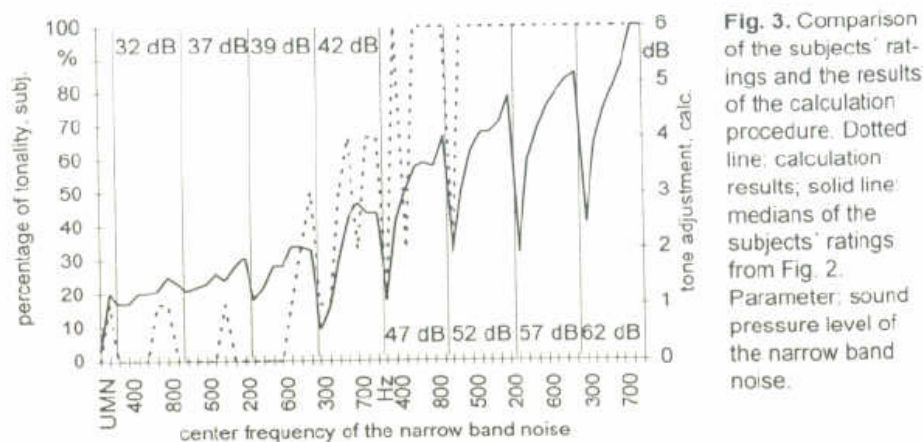
*Ellermier and Daniel 2003 (ref 2)*

3.15 This work could be regarded as a small 'meta-analysis' of the above studies in that it used previous data to compare the effectiveness of the DIN, TNR, PR and proposed Pitch Model in rating the tonalness of various sounds. The main findings have been described above, but here we summarise the general conclusions:

- The E-DIN 45681-2002 performed better than the ANSI S1.13 TNR and PR methods for the assessment of prominent tones in environmental sounds.
- The E-DIN 45681-2002 performed better than the previous E DIN 45681-1992, as the frequency dependence of prominence was slightly improved by using the masking index. However tonal components with low frequencies around 125 Hz are still overestimated.
- All 3 methods (DIN, TNR and PR) are not adequate for the assessment of weak time varying tonal components. For such applications, a Pitch Model is suggested which takes into account the time and frequency resolution capabilities of the ear, as well as the masking processes taking place in the ear.

*Beckanbauer, Stemplinger and Seiter 1996 (ref 5)*

3.16 This work compared the tone adjustments of DIN 45681-1995 with subjective ratings. It used synthetically generated sounds to simulate industrial noise immersions. Narrow band noise signals with a bandwidth of 30 Hz were used as the tonal components, together with a broadband masking sound. The findings are shown in the next figure.



3.17 The findings showed that the frequency dependence of the tonal adjustment required improvement – the higher the frequency, the more tonal the sound was rated. The work introduced a simple weighting function to take this into account. It was suggested that the shortcomings identified in this work, and the solution adopted should be considered in the next update of the standard.

*Sagemuhl and Schmidt, 2001 (ref 6)*

3.18 The revision of E DIN 45681 (tonality) - 1992 is investigated in this piece of work. The work introduced the changes incorporated in the revised version of the standard. There were 7 proposed modifications in all, which were drawn up by the 'Tonality' working group of NALS A2, which are described. These modifications were tested against Pompetzi's subjective data. The modifications were:

- A new iterative procedure for determining the sound power levels of the tone and of the masking noise.
- A reduction of the frequency line spacing (analysis resolution) from 8% to 4% of the critical band
- The introduction of a correction for the filter window characteristics.
- The introduction of the masking index  $a_v$  – a frequency dependent factor.
- The taking into account of the finding that the presence of 2 neighbouring pronounced individual tones within a frequency group caused a reduction of the noise if one of the tone is eliminated.
- The introduction of a tone penalty  $K_T$  as a function of  $\nabla L = L_g - a_v$ , to take into account the different assessment of pronounced tones from eth tone penalties envisaged in the draft document.
- The use of the A-weighted sound pressure level.

*Ellermeier and Daniel, 2002 (ref 7)*

3.19 In this work, the authors focussed on the quantitative measurement of the tonality sensation, and were concerned about developing a pure ratio scale using a paired comparison technique. 57 subjects were used to rate 11 sounds that consisted mainly of tyre sounds with added tonal features. The main findings are shown in the next figure.

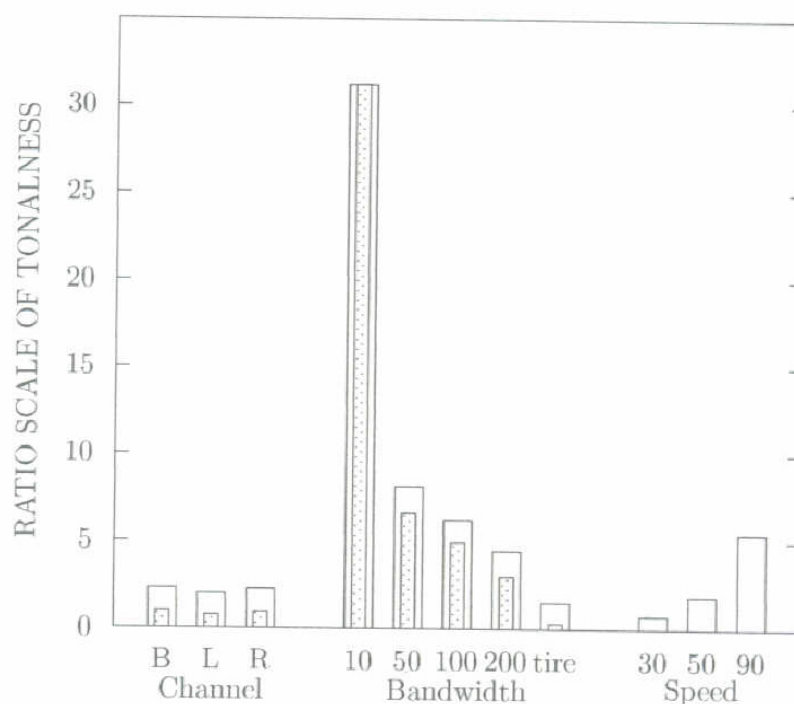


Figure 1: Ratio-scale values of tonality according to the *BTL* (narrow, dotted bars) and *preference tree* model (wide, unfilled bars). The values generated by the two models are scaled so as to coincide at the highest score. Estimates are based on 55 (possible comparisons)  $\times$  57 (subjects) = 3135 judgments. The three leftmost bars refer to variations of the binaural configuration of one specific test sound (s. method section); the three rightmost bars show the effect of tire speed, and the five central bars demonstrate the effect of adding narrow-band noise of various bandwidths to a recorded tire sound.

3.20 Although the subjective judgments do not appear to have been directly compared to the TNR and PR methods, the findings did reveal some shortcomings of these methods. It was found that narrow-band noise components produce strong tonal sensations approaching, but not quite reaching that of sinusoids of equal signal-to-noise ratio – which has implications for TNR. It was also found that the decline in tonality that occurs when the noise bandwidth is widened, even before the critical band is reached has implications for PR. Again, Ellermeier and Daniel proposed the Pitch Model as a better objective descriptor.

*ICWG 2001/2 (ref 8)*

3.21 A study by the International Committee Working Group (ICMG) on Noise from Information Technology and Telecommunications Equipment (ITTE) was conducted. The group undertook a comparison of the TNR and PR methods for the identification and evaluation of prominent discrete tones in product noise emissions. Although for many sounds, both methods had been found equivalent and to correlate well with subjective ratings, some conflicting results remained. Therefore this group set out to resolve these conflicts and ultimately aimed to optimise a single method.

3.22 A round robin test was carried out, using 40 test noises (28 artificial, 18 real), with 28 listeners (engineers) rating the tonal prominence on a 7-point scale. A parallel test was completed with 'naïve' listeners. Two laboratories analysed the signals using the TNR and PR methods. Both objective measures gave a good fit to the subjective data, as the following figures show:

Fig. 3. Engineers' MSR for artificial sounds - TNR

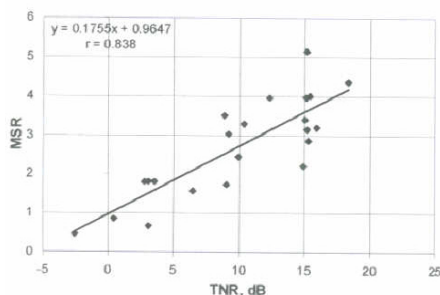


Fig. 4. Engineers' MSR for artificial sounds - PR

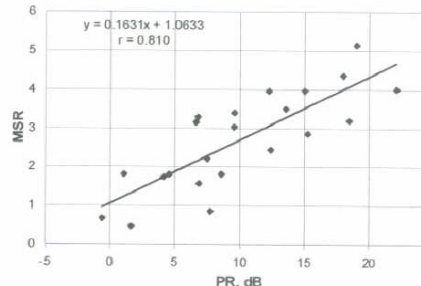


Fig. 5. Engineers' MSR for 17 product sounds - TNR

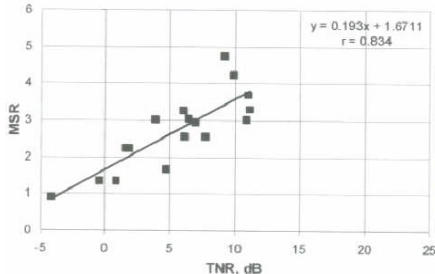
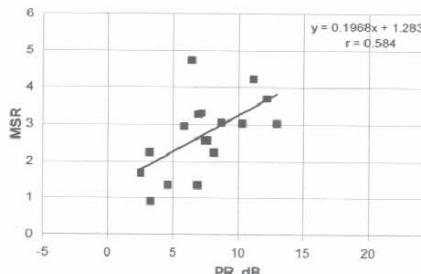


Fig. 6. Engineers' MSR for 17 product sounds - PR



3.23 However a number of shortcomings were identified of the existing TNR and PR methods.

- A frequency correction was needed, since low frequency tones were found to be less prominent than high frequency tones.
- The criteria for prominence needed to be increased.
- Tonal harmonics were not handled correctly, suggested by the difference in subjective response to the real and artificial noises.

3.24 In 2002, the suggested modifications to the procedures for determining prominent discrete tones were described, as a result of this test work. These included:

- The low frequency corrections
- The change in criteria of prominence
- The determination of lower and upper critical bands
- The extension of the PR to low frequencies

3.25 It was recommended that both objective measures should be continued to be used, as no method was significantly better than the other. More data should be gathered to determine if eventually a convergence to a single method was possible.

**Review of previous research on intercomparisons or testing of tonal detection methods - Wind Turbine Assessment Methods**

*Bass 1999 – A critical comparison of standard tonal analysis methodologies, report no. 52/RES/2006, Issue 1, 19 January 1999 (ref 9)*

3.26 This work examined a number of tonal analysis methodologies available in 1999. These were principally those relating to wind turbine assessment methods. These included:

1. Danish National Agency of Environmental Protection (1984), Guideline No. 6, 'Measurement of Environmental Noise from Industry – The Joint Nordic Method for the Evaluation of Tones in Broadband Noise'.
2. International Energy Agency (1994), 'Recommended Practices for Wind Turbine Testing and Evaluation, Vol. 4, Acoustics: Measurement of Noise Emission from Wind Turbines', 3rd edition.
3. EN 61400-11:1999 or IEC 61400-11:1998, 'Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques', November 1998
4. The Working Group on Noise From Wind Turbines (1996), 'The Assessment and Rating of Noise from Wind Farms', ETSU Report ETSU-R-97
5. International Energy Agency (1997), 'Recommended Practices for Wind Turbine Testing, 10: Measurement of Noise Immission from Wind Turbines at Noise Receptor Locations', 1st edition.
6. Theofiloyiannakos D (1998), 'Greek Noise Immission Procedure', CRES, Greece.
7. MEASNET Group (1997), 'Acoustic Noise Measurement Procedure', Version 1.

3.27 Interestingly, from this report we can identify a few more methods not previously examined in our work, for example 1, 2, 5, 6 and 7. However, these methods are essentially similar to the Joint Nordic Method and many have been superseded. All the methods are described fully in the references. We could at this stage review these additional methods, but the work described here does this anyway, but more importantly the work forms the basis for specifying an 'ideal' method for classifying tones in noise (focused on wind turbines) which in turn led to the new IEC 2002 standard. It is therefore not thought necessary to review these additional methods, as they would still go into the same wind turbine grouping for later analysis and review.

