

# National Measurement System Acoustics Programme:

## NMS Project 2.2: Environmental Noise

Progress Report No. 3 by:

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## 1.0 Introduction

- 1.1 This is the third quarterly report delivered under the DTI NMS Project 2.2: Environmental Noise contract, in accordance with the reporting schedule set out in the agreed contract documentation.
- 1.2 The project programme was agreed internally amongst the project team members and included as part of the first quarterly progress report. The programme is broken down into three separate work packages, WP1, WP2 and WP3. Following the outcome of the second quarterly reporting period, the programme associated with work packages WP2 and WP3 was modified from that originally timetabled. The modifications reflected the outcome of initial interviews aimed at developing a questionnaire to establish the major perceived sources of uncertainty in environmental noise measurements. This change was reported in the second quarterly report and reflected in the modified project programme appended to that report.
- 1.3 The present report therefore compares the progress achieved in the third quarter against the modified project programme appended to the second quarterly progress report. The project, however, remains divided into four main areas:
- Project management and administration
  - WP1 – Classification of Acoustic Features
  - WP2 – Consistent Measurement of Background Noise
  - WP3 – Reproducibility of noise measurements over a range of sources
- 1.4 The format of all progress reports, including the present report, is to devote one section to each of the above work areas.

**NOTE: THIS DOCUMENT IS PROVIDED IN SUPPORT OF REFERENCES OUTLINED IN THE WP1 FINAL REPORT. THIS DOCUMENT HAS BEEN EDITED TO CONTAIN MATERIAL THAT IS ONLY RELEVANT TO WP1. ALL OTHER WORKS RELATING TO WP2 AND WP3 ARE REPORTED SEPARATELY ON THE PROJECT WEBSITE DOWNLOADS SECTION**

<http://www.hla-projects.co.uk/>

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### 3.0 WORK PACKAGE WP1

- 3.1 Responsibility for delivery of WP1 falls predominantly to Bernard Berry (BFB) and Nicole Porter (NDP).

#### Familiarisation & Identify State of the Art Methods

- 3.2 Completed in the project's second quarter, as reported in the second quarterly progress report, although the task will continue throughout the project in order to ensure that any new publications issued within the duration of the contract are identified and reported.

#### Comparison of Methods with Recommendations

3.3 Development, testing and release of WP1/2/3 common questionnaire

Completed in accordance with agreed amended format which separated the WP1 questionnaire from the WP2 and WP3 questionnaires, as detailed in the second quarterly progress report.

3.4 Analysis and reporting on questionnaire outcomes

Completed, as reported in the second quarterly progress report

3.5 Examine principles of each method

This element of the work has seen the focus of efforts on WP1 during the third quarter. Progress has been fully in-line with the expectations of the project programme such that this element of the work is now complete. Summary results of this section of the work are presented in the following Tables 1 to 3 inclusive. The results are given in the separate tables as described below:

1. In the last progress report the collation of a list of methods and key references for the classifications of acoustics features was completed. For the sake of completeness this list is repeated in **Tables 1a and 1b**, with some details updated.
2. Each of these methods has now been described in terms of their development and application, together with the principles of the features classification method. Details for tonal features are given in **Table 2a** and details for impulsive features are given in **Table 2b**.
3. Next, each method has been examined in terms of:
  - the level of sophistication/technical complexity e.g. subjective versus objective, filter bandwidth analysis requirements,
  - the extent to which the method represents the capabilities of the ear, and
  - whether the method estimates the sensory level of the feature and/or the extent of an adverse response.

The results of this analysis are given for tonal and impulsive features in **Tables 3a and 3b** respectively.

3.6 Evaluate extent of real world testing of methods

The next stage of the work will be examine the key stages of development of the methods i.e. how one method may be linked or may have led to the development of another. Using all the information obtained, the origin of the fundamental principles of each method will become clearer, and the inter-relations between the methods will be more clearly understood. All this information will be used to categorise the methods into 'group' for analysis. The first stage of analysis of the groups will be in terms of real world testing. It had originally been programmed that this element of the work would be run in parallel with the examination of the principles of each method. However, it has become apparent through the third quarter that the evaluation of the extent of real world testing is better run in parallel with the task of evaluating the practicality of each method. This task

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is programmed to occur during the next quarter from September 2003 to November 2003. The final stage will examine the practicality of implementation and measurement inter-comparisons.

3.7 Exploration of web based software

The project area of the web-site is now fully developed and operational as a database of documents. As required in the project programme, the potential development of the site as an upload area for sample audio recordings has been investigated. The idea here is that parties who are interested in submitting recordings of noise featuring particular acoustic characteristics (potentially for subsequent testing in accordance with the methodologies identified under WP1) can be offered a simple and direct means of doing so. The investigation, including practical testing, has concluded that the site is capable of being used as an upload area for digital audio files.

3.8 Implementation and maintenance of web based software

Having established the practicalities of the project web-site being used for the direct upload of audio data, the feature is presently being coded into the software.

3.9 Evaluate practicality of implementation of methods

In accordance with the project programme, this is the next task of WP1 to be undertaken in the fourth quarter. As described under 3.6 above, this task will be run in parallel with the evaluation of the extent of real world testing of the methods.

Classification of Acoustic Features

**Table 1a: List of methods used to describe tonal features and the key references describing the principles of each method.**

Decade	Method	Key reference describing the principles of feature classification
Up to 1960s		
	Fletcher's equal loudness contours	Equal loudness contours, Fletcher H.F. et al. 1953 (full reference not known)  ISO 532B, Calculation of loudness.
	Zwicker's tone to noise ratio procedure	Zwicker, Uber psychlogische und methodische Grundlagen der Lautheit, Acustica 8, p237-258, 1958