3.28 However, what is important in this work is the summary of shortcomings identified for each method. These are reproduced in the table below:

Method	Shortcomings (taken from ref Bass)
IEA NOISE EMISSION METHODOLOGY (1994)	<p>The methodology defined in this document assumes a fairly high level of expertise on the part of the reader, and several terms are used without definition, e.g. effective analysis bandwidth, 'picket fence' effect etc. As these can affect assessment results, this is clearly not satisfactory. Other areas where the document does not appear to be sufficiently specific include:</p> <ul style="list-style-type: none"> <li>• the user is allowed to use only 50 short term spectra to determine the tone level, whereas they require 200+ to determine the masking level. This allows an unwanted element of user choice into the methodology.</li> <li>• allowing 'visual averaging' of the sound level within critical bands' introduces subjectivity into the analysis;</li> <li>• it is not clear if the correction specified in the 'energy sum' method for determining the masking level, where the effective analysis</li> </ul>



	<p>bandwidth is greater than the frequency resolution, should also be applied to the 'average level' method.</p> <ul style="list-style-type: none"> <li>the criterion curve is shown in a figure, but not defined. It is assumed to be the same as that specified in the Joint Nordic Method, ie:</li> </ul> $Criterion Curve = 4.5 - \log \left[ 1 + \left( \frac{f}{502} \right)^{2.5} \right]$ <p>where <math>f</math> is the critical band centre frequency in Hz. The threshold for masking is 6.5 dB below this.</p> <ul style="list-style-type: none"> <li>there is no definition of what is 'tone' and what is 'masking' within critical bands;</li> <li>there is no definition of how to determine whether a tone is stationary or non-stationary.</li> </ul>
<p>IEC METHODOLOGY (NOVEMBER 1998)</p>	<p>Whilst being substantially the same as the IEA noise emission methodology, the differences that exist profoundly affect the results obtained. The most important differences are:</p> <ul style="list-style-type: none"> <li>the non-stationary approach is mandatory, whereas in the previous document the choice between 'stationary' and 'non-stationary' approaches was left to the user, with inadequate guidance on which to choose;</li> <li>the user has to use the same 200+ short term spectra for determining the tone levels as are used to determine the masking levels. The IEA document allowed only 50 of these spectra to be used, at the user's discretion. This removes an unwanted element of user choice from the standard;</li> <li>no criterion curves are defined, and the user is given no guidance on whether tones are prominent, audible or masked, a retrograde step;</li> <li>'visual averaging' of the sound level within critical bands' is not allowed, removing an area of subjectivity from the previous document.</li> </ul> <p>As before, a fairly high level of expertise is assumed on the part of the reader, and several terms are used without definition.</p>
<p>IEA NOISE IMMISSION METHODOLOGY (1997)</p>	<p>Whilst being the same as the IEA &amp; IEC noise emission methodologies in outline, the methodology in the IEA noise immission document attempts to offer specific procedure definitions in areas where, previously, there has been little guidance. The intention is to make the methodology more prescriptive, with little room for interpretation on the part of the user. Probably the most significant improvement is the definition of a procedure to identify spectral lines as tone, masking or neither within individual critical bands.</p> <p>An obvious improvement over previous methodologies is that little jargon is used, and where there are specific requirements, these are explained in the text, eg how to obtain an 'F' time weighting when measuring spectra etc.</p> <p>One shortcoming of the methodology is that, whilst the user is offered the choice between stationary and non-stationary approaches, and is warned that this will result in different indicative numbers for tonal excess, no criterion curves are defined, so that the numbers that result are of little practical use.</p>

<p><u>GREEK METHODOLOGY (SEPTEMBER 1998)</u></p>	<p>The Greek tonal assessment methodology offers further improvements to the method suggested in the IEA noise immission document. The objective method of discriminating between stationary, and non-stationary, tones is particularly welcome. There are two areas, however, where the Greek method appears weak, i.e.:</p> <ul style="list-style-type: none"> <li>• although a Hanning window is used, no correction is made for its use;</li> <li>• regarding the non-stationary method, rather than obtaining <math>\geq 50</math> short term, instantaneous spectra over the total time period of 5 min for a fixed speed machine and 2 min for a variable speed machine, it would be preferable, and more in keeping with previous methodologies to obtain:             <ul style="list-style-type: none"> <li>• for a fixed speed machine, <math>\geq 50</math> short term, instantaneous spectra for each of the 1 min periods evaluated;</li> <li>• for a variable speed machine, <math>\geq 10</math> short term, instantaneous spectra for each of the 10 sec periods evaluated.</li> </ul> </li> <li>• there is an inconsistency between stationary and non-stationary procedures regarding whether the tonalities values from the several repeats the methodologies require are energy averaged (stationary approach) or arithmetically averaged (non-stationary approach).</li> </ul>
<p><u>MEASNET (OCTOBER 1997)</u></p>	<p>The MEASNET tonal assessment methodology appears to be a stripped down version of that in the IEA noise immission, and does not consider non-stationary tones. This, together with the number of differences and omissions that exist, suggests that the numbers resulting from this methodology should be used with caution. However, the technique for characterising the wind speed dependence of tonality is a welcome addition. Other problems include:</p> <ul style="list-style-type: none"> <li>• no criterion curve is defined, so that it is not possible to comment on the relevance of the final tonality figure obtained (although the methodology omits to describe how the tonality is actually determined);</li> <li>• a Hanning window is specified, but no correction is made for its use;</li> <li>• the critical bands specified are not the same as for the Joint Nordic method so that it is not certain whether the Joint Nordic criterion curves still apply.</li> </ul>

3.29 The findings of the work principally propose an 'ideal' assessment methodology based on refinements to the 1984 Joint Nordic Method that include:

- a definition of what is 'tone' and what is 'masking' within a critical band, taken from the IEA noise immission document;
- a method for deciding whether a tone is stationary or non-stationary, taken from the Greek methodology;
- criterion curves so that tones can be assessed as masked, audible or prominent, taken from the Joint Nordic & IEA Emission documents;
- a method for describing the wind speed dependence of tonality, taken from the MEASNET methodology

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**Review of previous research on intercomparisons or testing of tonal detection methods - Joint Nordic Based Methods**

*Pedersen (refs 10 and 11)*

3.30 The 1984 version of the Joint Nordic Method (JNM) underwent a number of proficiency tests between laboratories. We cannot comment on these tests here as the report is in Danish in *ref 10*. However, this work showed a need for clarification of some details. On the basis of these proficiency tests (up to 35 participating laboratories) and the need for a general method also capable of handling noise from wind turbines, a new investigation was made also including tones with amplitude and frequency variations. This is described in Danish in *ref 11*.

3.31 This work and from general experience of applying the method led to JNM2 in 1999.

*Hayes McKenzie et al (ref 12)*

3.32 This work was conducted in 1995 and had 4 main objectives:

- To undertake high quality recordings of wind farm noise.
- To objectively analyse samples of the recordings to establish tone penalties.
- To perform subjective listening tests to correlate subjective perception with the objectively measured levels.
- To recommend a practical objective analysis procedure and tonal penalty rating scheme which best correlated with the results of the subjective listening tests.

3.33 The work used as its starting point the Joint Nordic Method to establish the tones relative to the broadband masking noise levels. A computer based fully automatic procedure was adopted. The analysis system used a Diagnostic Instruments PL202 FFT analyser as its data acquisition front end, and a PC that accepted the spectra via a serial link for subsequent implementation of the JNM. The first step of the analysis was to calculate RMS averaged spectrum from the transferred data – the method for stationary tones. The JNM also has a procedure for variable tones. This process was also used and the results were denoted as ‘Stationary tones (RMS) case’ and ‘Non-stationary tones (MAX) case’. The overall rating was given from the objective analysis as ‘inaudible’, ‘audible’, and ‘prominent’.

3.34 9 test noises were used in the subjective listening tests, with 10 subjects (principally members of the ETSU working group although 3 naïve subjects were included). These test noises were also rated as ‘inaudible’, ‘audible but not prominent’, or ‘prominent’. They were then asked to indicate a tonal penalty for each, with the naïve subjects given copies of advice in BS7445 i.e. that an audible tone would warrant a penalty of 20-3 dB, a prominent tone 5-6 dB. Subjects were then asked to adjust the level of a reference noise signal (pink noise shaped to emulate a typical wind farm noise spectrum but without any tonal component) to give the same subjective loudness as that of the wind farm noise sample.

3.35 The results showed that the JNM stationary (RMS) analysis procedure correctly determined the overall subjective audibility of tones for all samples. The non-stationary tones (MAX) analysis procedure tended to overpredict audibility.

3.36 Comparison of the subjective tonal penalties with objective tone sensation levels (the level of the tone above audibility according to the JNM criterion curve) showed a good correlation, with a suggested subjective tonal penalty of 1 dB for each 1 dB increase in tone sensation level. The work concluded that the tonal analysis procedure set out in JNM for stationary tones could be successfully applied to assess the audibility of total noise radiation from wind farms and that the threshold of audibility is approximately correct, and that a sliding scale of 1 dB per 1dB increase in tone sensation level above this threshold should be applied to any audible tones, up to a maximum tone penalty of 6 dB.

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**Review of previous research on intercomparisons or testing of tonal detection methods - Miscellaneous**

*Porter 1995 (ref 13)*

- 3.37 In 1995, as part of an NPL study into the assessment of industrial noise, a short evaluation of the ISVR tonal methodology was completed. It was recognised that this method had limitations; that is was only applicable to a single discrete tone in a steady state broadband background noise. No data was available on multiple tones (either closely or not so closely spaced) and the effects of a non-steady background noise. The method at that time took into account multiple tonal components widely spaced in the frequency spectrum by identifying the tonal component with the highest sensation level and then assuming that all other tonal components are part of the broadband background noise component. As Flindell (who developed the method) pointed out, the method could easily be modified to remove the effect of any other components from the broadband background noise if required, but no data were available to support any particular strategy.
- 3.38 The NPL work by Porter involved three separate short tests, (1) subjective perception of two-tone complexes (2) detection thresholds of a tone in the presence of another (3) detectability thresholds of single tones in broadband background noise. These tests were very preliminary and limited but provided useful indications. Three main problems were identified as requiring attention, in order to extend the tone detection to more complex tones:
- The upward spread of masking
  - The estimation of background noise spectra
  - The effects of modulation.

*Hastings at Al (ref 14)*

- 3.39 *Hastings at al (ref 14)*
- 3.40 In 2003, this paper reports on a number of subjective experiments and investigates TNR, PR, JNM and Aures' models of tonalness. The work first of all comments on observed deficiencies in the models, and points out that the Aures' model predicts tonalness, whereas the others predict the prominence of a tone (which is not necessarily a good predictor of tonalness). Two sets of studies are described.
- 3.41 In the first study, the effect of roll-off rate on the perception of the tonalness of bandpass filtered noise was examined. The experiments had three main aims: to verify Aures' model, to determine whether the psychoacoustic testing method affected the tonalness evaluations, and to examine how roll rate affected the tonalness of a sound. This work related only to the Aures' model, which was used to calculate tonalness using the Bradley-Terry-Luce model to transform the response data to tonalness ratings. 45 sounds were used made up of band pass, pure tones and white noise and 17 subjects were asked to choose a sound that was the more tonal in a series of paired comparison tests. The work concluded that roll-off rates of tonal features in spectra affect perception of the tonalness of sounds and so a combination of bandwidth and roll-off rate must be used when estimating tonalness. This effect may be related to the downwards frequency masking effects in the human auditory system. A modification of the Aures' metric was proposed, although more research was required to fine-tune this.
- 3.42 The second study was focused on developing an understanding of how frequency modulation affects tonalness. 6 subjects were asked to evaluate the tonalness of tones with randomly varying frequency. The performance of all the metrics as predictors of tonalness or tonal prominence for these types of sounds is discussed. Sixteen frequency-modulated sounds were used again using paired comparisons. The findings suggested that trackable nonstationary behaviour of frequency modulated tones leads to difficulties when using tonal metrics that are derived from estimated spectra. The problem was identified as one of bandwidth estimation, although estimation of the noise
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contribution can be problematic due to the wide region of the spectrum affected by the presence of the moving tone. A methodology to remove the trackable frequency component was proposed as a means to produce a more realistic measure of bandwidth but again requires further research.

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**Review of previous research on intercomparisons and/or testing of impulse detection methods**

*Berry, Fuller, John and Robinson 1979 (ref 15)*

3.43 This study, carried out at NPL, was primarily aimed at the development of a correction to be added to the descriptor EPNL, for application in the Noise Certification of helicopters. It arose from a requirement of the International Civil Aviation Organization ICAO, on which the ISO were consulted, who then set up a special international Working Group. A series of psychoacoustical experiments were carried out using recorded and simulated helicopter noises, and the results were related to various objective descriptors. The descriptors included were;

- Crest factor [peak to RMS, A-weighted],
- A special descriptor proposed by NPL, which involved the calculation of the variance in the time-series of short-term RMS values of signal amplitude,
- A similar method proposed by France, which used the Kurtosis statistic of the time series,
- A descriptor proposed by Westland Helicopters,
- A descriptor proposed by South Africa.

3.44 After several stages of “short-listing”, and further refinement of methods, the ISO WG eventually produced a formal proposal to ICAO for a method based on a hybrid of the NPL and French methods.

3.45 The significance of this early work is that it was the first ever use at NPL of digital time-series processing, and it formed the basis of later phases of work on short-term  $L_{Aeq}$ .

*Berry 1987 (ref 16)*

3.46 In a 2-year programme of work on the evaluation of impulsive noise at NPL, Berry conducted laboratory experiments on the dependence of judged annoyance on various physical parameters of impulsive noise, such as repetition rate, decay time etc. Using the data from these experiments, the performance of a number of objective descriptors was compared. This work introduced the concept of  $L_{Aeq}$  with a very short time period, 10ms.

3.47 The descriptors were;

- $L_{Aeq}$  [Impulse time-weighting] –  $L_{Aeq}$
- Crest Factor
- The ISO Descriptor for helicopter noise described above
- Standard deviation of the time-series of  $L_{Aeq}$  [10ms]
- Kurtosis of the time series
- Saliency – defined as the difference, over a one-second period, between the maximum value of  $L_{Aeq}$  [10ms] and the one-second value.

3.48 The ISO descriptor performed best, although it was noted that “ the choice of a descriptor or method for use in environmental noise assessment will be based not only on consideration of the relationship between values of the descriptor and annoyance but also on practical aspects such as the feasibility and ease of practical implementation.”

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*Berry 1989 (ref 17)*

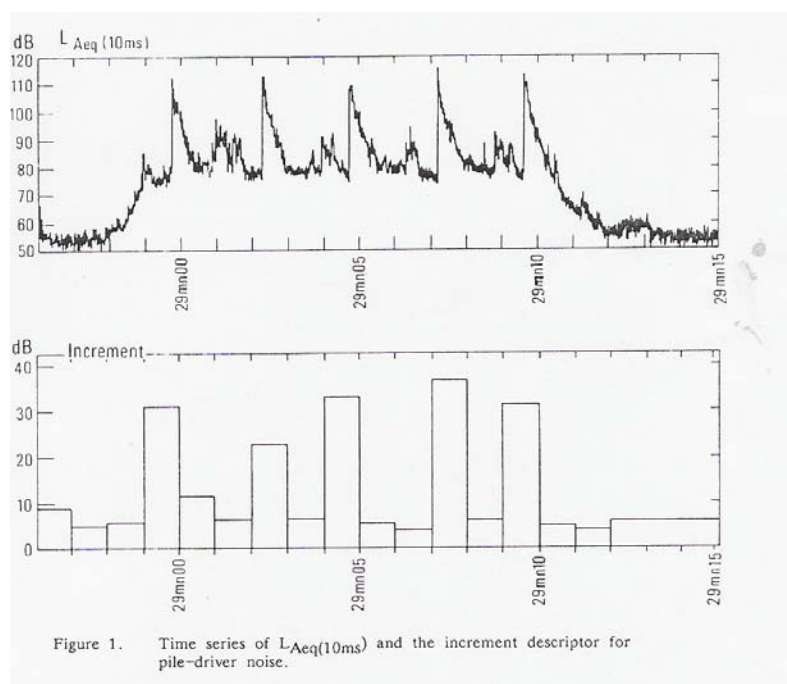
3.49 In the context of the EC-funded “Joint Project on Impulse Noise”, the above 1987 NPL work was taken further. A “common set” of 40 noises had been assessed by subjects in experiments in 3 countries. 4 questions had been used;

- A rating of annoyance, using a 10-point category scale,
- A rating of Impulsiveness,
- A yes/no decision on whether the noise was “clearly impulsive”,
- A rating of the annoyance of the “impulsive part” of the noise.

3.50 Correlations were made of the subjective data against the following descriptors;

- $L_{Aeq}$  Impulse –  $L_{Aeq}$
- Crest Factor
- The ISO Descriptor for helicopter noise described above
- Standard deviation of the time-series of  $L_{Aeq}[10ms]$
- Salience – see above.
- Increment – defined as the maximum positive difference between successive values in the time series of  $L_{Aeq}$  [10ms]

3.51 The concept of short-term  $L_{Aeq}$ , and the Increment descriptor are shown below, in a Figure from the 1989 ICA paper.



3.52 The Increment descriptor gave the highest overall correlations, taking into account data from all 3 countries, and all 4 questions.

*Brambilla and Caretti 1989, 1990, and Brambilla 1998 (ref 18, 19, 20)*

3.53 Brambilla, at the Italian Institute of Acoustics [IDAC] in Rome, who had been a participant in the CEC Joint Project on Impulse Noise, took the above work further. In a

paper at the NoiseCon '90 conference in Austin Texas, he re-analysed subjective data from the earlier experiments.

3.54 Noises used are shown in the next table.

Sounds judged non-impulsive	Equivalent Level $L_{Aeq}$ dB(A)					Sounds judged impulsive	Equivalent Level $L_{Aeq}$ dB(A)						
	35	40	45	55	65		70	35	40	45	55	65	70
Road Traffic							Gunfire						
Workshop	-	40	-	55	-	70	Hammering Wood	-	40	-	55	-	70
Bandsaw	-	40	-	55	-	70	Fire Alarm	-	40	-	55	-	70
Diesel Taxi	-	40	-	55	-	70	Hammering Metal	-	40	-	55	-	70
Lawnmower	-	40	-	55	-	70	Metal Beating	-	40	-	55	-	70
Boat Diesel	-	40	-	55	-	70	Sawing Machine	-	40	-	55	-	70
Road Drill	-	40	-	55	-	70	Typewriter	-	40	-	55	-	70
Air Compressor	-	-	-	55	-	-	Pile Driver	-	-	-	55	-	-
Car Doors Slamming	-	-	-	55	-	-	Telephone	-	-	-	55	-	-
Birdsong	-	-	-	55	-	-	Motorcycle Idle	-	-	-	55	-	-
Outdoor Tennis	-	-	-	55	-	-	Dogs Barking	-	-	-	55	-	-
Motorcycle Passby	-	-	-	55	-	-	Church Bells	-	-	-	55	-	-
Drop Hammer	-	-	-	55	-	-							
Scrapyard	-	-	-	55	-	-							

3.55 52 subjects made judgements using the 4 sets of questions outlined in the 1989 Berry paper above. Judgements of Impulsiveness [Question 3] were related to values of the Increment descriptor, and are shown below:

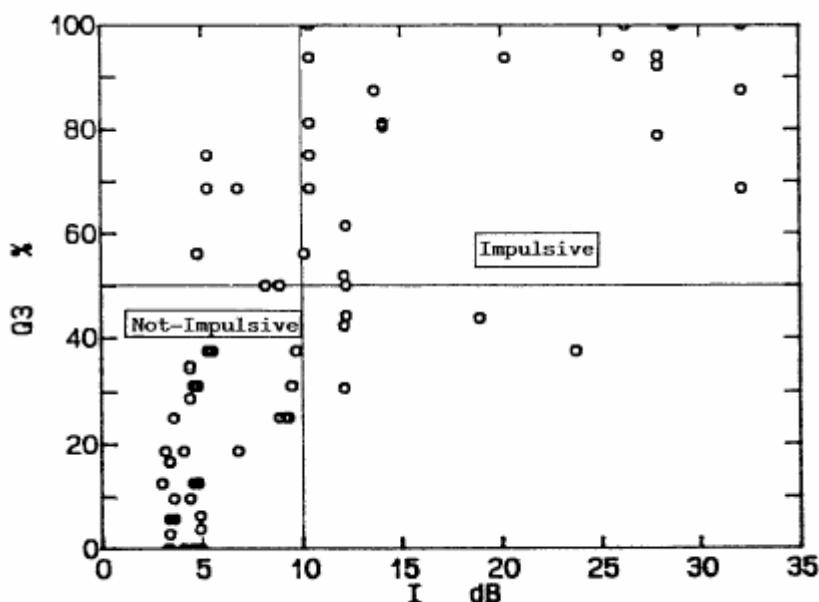


Fig. 1 - Onset of impulsivity and increment descriptor I

3.56 Based on this analysis Brambilla proposed that noises for which the value of the Increment descriptor exceeded 10 dB could be classified as Impulsive.

3.57 At the 16th ICA in Seattle in 1998, Brambilla described a further study. [ref 20]. Experimental data collected in the earlier CEC project studies were re-analysed. The subjective responses on the clear perception of impulsivity were correlated to the

selected descriptors of impulsivity to determine the corresponding threshold values for the onset of impulsivity and to evaluate how they were appropriate and sensitive in describing the perception of impulsivity.

3.58 The following objective parameters were considered for the comparison:

- a)  $L_{Aeq}$  Impulse -  $L_{Aeq}$
- b) Increment I, computed from the short-term  $L_{Aeq}$  10ms time series values considering only the positive differences between successive  $L_{Aeq}$  10ms values and taking the maximum
- c) “raising R”, as above but the positive differences between successive  $L_{Aeq}$  10ms values are added up together until a decrease of  $L_{Aeq}$  10ms occurs, therefore  $R \geq I$  (see below).

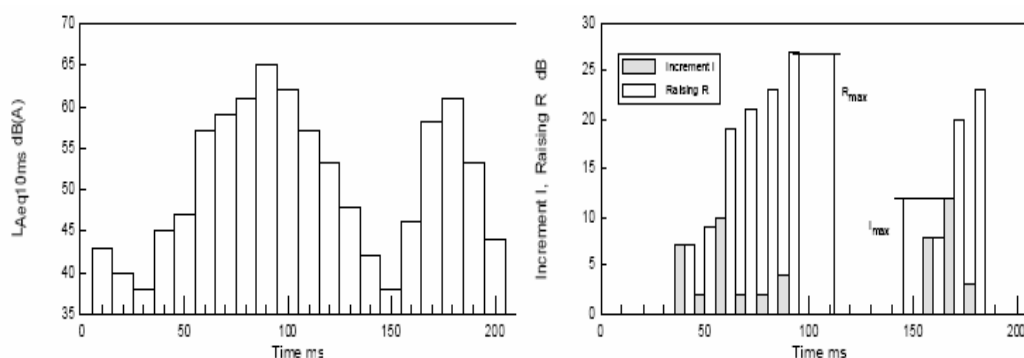


Figure 1. Definitions of increment I and raising R

3.59 Experimental subjective data relate to judgements on 26 environmental sounds heard in a Listening Room at IDAC, at  $L_{Aeq} = 55$  dB(A) for 20 seconds, by a group of people varying between 48 up to 112 subjects.

3.60 Results showed the descriptor “raising R” showed the best performance, while the results for increment I showed it to be the most “specific” descriptor for impulsivity. In other words it ranked highest in terms of the number of noises which were both judged subjectively to be impulsive and had high values of the objective descriptor. Results also confirmed that the “threshold value” of 10 dB for the onset of impulsivity previously determined was appropriate.

*Ikeda and Flindell 1993 (ref 21)*

3.61 Ikeda and Flindell explored the application of a general “masked threshold” approach which had already been successfully used in earlier work on tonal penalties [h]. The main experiment involved 24 listeners, and 12 synthetic impulsive noises, formed from an octave band pink noise signal which was time-shaped to have a 20ms rise time and 3 possible decay times – 50, 200 and 800 ms. 4 octave band centre frequencies were used – 500Hz, 1kHz, 2kHz, and 4kHz

3.62 Masked thresholds of the sounds, heard against a background of steady road traffic noise, were not adequately explained by the  $L_{Aeq}$  of the impulse sound. However threshold levels could be predicted within a few decibels by comparing the instantaneous frequency spectrum of the impulsive sound against the long-term average spectrum of the steady road traffic background sound. This instantaneous spectrum was obtained from the FFT of 80msec time windows, incremented by 4msec each time, in order to capture the peak impulse within the FFT time window. Results also showed a statistically significant association between reported annoyance

judgements and the Sensation Level of the impulse sound, [defined as the difference between the actual level of the sound and the masked threshold]

*Pedersen 2000 (ref 22)]*

3.63 In the late 1990s the Danish EPA funded an investigation by the Delta laboratory which involved a review of previous studies - including the NPL studies described above. New listening tests and analyses were also carried out. The first full report on this is in Danish with a long summary in English (ref 23).

3.64 The essence of the full report, describing how the method was developed from an intercomparison of a wide range of possible "physical measures" was then published in the Proceedings of Internoise 2000, (ref 24) together with a short "Amendment" in the form of a Delta report [AV153300] (ref 25)].

#### Listening tests and results

3.65 The following provides a discussion of the listening tests and results, based on the full report;

<http://www.mst.dk/udgiv/publikationer/2001/87-7944-375-3/html/indhold.htm>

3.66 In the Delta listening tests, described in the full report and in the Internoise 2000 paper, 5 expert listeners and 12 "ordinary " people were asked to judge 3 attributes of the test sounds, under the assumption that the test sounds were representative of the noise outside their houses.

3.67 These attributes were;

- Prominence
- Degree of intrusiveness of the impulses
- Annoyance

3.68 The 5 experts were also asked to mark on a 5 point scale whether the impulses were so clearly audible that a 5 dB penalty would be given. The sounds were 30 "industrial and other" sounds – in 3 groups

Group L:  $L_{Aeq} = 40$  dB of the noise samples.  $L_{Aeq} = 40$  dB of background noise. 17 listeners (panel + experts). Artificial head recordings of "real sounds" presented on headphones. The sound samples were unknown to the listeners.

Group H:  $L_{Aeq} = 60$  dB of the noise samples.  $L_{Aeq} = 40$  dB of background noise. Rest as group L.

Group P:  $L_{Aeq} = 60$  dB of the noise samples. No background noise. 5 listeners (experts). Mono recordings of artificial and "real sounds" presented on headphones. The listeners knew the sound samples from a laboratory proficiency test.

It is seen that the P-group differs from the L- and H-groups in several aspects.

3.69 Each sound had duration of approximately 30 sec. and was presented together with natural background noise with a constant A-weighted level of 40 dB. The sample numbers were announced with (calibrated) natural speech. The artificial head recordings were presented twice over calibrated open headphones. 12 photographs (42cm by 60 cm) from outdoor residential environments were put on the walls of the listening room.

3.70 The data analysis was mainly based on linear regression with the average of the listeners' judgements of "Prominent" as the Y-input and one or more objective measures or transformations of these as variables. Test for the significance of the variables was also made. The following measures based on the A-weighted sound pressure levels were tested:

- $L_{AmaxF} - L_{Aeq}$  in one-second periods,
- $L_{A, F} - L_{A, S}$  as a running measurement,
- $L_{Amax F, 30sec}$ ,
- $L_{AmaxF} - L_{Aeq, 30sec}$ ,
- $L_{AmaxF} - L_{A95}$  in 30-second periods.
- Onset rate (dB/s)
- Level difference (dB from background SPL to 90% of max. SPL).

F and S denote time weightings F and S, respectively.

3.71 The following psychoacoustic measures were tested:

- Loudness (sone),
- sharpness (acum),
- roughness(asper),
- fluctuation strength (vacil),
- onset rate (sone/sec.) and
- level ratio (sone/sone) from
- background level to 90% of max. level).

3.72 It was concluded that no single parameter could characterise - with sufficient accuracy - the prominence of the impulses or the extra "annoyance" (extra = the part of the "annoyance" not already explained by  $L_{Aeq}$ ) caused by the impulses.

3.73 Metrics, or descriptors, with more than one parameter were then tested. The main conclusions were based on the L- and H-samples, with additional analysis performed on all noise examples. The data analysis is mainly based on linear regression with the average of the listeners' judgements of "Prominent" as the Y-input and one or more objective measures or transformations of these as variables. Test for the significance of the variables was also made. Good correlations were found between "Prominent" and the logarithm of the onset rate and the logarithm of the level difference. The best results of the A-weighted variables were obtained with the following combination:  $2.41 \cdot \log(\text{onset rate}) + 3.43 \cdot \log(\text{level difference})$ ;  $R^2 = 0.74$  for L- and H-samples and  $R^2 = 0.57$  if P-samples were included.

3.74 For a similar combination of psychoacoustic data,  $R^2 = 0.75$  was obtained for L- and H-samples and  $R^2 = 0.60$  if P-samples were included. If also sharpness was included, the  $R^2$ -values increased to 0.78 and 0.61. The highest  $R^2$ -value was 0.83 obtained with a combination of several psycho-acoustic parameters

3.75 A result based on a combination of the psychoacoustic-related measures for level difference (sone ratio:  $\text{sone}_{background} / \text{sone}_{max}$ ), onset rate (sone ratio/s), and sharpness are shown in first figure below. Although this seemed promising, an A-weighted measure was preferred for practical reasons.

3.76 Thus, a combined measure consisting of onset rate and level difference gave good correlation with the listening tests ( $R^2 = 0.74$ ). Higher correlations were obtained with

psychoacoustically based measures, but these were still considered too advanced for practical use.

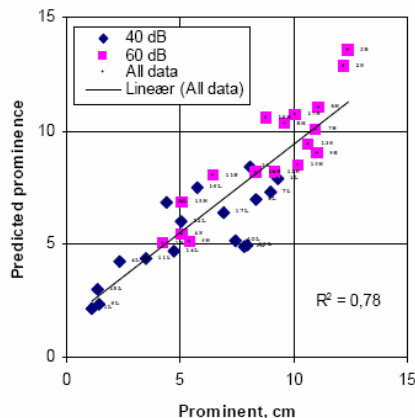


Figure 1. The listeners' judgements of "Prominent" and the prominence predicted from psychoacoustic measures based on sone and sharpness.

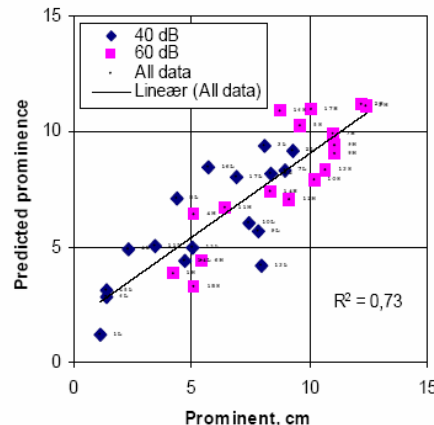


Figure 2. The listeners' judgements of "Prominent" and the prominence predicted from A-weighted measures with time weighing F.

### Proposed Method

3.77 As mentioned a linear combination of log (onset rate) and log (level difference) gave the highest R2-value, but the constants were not critical, with low values for slow (50 km/h) car passes-by and high values for sharp and loud artificial pulses. The measure was furthermore designed to give a maximum value around 15.

3.78 The optimised equation which gave an R2-value of 0.73 is:

$$\text{Predicted prominence: } P = 3 \cdot \log (\text{onset rate}) + 2 \cdot \log (\text{level difference})$$

3.79 Log is the logarithm with base 10. The correspondence with the listeners' judgements is shown in second figure above.

3.80 The authors then went on to propose an adjustment or penalty KI to the measured  $L_{Aeq}$  for impulsive sounds with onset rates larger than 10 dB/s, based on the predicted prominence P;

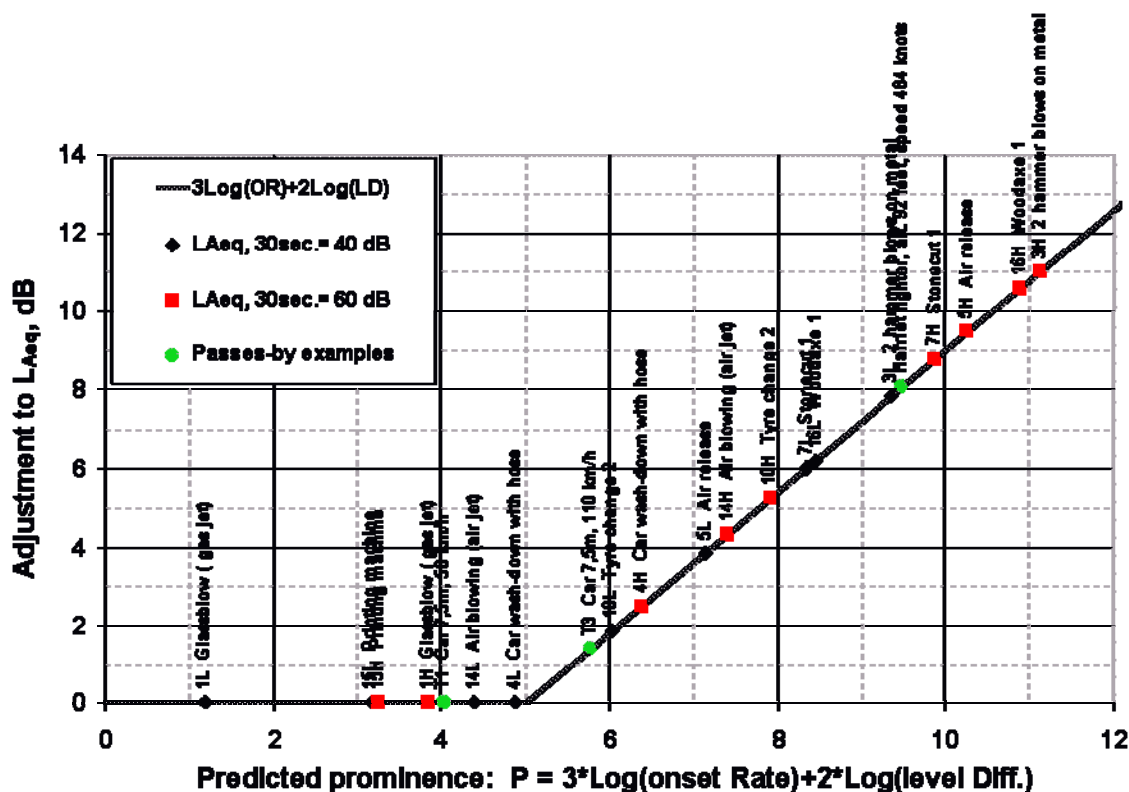
$$\text{Adjustment to } L_{Aeq}: K_I = 1.8 \cdot (P - 5), \text{ for } P > 5, K_I = 0 \text{ for } P \leq 5$$

3.81 It was suggested that this adjustment is made to  $L_{Aeq}$ , 30min on the basis of the one event with the maximum value of P in the 30-minute period. The following figure illustrates this equation and shows the adjustment KI to  $L_{Aeq}$  for some noise examples. It was noted that;

Note 1: The general form of Equation (2) is:  $K_I = k_3 \times (P - k_4)$ , for  $P > k_4$ ,  $K_I = 0$  for  $P \leq k_4$ . The constant  $k_3$  gives the inclination of the correlation between  $K_I$  and P, and  $k_4$  defines the lower limit for adjustment to  $L_{Aeq}$ . The constants  $k_3$  and  $k_4$  are preliminarily set to give an approximate correspondence with the extra annoyance reported in the literature for different kinds of noise sources. The adjustment is not made on the background of the listening tests in the present study. As the annoyance depends on the level and characteristics of the

noise, the kind of sound source, the context and social factors, and as the adjustment  $K_1$  is meant to compensate for the extra annoyance from the impulses, it might be considered to operate with sourcerelated and/or level-dependent values of  $k_3$  and  $k_4$ .

Note 2: The time period of 30 minutes for adjustment of  $L_{Aeq}$  is set as a preliminary period from considerations of reasonableness and ease of measurements and administration. There are no systematic investigations behind this period, and the principle should be considered in more detail when such investigations are made.



3.82 A further paper, primarily concerned with detailed definition and specification of the Prominence method, was then published at Internoise 2001 (ref 26)]

Round Robin testing of Prominence method

3.83 At around the time the Prominence method was being finalised and formally proposed to the NORDTEST organisation, the DELTA laboratory set up a “Round Robin” test. The aim of this was to test the proposed method and to determine the measurement uncertainty by carrying out comparison measurements between 4 different Nordic laboratories using different measuring set ups.

3.84 The laboratories involved were;

- SP Swedish National Testing and Research Institute, Borås, Sweden
- DELTA Akustik & Vibration, Lyngby, Denmark
- VTT Building Technology, Finland
- KILDE Akustikk AS, Bergen, Norway.

3.85 The following is a summary of the key points documented in the Report of the Round Robin (ref 27).

Signals

3.86 DELTA provided a CD with 54 impulse sound samples, used at their listening tests. 11 of them were chosen to be included in the project. The other members of the group were invited to contribute with additional sound samples, typical for their countries. SP distributed an additional CD with in total 10 impulse sounds, 5 of them only optional to analyse, recorded by KILDE and SP. The impulse sound samples are listed in the table below.

*Analysed impulse sound samples.*

Sample	Source	Recorded by
2L	Hammerblows on metal	DELTA
5L	Air release	DELTA
7L	Stonecut	DELTA
9L	Tyre change	DELTA
16L	Woodax	DELTA
2H	Hammerblows on metal	DELTA
5H	Air release	DELTA
7H	Stonecut	DELTA
9H	Tyre change	DELTA
16H	Woodax	DELTA
5P	Door slamming and starting car	DELTA
NT1	Skateboard ramp	KILDE
NT4	Container truck	KILDE
NT7	Car in tunnel opening	KILDE
NT8	Timber sorting machine	SP
NT9	Church bells	SP

3.87 The samples marked with "L" had the same LAeq for the impulses as for the background noise. The samples marked with "H" had 20 dB higher LAeq for the impulses than for the background noise. The additional samples are marked with "NT". The time length of the samples was 30 s.

Measurements

3.88 The participants measured and analysed the selected recordings on the CDs. They were initially instructed to perform the measurement according to the "NORDTEST draft 2" method. When the measurements started some questions were raised about how to interpret the definition of "Onset Rate". A "NORDTEST draft 3" test method with a new definition of "Onset Rate" was sent out. At that time VTT had already carried out their measurements according to the "NORDTEST draft 2" method. The other participants used the "NORDTEST draft 3" method. However, no systematic or significant difference between the VTT result and the others was found. Each laboratory used slightly different sets of equipment.

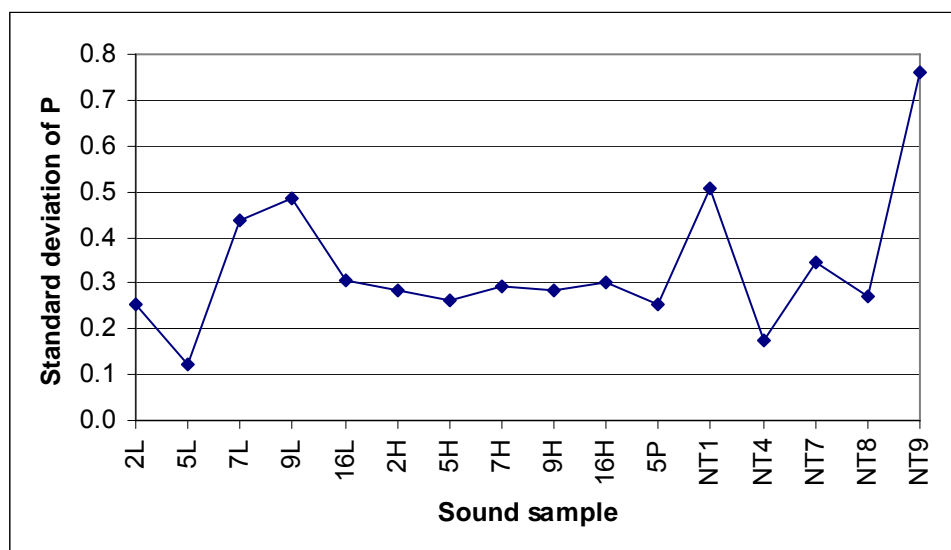
Results

3.89 Results were presented for;

- Impulse adjustment KI for each of the 4 labs and 16 noises,
- KI for each lab, relative to the arithmetic mean of all lab results,
- Standard deviation of KI
- Standard deviation of Prominence P
- Measured 3 lg (onset rate) for each lab and each noise

- Measured 3 lg (onset rate) re. arithmetic mean.
- Standard deviation of 3 lg(onset rate).
- measured 2 lg (level difference)
- measured 2lg (level difference) re. Arithmetic mean
- standard deviation of 2lg(level difference)

3.90 By way of example, the results for standard deviation [across 4 labs] of Prominence are shown below.



#### Overall conclusions

3.91 It was concluded that the impulse adjustment of  $L_{Aeq, KI}$  can be determined with a mean standard deviation of 0,6 dB, using the proposed method. The main contributor to the standard deviation is the measurement of onset rate. The standard deviation of the onset rate can be decreased for short impulses by limiting the permitted range of sampling of  $L_{pA,F}$  to 10-25 ms. Taking into account that three of the participants used the method for the first time in this Round Robin test that the method was changed slightly after one of the participants made his Measurements that one of the participants made a consequent deviation from the method that different equipment and sampling procedures (5-32 ms) were used by the four participants a mean standard deviation of 0,6 dB is acceptable in comparison with the other uncertainties seen in environmental noise measurements.

#### Later developments

3.92 Following the Round Robin, a number of minor modifications were made to the method and a formal proposal (*ref 28*) was made to the Nordtest organisation [[www.nordtest.org](http://www.nordtest.org)]. This method was approved as "Nordtest method NT Acou 112 " in May 2002 (*ref 29*). It can be downloaded from;

<http://www.nordtest.org/register/methods/mlibrary/macou/acou112.pdf>

3.93 The method was then proposed to the ISO Working Group 45 responsible for the revision of ISO 1996. For completeness the description of the method as proposed to ISO is given in our annex 1.

## 4.0 INVESTIGATION OF IMPLEMENTATION OF METHODS – COMMERCIAL AND “RESEARCH”

- 4.1 For this present phase of the project, dealing as it does with the issue of the practicality of actual implementation of these methods, it was decided that we needed a systematic enquiry into whether any of the set of methods we were investigating were already fully implemented in existing commercial instrumentation. It was also felt necessary to ascertain if such instrumentation might already provide the basic “front-end” processing of acoustic signals, as a basis for implementing the methods by later post-processing.
- 4.2 We also noted that, during various stages in the course of the review of methods, information was being acquired, and more could be obtained, on the specific details of how certain methods had been implemented within the research studies being reviewed. This section of the report therefore documents the information obtained on Commercial and also on Research Implementation.

### Commercial implementation of tonal and impulsive methods

- 4.3 Although information is available on the websites of instrumentation companies, and could be searched, a more direct email enquiry was preferred. Amongst the reasons for this were that personal contacts with instrumentation experts at the companies could be used to maximise the amount of information gathered, and that additional, “non-standard”, information was being sought.

#### Questions

- 4.4 The full text of the email enquiry is given as Annex 2. The other documents referred to in that email, which summarise the methods, are included as Annex 3. Essentially, having set out the context by summarising the project, and supplying a copy of the relevant Internoise 2004 paper, we asked recipients to look at the descriptions of the methods and advise us;

1. *if any of the methods are already implemented in current commercially available instrumentation, or*
2. *if any instrumentation you are familiar with could provide the basic "front-end" processing, such as frequency analysis, or very short-term LAeq, from which the methods could be implemented with additional processing."*

- 4.5 This second question was considered to be very important in establishing the feasibility of implementing methods which were included in our review, but which had not reached full commercial implementation.

#### Contacts

- 4.6 The six instrumentation companies who were most active in terms of current UK advertising of relevant products were selected; AcSoft, Brüel & Kjær, Cirrus, Cassella-CEL, Ian Campbell Associates [Norsonic] and [ANV Measurement Systems](#) [Rion].

#### Responses

- 4.7 To date we have received 4 detailed replies. These are summarised in Table 1, related to methods for Tones, and Table 2 for Impulse methods. An additional reply was received from Casella-CEL, which indicated that none of those companies' products implemented any methods “directly”, but that their products could provide the basic front-end processing, from which any of the methods could be implemented. In addition, Dudley Wallis of Cirrus commented – “Implementing a 'method' is not the task of lowly instrument manufacturers, instead we see the problem as one of acquiring the data and writing an external routine to get any index you want. The 'economies of scale' dictate this route.”

# NATIONAL MEASUREMENT SYSTEM ACOUSTICS PROGRAMME

## NMS PROJECT 2.2: ENVIRONMENTAL NOISE



Table 1. Implementation of tonal methods

COMPANY	AcSoft	B&K	Cirrus	Norsonic
<p>Qu. 1 Methods implemented DIRECTLY in Existing commercial instrumentation</p>	<p>The Svantek 94x series of instruments have options Tonality according to the Joint Nordic method (principally for wind turbines) en.</p> <p>Symphonie from 01dB has options for real-time PNL and EPNL principally for aircraft noise.</p>	<p>Of the tone methods described, B&amp;K 2260 can min cope with ISO 1996 1/3 octave band procedure, Part 1: 1982, Part 2: 1987, Part 3: 1987 (same as BS 7445; 1991)</p> <p>DIN 45681 tone to noise ratio, 2001</p> <p>JNM, (version2), 1999</p> <p>Not fully checked how 2260, 2250 and/or PULSE can be used.</p>		<p>DIN45681 1992 &amp; 2001 are fully implemented in Norsonic Nor-110 and Nor-121. A new issue of the firmware for the Nor-121 is due in the late Summer and this will add the implementation of the ISO tone standard. .</p>
<p>Qu.2 Front-end processing, with possible additional post-processing</p>	<p>Symphonie/Harmonie, and SoLio measure real-time 1/3 octaves, for downstream processing, so any parameter requiring the use of short-time 1/3 octave time histories can be proposed.</p> <p>Additionally, Symphonie/Harmonie measure real-time FFT or multispectra from post-processing, and can therefore be used as a tool for tonal analysis.</p> <p>Svantek 94x range of instruments have options for 1/3 octave real-time as well as FFT analysis for post-processing</p> <p>As post-processing in dBTRAIT software, SIP95, Solo, Harmonie and Symphonie data can be used to evaluate tonal components from 1/3 octave data to ISO1996 and BS4142.</p>		<p>Our Pulsar model 33 has 1:3 octaves and stores these as though they were short Leq. It can store a few hundred thousand.</p> <p>The 33 would make the basis of ANY of your methods I think - if it were commercially viable. Model 33 has been Pattern Approved ... if there is a proven need and a profit, they will beat anyone.</p> <p>The CR:831 does 1:3 octaves but NOT in real time as well as short Leq; it is a PTB approved serial instrument</p> <p>1/24 we do not do.</p>	<p>The multi-spectrum facilities of the Nor-118 and 121 will give the basic data in both the time and frequency domain for the evaluation of both tonal and impulsive noise, again the user can automate the post processing using the macro features of NorReview.</p> <p>Also in Nor-121 and 118 multi-spectrum facilities are provided to allow post processing to identify tones to the ISO 1996 &amp; ANSI 12.9 procedures</p>

# NATIONAL MEASUREMENT SYSTEM ACOUSTICS PROGRAMME

## NMS PROJECT 2.2: ENVIRONMENTAL NOISE



Table 2. Implementation of impulse methods

COMPANY	AcSoft	B&K	Cirrus	Norsonic
Qu. 1 Methods implemented DIRECTLY in Existing commercial instrumentation				
Qu.2 Front-end processing, with possible additional post-processing	Symphonie/Harmonie measure short Leq down to 20ms in real-time, and Solo measures down to 10ms in real-time. Short Leq down to a resolution of 2ms can be calculated from raw audio records.	I have tested the Pedersen Prominence method as part of the official Round Robin test (see mail) - I think using PULSE.	<p>The CR:236 AS as you know did 10ms and the current CR:245 can as well, if we changed the ROM and after a few minutes work. Similarly all the airport monitors can do the same.</p> <p>2. The CR:800 can do 10ms, although the commercial PTB approved version is 1s. The 800 has a limited linearity span however, PROBABLY about 60dB at 10ms</p> <p>3. A new unit, (internal code CR:900) has the same basic possibilities as the 800 but with a 100?dB span at 10ms. This was a DTI sponsored instrument and will be at Internoise - I am told!</p> <p>4. The 700 series can acquire A-frequency and F-time-weighting data as standard into memory in place of short Leq.</p>	Both the Nor-118 and 121 provide time profiles of LAeq, Lmax, Lpk, etc from which the necessary information to calculate the Pedersen or NPL methods for determination of the impulsive content. These profiles can be as short as 5 ms if required. The NorReview post processing package implements standard Excel Macros and these could be used to search the data for the specified time history. The Nor-840 will provide FFT multi-spectra and from this the ISVR masked threshold method may be implemented via post processing

**“Research” implementation - Tonal**

- 4.8 Email inquiries to A Hastings revealed that for the Aures method, Matlab was used to carry out the calculations. The implementation is not quite ready for release and is not intended to be commercial software. The implementation uses as it input calibrated .wav files. The Head Acoustics ArtemiS software does have a version implementing the method.
- 4.9 Email inquiries to Hayes McKenzie relating to both the ETSU and IEC standard revealed details of these implementations into instrumentation. The ETSU method was implemented in some software developed by Renewable Energy Systems developed some software, this was used in conjunction with a sound card. Hayes McKenzie used a combination of Acsoft software and Microsoft Excel. They also mention the RES software which can be obtained from RES. Hayes McKenzie have an older copy which we could be forwarded. For this one requires an input in the form of a txt file format or a specific dsp format. For IEC assessments Hayes McKenzie used an implementation in Excel using Symphonie system examining 12 \* 10 second averages to determine tone levels. There is also a DIN standard implementation in VBasic which works well if you get you data into a format it can read. This comes attached to the DIN standard and is downloadable.
- 4.10 Email inquiries to Matt Nobile in USA resulted in some information about his implementation of the TNR and PR methods. He used a standard FFT analyzer with a pc for post-processing. He commented that the PR was much easier to automate than TNR since all of the band edge frequencies are determined; no need for human decision making. He was also aware of that B&K has implemented Prominence Ratio and possibly TNR in their Sound Quality package (separate software for PULSE), and HEAD Acoustics has done the same in one of their software packages. Also, the National Instruments Sound Power Plus package does both PR and TNR.

**“Research” implementation - Impulse***Pedersen method*

- 4.11 From the detailed report on the Round Robin (ref 27) we can see how each of the 4 Scandinavian laboratories – DELTA, VTT, KILDE and SP - implemented the Prominence method, and so get valuable insights into this important aspect. The following is an extract from the report (ref 27).

*Round Robin - Measurements*

- 4.12 The participants measured and analysed the selected recordings on the CDs. They were initially instructed to perform the measurement according to the “NORDTEST draft 2” method. When the measurements started some questions were raised about how to interpret the definition of “Onset Rate”. A “NORDTEST draft 3” test method with a new definition of “Onset Rate” was sent out. At that time VTT had already carried out their measurements according to the “NORDTEST draft 2” method. The other participants used the “NORDTEST draft 3” method. However, no systematic or significant difference between the VTT result and the others was found.

*Round Robin - Equipment and method used - DELTA*

- 4.13 CD player Sony D-181. A HHB Portadat type PDR 1000 was used as analogue to digital converter. The digital signals were fed to a PC with NOISELAB analysing software from DELTA. NOISELAB computes a running true time level recording of the A-weighted sound pressure levels with time weighting F. The computed sound pressure levels are sampled every 25th ms. Based on a visual judgement supported by cursor readings the “worst” impulse from each sound example was selected for a detailed analysis. The “reverberation time” and level difference were measured for the part of the impulse which had a gradient larger than 10dB/s. The onset rate was computed by means of linear regression.

*Round Robin - Equipment and method used - VTT*

- 4.14 CD player JVC XL-V230. A Norsonic 830 real-time analyser with advanced transient measurement option was set up for transient measurements to measure A-weighted level versus time with time-weighting F. Sampling period 32 ms. For each sound sample level versus time was printed and one impulse for each sound sample was chosen. For each impulse a straight line representing the impulse was determined. For each impulse level difference and onset rate (based on 10-90 % and 50-95 % of the level difference) was determined along this line.

*Round Robin - Equipment and method used - KILDE*

- 4.15 Audio CD player. A NORSONIC analyzer 121 was set for A-weighted measurements with time weighting F and sampling period 10 ms. A NORSONIC Nor-Profile (Software analysing N-121 instrument files) was used to produce graphs on a PC. Using cursors defining start point and end point on graphs, the corresponding time and level data were copied to a spreadsheet, calculating level difference (LD) and onset rate (OR). All level vs. time graphs were initially inspected visually, pointing out impulses for further analysing, with regard to LD and OR. Up to 6 impulses were analysed for one sound example. The impulse with the highest calculated prominence P was chosen. The onset rate was calculated as the line between the start point and end point. This method has earlier been proven to give result that differ up to 0,4 dB from the proposed linear regression method.

*Round Robin - Equipment and method used - SP*

- 4.16 CD player Sony D-E301. A Sound Level Meter B&K 2230 was set for A-weighted measurements with time weighting F. The Sound Level Meter DC output was connected to a HP 3562A signal analyser, set to time capture mode. Sampling interval 5 or 10 ms as given in the table below. The data was finally transferred to an Excel workbook. Excel was used to point out start points and end points of the onsets. Up to 6 of the onsets that visually looked “worst” were selected for closer analysis. The onset rate was determined by applying the Excel regression function on the samples between the start points and end points. The Excel regression function is approximating a line with the least square method.

*Table 2. Sampling interval used by SP.*

Sound sample	2L	5L	7L	9L	16L	2H	5H	7H
Sampling interval	5 ms	5 ms	10 ms	10 ms	10 ms	10 ms	10 ms	5 ms
Sound sample	9H	16H	5P	NT1	NT4	NT7	NT8	NT9
Sampling interval	10 ms	5 ms	5 ms	5 ms	5 ms	5 ms	5 ms	5 ms

- 4.17 It can be noted from the descriptions given in the report on the Round Robin tests that implementation of the Prominence method still requires extensive “manual and visual” processing by a skilled person. We are in communication with the Delta organisation concerning new software that is currently being tested, which will allow more “automatic” implementation of the method.

*Round Robin - Equipment and method used - NPL method*

- 4.18 In the NPL studies described earlier [Berry 1989 etc ] , within the EC-funded “Joint Project on Impulse Noise”, a prototype “Short-Leq” Sound Level Meter [SLM] was developed by Cirrus Research Ltd, under a special contract with NPL. This device stored a series of values of LAeq every 10ms in a large internal memory. The SLM was then interfaced to a PC, running Cirrus software in order to download the time series, view it graphically and then estimate values of Increment using an on-screen cursor.

*Round Robin - Equipment and method used - ISVR Method*

- 4.19 Details are not clear in the ISVR report but we understand that signals in the ISVR experiments were simply analysed in terms of FFTs “on-line” by ISVR Data Analysis Centre, according to the method described in referenced report.

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## 5.0 SUMMARY AND DISCUSSION OF FINDINGS

### Extent of real world testing

- 5.1 Summary tables 3 and 4 below sum up the main points of previous research either comparing methods and/or testing the objective methods against subjective response. These effectively provide information on the extent of real world testing.

#### *Tonal character*

- 5.2 The most tested methods are within the group of methods based on tone-to-noise ratio, prominence ratio (TNR, PR and DIN). These methods have been tested on both artificial and real environmental test sounds with between 190 and 215 test subjects. Shortcomings of these methods have been related to the perceived tonality of 2 tone complexes, and the overestimation of low frequency tonal sounds. The DIN standard 2002 appears to perform better than the TNR and PR methods, thought to be due to the introduction of the masking index function in the DIN 2002 standard. Research findings also suggested that trackable nonstationary behaviour of frequency modulated tones leads to difficulties when using tonal metrics that are derived from estimated spectra. The methods are found not to be adequate for time varying tones for which an alternative model has been proposed, the Pitch Model, which is suggested to perform better for these types of sounds. The need for a frequency correction, modifications for the criteria of prominence, the handling of tonal harmonics for PR and TNR have been recognised and in 2002 modifications have been proposed to overcome these. However, it is notable that despite much within group testing and external review, no single method has been recommended at this time for rating the prominence of tonal character of sounds.
- 5.3 The Joint Nordic Method presents a method for the audibility of tones in noise. It has been widely tested on both artificial and environmental sounds. It appears to be the most adopted method in Europe for assessing the audibility of tones in noise, following reviews of its application. In particular variations of this methods have been used for wind turbine noise and it is included in the draft ISO standard ISO 1996 'Description and measurement of environmental noise', Part 2, Annex C. It has identified shortcomings in relation to non stationary (time varying) signals. Additionally research findings also suggested that trackable nonstationary behaviour of frequency modulated tones leads to difficulties when using tonal metrics that are derived from estimated spectra.
- 5.4 The ISVR method is still really in a research phase at present, and has only had very limited testing in the laboratory using artificial sounds. There are a number of uncertainties including dealing with 2 or more tone complexes, non-stationary or non broadband background noise and the effects of modulation. Although the method shows real promise, more development may be required before it can be recommended for implementation today, and therefore this method will not be considered in the remainder of this work.
- 5.5 The PR, TNR, JNM and ISVR methods all relate to prominence of tones in noise rather than perceived tonality, such as the Aures method. The Aures' method has been tested on over 20 artificial sounds although these experiments was specifically aimed at findings solutions to overcome recognised problems with effects of roll-off rates on the perception of the tonalness of bandpass filtered noise developing an understanding of how frequency modulation affects tonalness.
- 5.6 There therefore appears to be some within group testing, but no intergroup testing. All the methods are being developed and refined, and this is an ongoing evolutionary process. However, at this time there appears to be a main theme of refinement for all methods focussed around frequency corrections, time varying issues, and multiple tones. All the methods could be refined but there is a lack of data on the algorithms required so more research testing would be needed to overcome the identified shortcomings.
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*Impulses*

- 5.7 As the Summary tables show, early work at NPL involved intercomparisons of a range of methods. These included several methods based on processing of the time-series of  $L_{Aeq [10ms]}$ . The Increment method which arose from this NPL work was independently supported by the work of Brambilla in Rome.
- 5.8 The ISVR Masked Threshold method, while conceptually interesting has limited testing in terms of the number and type of noises used. It should also be noted that the method relies on calculation of the difference between FFT spectra for the impulse and the spectrum for a background noise. Whilst this is an important part of the research undertaken to develop the method it becomes a major shortcoming for more general application. It would be necessary to analyse both the impulse and the background noise, or for the analysis system to hold some kind of reference noise spectrum. Although the method shows real promise, more development may be required before it can be recommended for implementation today, and therefore this method will not be considered in the remainder of this work.
- 5.9 It can be seen in respect of the Prominence method that a reasonably large range of noises has been used in the testing, and that a range of candidate methods has been compared. However one possible limitation is that a small number of listening subject have been used.

**Practicality of implementation**

- 5.10 Summary tables 5 and 6 present the information gathered on commercial and research implementation, in the form of tables indicating the extent of implementation for each of the selected methods, bringing together both the information on the commercial implementation email inquiries and the responses on 'research' implementations. These tables effectively provide information on practicality of implementation.
- 5.11 For tones, it seems from the summary tables that examples of practical implementation are available for nearly all the listed methods. However, many of these are Research implementations, noted from the various publications reviewed, rather than commercially available implementations.
- 5.12 For impulses, full implementations are less available.
- 5.13 For both tonal and impulsive methods, there are many cases where methods can be implemented by post-processing and current instruments are designed in such a way that post-processing can be used to implement almost any method. However such a situation means that there is a lack of standardisation in exact details of how methods are implemented, leading to greater variability in measured values.
- 5.14 Readers of this report should note that commercial instruments are subject to constant development and it is advisable to check with manufacturers for details of latest specifications.

**General Comments**

- 5.15 It has also become clear that the topic is in a constant state of evolution. When one examines in detail the nature and scale of the research effort which has gone into the testing of various methods it is clear that we cannot expect, with our resources, to apply further meaningful testing, nor to refine any methods within the realms of this work, but merely document and comment on progress. There are several "levels" of intercomparison that could be envisaged. The most complex of these would require a wide range of noise samples to be evaluated on a subjective basis by a large panel of listeners, and for the same noise samples to be assessed by various objective methods. It would seem that in this project further work on intercomparisons should be focussed on a small-scale intercomparison to get information on practicality and the most suitable 'purposes'/ applications.
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Summary table 3: Extent of real world testing of tonal procedures

Tester	Methods tested	Noises Used	No of Subjects	General Comments
Dressen and Weber 95 Expt 1, and later by Daniel et al 2002	TNR PR DIN 2002	Artificial: 1 or 2 tones in pink noise with increasing TNRs Environmental: varying tonality	15	<ul style="list-style-type: none"> <li>Prominence of tones judged by adjusting a slider ranging from 'not', 'medium', 'rather' to 'very' prominent. This suggests that experiment more related to classification of tone plus sensory level information, annoyance not judged directly.</li> <li>All 3 methods predict prominence of artificial sounds well, although prominence of two tones slightly overestimated by all methods.</li> <li>DIN standard appeared to rate environmental sounds better than for TNT and PR.</li> </ul>
Dressen and Weber 95 Expt 2, and later by Daniel et al 2002	TNR PR DIN 2002	Artificial: tonal components in pink noise, frequency varying from 66 to 8000Hz.	10	<ul style="list-style-type: none"> <li>Aim was to investigate the influence of frequency on prominence.</li> <li>Prominence of tones judged by adjusting a slider ranging from 'not', 'medium', 'rather' to 'very' prominent. This suggests that experiment more related to classification of tone plus sensory level information, annoyance not judged directly.</li> <li>DIN standard performed better than TNR and PR methods.</li> <li>Prominence of low frequencies was overestimated by all three methods.</li> </ul>
Daniel et Al, 1998 and later by Daniel et al 2002	TNR PR DIN 2002 Pitch model	Artificial: tyre sounds with pure tones or narrow band noise added.	25	<ul style="list-style-type: none"> <li>Tones judged on a 6 point category scale from 'not tonal' to very tonal'. This suggests that experiment more related to classification of tone plus sensory level information, annoyance not judged directly.</li> <li>Perceived prominence of tonal components was rated as low, due to spectral masking by tyre noise.</li> <li>All 3 methods overestimated prominence of tonal components around 500 Hz,.</li> <li>No account taken of the perceived differences in prominence for the added narrow band noise.</li> <li>Pitch model seemed to perform best, as applicable to time varying sounds.</li> </ul>
Pompetzki, 1998, and later by Daniel et al 2002	TNR PR DIN 2002	Environmental noise: 14 examples analysed by 30 offices	114 (experts)	<ul style="list-style-type: none"> <li>Tonal penalties judged subjectively, suggesting that tone could be classified as such if penalty &gt; 0, but attribute judged more related to effective annoyance judgments.</li> <li>Results used to revise E DIN 45681.</li> <li>DIN fared better than the TNR, which fared better than PR.</li> </ul>
Daniel et al 2002	TNR PR DIN 2002 Pitch model	Meta-analysis of all above data using the noises of above.	All of the above (164)	<ul style="list-style-type: none"> <li>E DIN (2002) performed better than TNR and PR of ANSI S1.13 for the assessment of prominent tones in environmental sounds.</li> <li>The E-DIN 2002 performed better than the E DIN 1992, due to introduction of the masking index. However tonal components with low frequencies of 125 Hz still overestimated,</li> <li>TNR, PR and DIN not adequate for time varying tonal components, but Pitch Model better.</li> </ul>
Beckanbauer et al, 1996	DIN (reported as draft of 1995)	Artificial: narrow band noise with bandwidth of 30 Hz added to broadband masking noise	8	<ul style="list-style-type: none"> <li>Work compared the tone adjustments of Din 45681 – 1995 with subjective ratings using magnitude estimation.</li> <li>Subjects were asked to rate the sounds by means of positive numbers, which correspond to perceived tonality (using magnitude estimation without standard anchor signal). Relative tonality between sounds was then calculated. Experiment therefore appears to reveal information on prominence of a tonal character relative to</li> </ul>



				<p>another sound, i.e. relative sensory levels of tones.</p> <ul style="list-style-type: none"> <li>Frequency dependency of tonal adjustment required improvement. – a simple weighting function tested and recommended for next version of standard.</li> </ul>
Sagemuhl and Schmidt 2001	DIN 1992	Changes to a proposed revised standard tested against Pompetski's subjective data, therefore suggests 14 noises used.	114?	<ul style="list-style-type: none"> <li>Changes to a proposed revised standard tested against Pompetski's subjective data.</li> <li>For Pompetski, tonal penalties judged subjectively, suggesting that tone could be classified as such if penalty &gt; 0, but attribute judged more related to effective annoyance judgments.</li> </ul>
Ellermeier and Daniel 2002	TNR and PR commented on	11 tyre sounds with added tonal features	57	<ul style="list-style-type: none"> <li>Work focussed on the quantitative measurement of a tonality sensation using a pure ratio scale.</li> <li>Paired comparisons, one of two sounds to be classified as more 'tonal'. Experiment related to classification and 'sensory levels'.</li> <li>Shortcomings of TNR and PR identified, Pitch Model against suggested as a better alternative.</li> </ul>
ICWG 2001/2	TNR PR	40 in total Artificial 28 Real 18	28	<ul style="list-style-type: none"> <li>Experiment used a 0 to 6 scale, ranging from 'inaudible' to 'extremely prominent'. Experiment related to classification and 'sensory levels', not annoyance.</li> <li>Shortcomings in methods identified, in particular the need for a frequency correction, the criteria for prominence needed to be increased, and that tonal harmonics not handled correctly (suggested by the difference in response to real versus artificial sounds)</li> <li>In 2002 modifications to procedures suggested to overcome shortcomings</li> <li>No single method recommended at this time, more data required.</li> </ul>
Bass 1999	A number of methods applicable to wind farm noise including IEC.			<ul style="list-style-type: none"> <li>Work comparing methods led to proposed 'ideal' assessment methodology based on refinement to JNM 1984.</li> <li>No actual testing of methods with noises reported.</li> </ul>
Pedersen 1984-99	JNM	35 labs		<ul style="list-style-type: none"> <li>Proficiency tests carried out between laboratories (details in Danish)</li> <li>Scales used unknown.</li> <li>Work led to new method capable of handling noise from wind turbines, so investigation made to include tones with amplitude and frequency variations (details in Danish).</li> <li>Work led to method of JNM2 1999.</li> </ul>
Hayes McKenzie et Al 1999	Principally JNM using RMS for stationary tones and MAX for non-stationary tones	9 windfarm recordings	10 (3 naïve)	<ul style="list-style-type: none"> <li>Test noises were also rated as 'inaudible', 'audible but not prominent', or 'prominent'.</li> <li>Subjects also asked to subjectively judge tonal penalty, to adjust level of a reference noise to give same loudness as noise as sample.</li> <li>JNM stationary (RMS) analysis procedure correctly determined the overall subjective audibility of tones for all samples. The non-stationary tones (MAX) analysis procedure tended to overpredict audibility.</li> <li>JNM tonal analysis procedure for stationary tones could be successfully applied to assess the audibility of tonal noise radiation from wind farms</li> <li>Threshold of audibility is approximately correct</li> </ul>



				<ul style="list-style-type: none"> <li>• A sliding scale of 1 dB per 1dB increase in tone sensation level above threshold should be applied to any audible tones, up to a maximum tone penalty of 6 dB.</li> <li>• Experiment revealed information on classification of tones and revealed information on tonal penalties.</li> </ul>
Porter 1995	ISVR	Artificial: Test 1: 2 tone complexes (8) in a broadband background noise Test 2: 2 tone complexes (8) in a broadband background noise Test 3: 8 tones in a broadband background noise	3	<ul style="list-style-type: none"> <li>• Experiment only related to classification of tonal character.</li> <li>• 3 tests (1) subjective perception of two-tone complexes (2) detection thresholds of a tone in the presence of another (3) detectability thresholds of single tones in broadband background noise</li> <li>• Three main problems were identified as requiring attention, in order to extend the tone detection to more complex tones: upward spread of masking, estimation of background noise spectra, effects of modulation.</li> </ul>
Hastings et al 2003 Experiment 1	Aures	Up to 45 artificial sounds: band pass, pure tones and white noise	17	<ul style="list-style-type: none"> <li>• The effect of roll-off rate on the perception of the tonalness of bandpass filtered noise was examined.</li> <li>• Subjects were asked to choose a sound that was the more tonal in a series of paired comparison tests.</li> <li>• The work concluded that roll-off rates of tonal features in spectra affect perception of the tonalness of sounds and so a combination of bandwidth and roll-off rate must be used when estimating tonalness.</li> <li>• A modification of the Aures' metric was proposed, although more research was required to fine-tune this.</li> </ul>
Hastings et al 2003 Experiment 2	Aures TNR PR JNM	16 artificial frequency modulated sounds	6	<ul style="list-style-type: none"> <li>• Experiment focused on developing an understanding of how frequency modulation affects tonalness.</li> <li>• The findings suggested that trackable nonstationary behaviour of frequency modulated tones leads to difficulties when using tonal metrics that are derived from estimated spectra.</li> <li>• The problem was identified as bandwidth estimation.</li> <li>• A methodology to remove the trackable frequency component was proposed as a means to produce a more realistic measure of bandwidth but again requires further research.</li> </ul>

Summary table 4: Extent of real world testing of impulsive procedures.

Tester	Methods tested	Noises Used	No of Subjects	General Comments
Berry et al.1979	Crest Factor NPL variance method I Kurtosis, France WHL method SA method	Recorded and simulated helicopter noise	31	<ul style="list-style-type: none"> <li>Annoyance judgements</li> <li>Hybrid of NPL and French methods preferred</li> </ul>
Berry et al 1987 and 1989	$L_{Aeq}$ Impulse – $L_{Aeq}$ Crest Factor The ISO Descriptor for helicopter noise described above Standard deviation of the time-series of $L_{Aeq}$ [10ms] Kurtosis of $L_{Aeq}$ 10ms Crest Factor Saliency Increment	Road traffic noise RTN and a range of simulated and recorded impulse noises	1987. 24 in each of a series of 3 main experiments  1989 16 subjects in each of 3 countries	<p>1987.</p> <ul style="list-style-type: none"> <li>24 in each of a series of 3 main expts</li> </ul> <p>1989</p> <ul style="list-style-type: none"> <li>Increment descriptor gave the highest overall correlations.</li> </ul>
Brambilla and Caretti 1989, 1990, and Brambilla 1998	Increment Raising R $L_{Aeq}$ Impulse – $L_{Aeq}$	RTN plus 25 varied noises – as in EC project [above]	52	<ul style="list-style-type: none"> <li>Raising R showed the best performance,</li> <li>Increment I the most “specific” descriptor for impulsivity</li> </ul>
Ikeda and Flindell 1993	$L_{Aeq}$ only Masked Thresholds using 80ms FFT	12 synthetic impulse noises	24	<ul style="list-style-type: none"> <li>Statistically significant association between reported annoyance judgements and the Sensation Level of the impulse sound</li> </ul>
Pedersen et al 2000	$L_{AmaxF}$ – $L_{Aeq}$ in one-second periods, $L_{A,F}$ – $L_{A,S}$ as a running measurement, $L_{AmaxF}$ , 30sec. $L_{AmaxF}$ – $L_{Aeq}$ , 30sec., $L_{AmaxF}$ – $L_{A95}$ in 30-second periods. Onset rate (dB/s) Level difference (dB from background SPL to 90% of max. SPL). <i>Psychacoustic measures</i> Loudness (sone), sharpness (acum), roughness(asper), fluctuation strength (vacil), onset rate (sone/sec.) and level ratio (sone/sone) from background level to 90% of max. level).	30 “industrial and other sounds “  – see also 3.87	5 experts 12 ordinary listeners	<ul style="list-style-type: none"> <li>Attributes judged = - Prominence - Degree of intrusiveness - Annoyance</li> <li>Experts also judged if 5dB penalty needed</li> <li>No single parameter could characterise - with sufficient accuracy - the prominence of the impulses or the extra “annoyance</li> <li>Combined measure consisting of onset rate and level difference gave good correlation with the listening tests (<math>R^2 = 0.74</math>). Higher correlations were obtained with psychoacoustically based measures, but these were still considered too advanced for practical use.</li> </ul>

**Summary table 5: Commercial and Research implementation of tonal methods**

METHOD	FULL IMPLEMENTATION	CAN BE IMPLEMENTED WITH POST-PROCESSING
ISO 1996 1/3 octave band procedure, Part 1: 1982, Part 2: 1987, Part 3: 1987 (same as BS 7445; 1991)	B&K 2260	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
ANSI 12.9 identification procedure 1988		AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
ANSI 1.1.3 tone to noise ratio 1995 TNR	B&K PULSE HEAD Acoustics National Instruments Sound Power Plus	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
ANSI 1.1.3 prominence ratio 1999 PR	B&K PULSE HEAD Acoustics National Instruments Sound Power Plus	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
DIN 45681 tone to noise ratio, 2001 DIN TNR	B&K Norsonic Nor 110 and 121 Vbasic version from DIN	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
JNM, (version2), 1999 (Draft ISO 1996-2 Annex C)	Acsoft – Svantek 94x B&K Norsonic [by Summer 2004]	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
ETSU method, 1996	RES Software	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
IEC wind turbine method, 2002		AcSoft-Symphonie, B&K, Norsonic <i>NOT Cirrus</i>
Aures' procedure, 1985	HEAD Acoustics Artemis software	AcSoft, B&K, Norsonic <i>NOT Cirrus</i>
ISVR tonal detection methodology, 1992		AcSoft, B&K, Norsonic <i>NOT Cirrus</i>



**Summary table 6: Commercial and Research implementation of impulsive methods**

METHOD	FULL IMPLEMENTATION	CAN BE IMPLEMENTED WITH POST-PROCESSING
Pedersen Prominence	No	AcSoft, B&K PULSE and 2230, Cirrus, Norsonic 830 and 121
NPL Increment method	CR 236 [current availability uncertain]	AcSoft, B&K, Cirrus, Norsonic
ISVR Masked threshold/ sensation level	No	AcSoft, B&K, Cirrus, Norsonic

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## 6.0 FUTURE WORK

- 6.1 Based on the considerations above we intend to devote the concluding months of the project to a number of small-scale intercomparisons, which are primarily aimed at deriving information on the practicality of implementation of various methods. This is so that we can provide guidance to the interested potential user, to supplement the large quantity of review-type information assembled so far
- 6.2 For tones, our work on previous testing has revealed that there exist 3 main sets of data that include test signals, objective analysis of the tonality of the signals and subjective assessment of those signals. These are the data based on Pompetzi, ICWG and Hayes McKenzie (although limited to wind turbine noise). In the next stage of work we will try to obtain one set of these original noise signals and analyse them further using additional objective analysis methods.
- 6.3 In the case of impulsive methods, we have already obtained CDs of noises used in various stages of work on the Danish Prominence method. For these noises we thus have information on relevant subjective quantities, as well as values of Prominence. The planned intercomparison will involve an “independent” implementation of the Prominence method, so that values of the physical quantities can be compared. In addition, the other selected methods will be implemented. Values will then be related to the known subjective quantities.
- 6.4 The stages in future work can this be summarised as;
- i. Acquisition of signals.
  - ii. Familiarisation with analysis systems
  - iii. Analysis and interpretation of results
  - iv. Drafting of Final WP1 Report

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## 7.0 REFERENCES

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## ANNEX 1

ISO TC 43/SC 1 N, Date: 2002-05-22

DRAFT ISO/CD 1996 2, ISO TC 43/SC 1/WG, Secretariat: DS

Acoustics — Description, measurement and assessment of environmental noise —  
Part 2: Determination of environmental noise levels

### Objective Method for Measuring the Prominence of Impulsive Sounds and for adjustment of LAeq

#### E.1 Introduction

Measurements carried out according to this annex yield as the main result a measure for the prominence of impulsive sounds in the immission point. The method aims at determining the prominence of impulsive sounds in correspondence with average subjective judgements made by listeners. Based on the prominence,  $P$ , a graduated adjustment,  $KI$ , to the measured LAeq is defined.

The adjustment to LAeq for impulses depends on how prominent the impulse characteristics are perceived through the continuous part of the noise including background noise.

The method in this annex is not intended for use with gunfire sound and high-energy impulsive noise

#### E.2 Definitions

Sound pressure levels, LpAF, mentioned in the definitions are A-weighted levels with time weighting F.

##### E.2.1 Impulse

The sudden onset of a sound is defined as an impulse.

NOTE The definition includes only the onset of a sound, not the sound as a whole. "Sudden" is based on an auditive judgement, which is expressed in terms of physical measurements in this annex.

The character and prominence of the impulse in the immission point depends on the character of the emitted sound, on the distance and propagation path from the sound source and on the background noise. The impulsiveness of a sound is characterised by the onset of the sound independently of the category of the sound source.

##### E.2.2 Onset

For the purpose of this method the onset of a sound is defined as the part of the positive slope of the time history of LpAF where the gradient exceeds 10 dB/s, see Figure E.1.

The starting point of an onset is the point where the gradient first exceeds 10 dB/s. The end point of an onset is the first point after the starting point where the gradient decreases to less than 10 dB/s. Irregularities (on the onset) shorter than 50 ms are disregarded.

##### E.2.3 Level difference

The level difference of an impulse is the difference in dB of LpAF between the level of the end point Le and the level of the starting point LS of the onset.

##### E.2.4 Onset rate

The onset rate is the slope in dB/s of the straight line that gives the best approximation to the onset.

NOTE For pass-bys of e.g. road vehicles, trains or aircraft the onset rates shall be found from the level range

Le-(Le-Ls)/2 to Le.

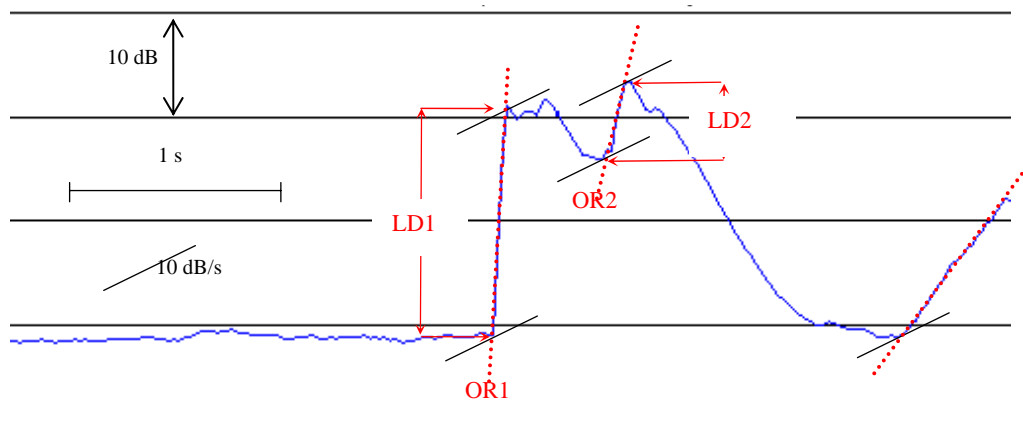


Figure E.1. Time history of the A-weighted sound pressure levels with time weighting F. The figure illustrates the onset rate (OR) and the level difference (LD) for the two most prominent impulses. Gradients of 10 dB/s are indicated with short line segments.

### E.3 Measurements

Measurements shall be made on the basis of  $L_{pAF}$ , the A-weighted sound pressure level with time weighting F. The electric background noise level in the measuring set-up shall be at least 10 dB lower than the acoustic background noise level. Special care shall be taken to ensure that the system is not overloaded during measurement.

The measurements may be performed by either digital or analogue methods or a combination of these.

#### E.3.1 Digital recording and signal processing

The A-weighted sound pressure level with time weighting F shall be sampled with time intervals in the range from 10 ms to 25 ms. Measurements made on the basis of short-term  $L_{eq}$ -values (e.g. 10 ms) shall be approximated (e.g. by computation) to time weighting F before the readings are taken.

NOTE Measurements based on a series of short-term  $L_{Aeq}$ -values may be converted to a series of  $L_{pAF}$ -values by the following formula:

$$L_{pAF,n} = 10 \cdot \lg \left[ \left( \left( \frac{\tau}{\Delta t} - 1 \right) \cdot 10^{\frac{L_{pAF,n-1}}{10}} + 10^{\frac{L_{Aeq,n}}{10}} \right) \left( \frac{\tau}{\Delta t} \right) \right]$$

$L_{Aeq,n}$  The n'th short-term  $L_{Aeq}$ -value

$L_{pAF,n}$  A-weighted sound pressure level with time weighting F at the time of the n'th  $L_{Aeq}$ -value,  $L_{Aeq,n}$

$\tau$  Time constant for the time weighting. For F:  $\tau = 125$  ms

$\Delta t$  Time between the  $L_{Aeq}$ -values (and the integration time)

$\lg$  is the logarithm with base 10

From a successive series of sound pressure levels with time weighting F,  $L_{pAF,n}$ , the starting point s and the end point e of an onset are defined from the procedure 1)-4). The symbols used are defined below.

- 1) The starting point s is the first point where the slope is larger than 10 dB/s:  $L_{s+1} - L_s > 10/f$ .
- 2) The end point e is the first point after the starting point where the slope is less than 10 dB/s:  $L_{e+1} - L_e < 10/f$ .
- 3) A new starting point occurs when condition 1) is met again.
- 4) If a new starting point s1 occurs within a period of 50 ms after the end point e, then end point e and start point s1 shall be neglected if the following conditions are met:

$$(L_{e1} - L_e)/(t_{e1} - t_e) > 10 \text{ dB/s and } (L_{s1} - L_s)/(t_{s1} - t_s) > 10 \text{ dB/s}$$

$e1$  is the end point after the new starting point  $s1$ . If point  $e$  is neglected, point  $e1$  takes over the name  $e$ .

$s+1$  denotes the point one sample after point  $s$ .  $L_s$  is the level of point  $s$ , and  $t_s$  is the time of sampling;  $L_e$  is the level of point  $e$  and  $t_e$  is the time of sampling, and so on.  $f$  is the sampling frequency.

For each onset the level difference is  $L_e - L_s$ , and the onset rate is found from the “least-squares method” (linear regression) of the points from  $s$  to  $e$  (incl.).

#### NOTES

- 1) For pass-bys of vehicles, aircraft ... the onset rates shall be determined over the level range  $L_e - (L_e - L_s)/2$  to  $L_e$ .
- 2) In some measuring systems, the onset rate may be determined from the F-weighted samples as  $-60/T$ , where  $T$  is the reverberation time measured directly on the onset of the sound. Other systems require that the sound samples are reversed before such a measurement can be performed.

#### E.3.2 Analogue recordings

By analogue recording care shall be taken that the vertical writing speed (the level) is not limited by the writing system. By recordings in true time a writing speed of at least 1000 dB/s is necessary.

By visual readings of the onset rate from level recordings, the horizontal speed (the time) shall be sufficient to ensure a satisfactory accuracy of the gradient of the onset. A slope of  $45^\circ$  is recommended.

By the approximation of the onset to a straight line, irregularities shorter than 50 ms on the generally increasing curve (even decreasing levels) do not indicate the start of a new onset.

#### E.4 Predicted prominence, $P$

In periods of half an hour a number of impulses with the apparently highest onset rates and level differences shall be selected. For noise with shorter duration the impulses shall be selected during the whole period. For each selected impulse the predicted prominence,  $P$ , is calculated from:

$$P = 3 \cdot \lg(\text{onset rate}/[\text{dB/s}]) + 2 \cdot \lg(\text{level difference}/[\text{dB}]) \quad (\text{E.1})$$

where the “onset rate” in dB/s and the “level difference” in dB are defined in the clauses E.2.4 and E.2.3 respectively.  $\lg$  is the logarithm with base 10. The impulse with the highest value of  $P$  gives the final result.

NOTE The general form of the expression for  $P$  is:  $P = k_1 \cdot \log(\text{onset rate}) + k_2 \cdot \log(\text{level difference})$ . The constants  $k_1$  and  $k_2$  have been estimated from the results of listening tests. It is also taken into account that the relation between  $P$  for very sudden and loud impulses and  $P$  for slow level changes shall be large.  $P$  was furthermore designed to give a maximum around 15. With the constants given in formula (1) the predicted prominence explains 73% of the variance in the answers from the listening test mentioned in [[2]].

#### E.5 Adjustment to $L_{Aeq}$

For sounds with onset rates larger than 10 dB/s the following adjustment  $K_1$ , based on the predicted prominence  $P$ , may be applied:

$$K_1 = 1.8 \cdot (P - 5), \text{ for } P > 5, \quad K_1 = 0 \text{ for } P \leq 5 \quad (\text{E.2})$$

It is proposed that this adjustment is made to  $L_{Aeq,30min}$  on the basis of the one event with the highest value of  $P$  occurring during the 30-minute period.

NOTES

- 1) According to this proposal the rating level  $L_{Ar,T}$  over the reference time interval  $T$  related to the impulse characteristics is found from:

$$L_{Ar,T} = 10 \log \left( \frac{1}{T} \sum_N \Delta t_N 10^{\frac{L_{Aeq,N} + K_{I,N}}{10}} \right)$$

where:

$T$  is the duration of the reference time interval

$\Delta t_N$  is the durations of the measurement time intervals, 0.5 hour

$L_{Aeq,N}$  is the equivalent noise level of the time periods  $\Delta t_N$

$K_{I,N}$  is the adjustments to  $L_{Aeq,N}$

- 2) The general form of formula (2) is:  $K_I = k_3 \cdot (P - k_4)$ , for  $P > k_4$ ,  $K_I = 0$  for  $P \leq k_4$ . The constant  $k_3$  gives the inclination of the correlation between  $K_I$  and  $P$ , and  $k_4$  defines the lower limit for adjustment to  $L_{Aeq}$ . The values of the constants  $k_3$  and  $k_4$  have been determined to give correspondence with the extra annoyance reported in the literature for different kinds of noise sources. As the annoyance depends on the level and characteristics of the noise, the kind of sound source, the context and social factors, and as the adjustment  $K_I$  is meant to compensate for the extra annoyance from the impulses, it might be considered to operate with values of  $k_3$  and  $k_4$  that depends on the category of sound source.
- 3) The time period of 30 minutes for adjustment of  $L_{Aeq}$  is a preliminary choice based on considerations of reasonableness and ease of measurements and administration. There are no systematic investigations behind this choice of period, and the principle should be considered in more detail when investigations of the relevant period are made.
- 4) If national guidelines prescribes a fixed adjustment of e.g. 5 dB for impulsive sounds, the method in this annex may be used as a support of a subjective judgement. It is recommended to give the 5-dB adjustment when  $K_I > 3$  and when the impulses are characteristic of the working operations.

### E.6 Accuracy

Although the information about the measurements shall be given in terms of sound pressure levels, the method is not sensitive to the absolute calibration of the measuring equipment.

The working conditions of the source may be more critical than for measurements involving long-term averaging as e.g. measurements of  $L_{Aeq}$ .

In [[3]] it was found that the mean standard deviations of the results of 16 different noise examples from 4 laboratories using 4 different measuring set-ups was 0.3 on the prominence  $P$  and 0.6 dB on the adjustment  $K_I$ .

### E.7 Documentation

As documentation for the analysis the following information shall be given:

- State that the measurement has been performed in accordance with the specifications in this annex
- Recording and analysis equipment, type, make and model
- Sampling rate for  $L_{pAF}$
- Procedure used for the measurement of level difference and onset rate
- The working conditions that cause the impulses and the time of the specific measurements
- Measured values of level differences and onset rates
- Calculation results of the Prominence  $P$ , and the adjustment  $K_I$  and associated uncertainties

### E.8 Examples

Examples of measurement results from references [2] and [3] are given in table E.1

Table E.1 Examples of the prominence  $P$ , and the adjustment  $K_i$  for different noise sources. Other results will occur for different conditions of distance, propagation path and background noise.  $L$  and  $H$  indicate  $L_{Aeq}$ -values of 40 dB and 60 dB, respectively, from the noise sources.

Noise source	$L_{AFmax}$	Level diff.	Onset rate	Prominence	Adj. $K_i$
	dB	dB	dB/s	$P$	dB
<b>Background noise <math>L_{PA,F} = 40</math> dB</b>					
Tyre change, pneumatic tool, L	48	7	38	6,4	2,6
Tyre change, pneumatic tool, H	67	17	76	8,1	5,5
Compressed air release, L	48	9	65	7,3	4,1
Compressed air release, H	67	27	140	9,3	7,8
Metal hammering, L	54	15	194	9,2	7,6
Metal hammering, H	75	35	222	10,1	9,2
Woodax, L	52	13	125	8,5	6,4
Woodax, H	72	17	353	10,1	9,2
<b>Vehicles</b>					
Door slamming and starting cars	67	9	130	8,3	5,9
Car passby 7,5m, 50 km/h	77	11	4	4,0	0,0
Car passby 7,5m, 110 km/h	84	14	14	5,8	1,4
Harrier fighter, Alt. 92 feet, Speed 484 kn.	126	64	91	9,5	8,1
<b>Other</b>					
Church bells	87	18	73	8,1	5,5

### E.9 References

- [1] Pedersen, T. H. *Audibility of impulsive sounds in environmental noise*. Inter-Noise 2000 CD-ROM proceedings.
- [2] Pedersen, T. H., *Impulsive noise. An objective measuring method for the prominence of impulsive sounds and for the adjustment of  $L_{Aeq}$* . AV 1005/00. DELTA report, 2000. (Report in Danish with expanded English summary)
- [3] Andersson, H., et al. *Round Robin Test of an objective measuring method for the determination of the prominence of impulsive sounds and for the impulse adjustment of  $L_{Aeq}$* . SP Rapport 2000:30, Acoustics, Borås 2000.



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## ANNEX 2 - EMAIL ENQUIRY

Dear Colleagues

We are currently working on a DTI project on environmental noise, which is outlined on our lead contractor's website at [www.hlaprojects.co.uk](http://www.hlaprojects.co.uk). The project has 3 related aspects, with a separate work package being organized for each aspect - details are in the attached paper for Internoise 2004.

Nicole Porter and I are responsible for the part of the work on the classification of acoustic features (tonal and impulsive). So far we have;

- developed a list of methods, and associated references to publications etc
- reviewed the methods, and documented them in terms of their development and application,
- examined the key stages in the evolution and development of the various methods.

This work has enabled us to select a number of methods that we are considering for further analysis (as outlined in the other attached documents).

The next stage of our work is to focus on the issue of the practicality of actual implementation of these methods. We are also reviewing the extent to which the methods have been the subject of any previous inter-comparisons.

PLEASE CAN YOU ASSIST BY ANSWERING THESE 2 QUESTIONS?

As an instrumentation expert, could look at the methods in the attached documents and advise us;

1. if any of the methods are already implemented in current commercially available instrumentation, or
2. if any instrumentation you are familiar with could provide the basic "front-end" processing, such as frequency analysis, or very short-term Leq, from which the methods could be implemented with additional processing.

This enquiry has gone to AcSoft, B&K, Cirrus, Cassela CEL, Ian Campbell Associates, and Rion. If you can suggest contacts at other instrumentation manufacturers/suppliers, to whom we should copy this, please let us know. Any other general comments would also be welcome.

\*\*\*\* A response by the end of June would be much appreciated \*\*\*\*

We very much appreciate your co-operation in this work. We will ensure you are kept informed of the outcome of the project, and are sent a copy of the report, when approved by DTI.

Your valuable contribution to the project will be acknowledged fully.

Many thanks

Bernard Berry and Nicole Porter

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*Contact details*

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## ANNEX 3 - DTI/NMS PROJECT – ENVIRONMENTAL NOISE JUNE 2004

Brief description of methods used to identify tonal features

*ISO 1996 1/3 octave band procedure, Part 1: 1982, Part 2: 1987, Part 3: 1987 (same as BS 7445; 1991)*

A note is included in this standard concerning the practical measurements required to determine the presence or otherwise of a prominent tone. Where the level of a 1/3 octave band exceeds the level of adjacent bands by 5 dB or more, a tone can be considered prominent. It does state that a narrow band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal. If tonal components are clearly audible and their presence can be detected by 1/3 octave analysis, a 5 to 6 dB adjustment is suggested. If the components are only just detectable by narrow band analysis, it is suggested that an adjustment of 2 to 3 dB may be more appropriate.

*ANSI 12.9 identification procedure 1988*

Method suggests that the 1/3 octave band containing the tone needs to protrude above the average level of the 1/3 octave bands either side by more than 15 dB for low frequencies (25-125 Hz), by more than 8 dB for mid frequencies (160-40 Hz) and by more than 5 dB for high frequencies (500-10000 Hz) for a prominent tone to be identified as present. It does not give an indication of the extent of an adverse response.

*ANSI 1.1.3 tone to noise ratio 1999*

The tone-to-noise ratio (TNR) is defined as the ratio of the power of a tone under investigation to the power of the critical band centred on that tone excluding the tone power. A tone is classified as prominent when the TNR exceeds 6 dB. If there is more than one tone within a critical band, the critical band is centred on the tone with the highest level (primary tone). The power of the tone with the second highest level (secondary tone) is added to the total tone power if its frequency is close enough. The noise power is the power in the critical band centred on the (primary) tone excluding the tone power and the power of a secondary tone if it exists. No frequency weighting is applied to the power spectral density. The maximum TNR for all detected tones is the result.

*ANSI 1.13, prominence ratio, 1995*

The Prominence Ratio is defined as the ratio of the power in the critical band centred on the tone under investigation to the mean power of the two adjacent critical bands. A tone is classified as prominent when the PR exceeds 7 dB.

*DIN 45681 tone to noise ratio, 2001*

Tones are automatically identified as local maxima in an A-weighted power level spectrum where the tone-to-noise ratio is greater than the masking index,  $a_v$ , (the TNR of the just audible tone). The masking index depends on the frequency of the tone. The noise power is computed by an iterative process that excludes all tonal components in the critical band. If there is more than one tone within a critical band, the critical band is centred symmetrically between the highest and lowest frequency of the detected tones. The noise power and masking index  $a_v$  are recomputed. The powers of all tones within the critical band are added to the total tone power. The maximum level difference  $DL = TNR - a_v$  for all detected tones is taken as the result. A tone penalty between 0 and 6 dB can be computed from DL. The maximum penalty of 6 dB is given for DL greater than 12 dB.

*JNM, (version2), 1999*

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The procedure is based on three main steps (1) Frequency analysis of the noise at receiver location, (2) Determination of sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band and (3) evaluation of the difference between the tone and the masking noise sound pressure levels by comparison with a criterion curve to determine the audibility of a tone. Analysis is in terms of critical bands, and FFT analysis is recommended. Version 2 applied a graduated 0-6 dB penalty. The audibility criterion that is defined is based upon Zwicker critical bands and is frequency dependent.

#### *ETSU method, 1996*

The procedure is based on the three main steps as above. The method deals with complex tones containing harmonic components. When an audible discrete tone comprises two or more harmonic components, only that component with the greatest audibility need be evaluated unless two or more harmonics lie in the same critical band.

#### *IEC wind turbine method, 2002*

The presence of tones in the noise at different wind speeds is determined on the basis of narrowband analysis. The difference between the spl of the tone and the masking noise is determined, based on critical bands (DLk) The spl of the tone is determined by energy summing all spectral lines identified as tones within a critical band. The tonal audibility is defined difference between DLk and the frequency dependent audibility criteria (formula given).

#### *Aures' procedure, 1985*

Equations are formulated to describe the effect of bandwidth, frequency and level of tonal components on perception of tonality. These effects are termed weighting functions and depend on bandwidth of the tonal component, center frequency of the tonal component, and the excess level of the tonal component. A correction factor is introduced so that the model predicts responses closes to the subjective responses. The perceived tonality is then computed from a combination of these terms, in a formula, which also incorporates another loudness weighting factor, and calibration term.

#### *ISVR tonal detection methodology, 1992*

The formula for tone penalty is based on a number of variables including tone frequency and sensation level of the tone (which is dependent on spl of tone, 1/3 octave band level of the broadband noise cantered on the tone frequency). It uses 1/24 octave band analysis in order to derive the levels in the approximate critical band).

### **Brief description of methods used to identify impulsive features**

#### *Pedersen Prominence [reference 1]*

From analogue or digital recordings of A-weighted SPL with F time-weighting, Onsets are defined where the positive slope of the time history has a gradient above 10dB per second. Level differences are then calculated over these onsets. Predicted Prominence P is then calculated as:

$$P = 3 \cdot \log [\text{onset rate}] + 2 \cdot \log [\text{level difference}]$$

Where there are a number of impulses in a 30-minute period the highest value of P is used. An adjustment  $K_1$  is then calculated from P as follows;

$$K_1 = 1.8 \cdot (P - 5), \text{ for } P > 5, \quad K_1 = 0 \text{ for } P \leq 5$$



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*NPL Increment method [reference 2]*

Defined as the maximum positive difference between successive values of  $L_{Aeq, 10ms}$ . Values greater than 10dB indicate an impulsive sound.

*ISVR Masked threshold/ sensation level [reference 3]*

Sensation level obtained from Instantaneous frequency spectrum of impulsive sound – using FFT of successively incremented 80 msec segments - compared to long term steady state spectrum of background.

### **Annex 3 References**

1. T D Pedersen, 2001. *Objective method for measuring the prominence of impulsive sounds and for the adjustment of LAeq*, Proceedings of Internoise 2001, The Hague.  
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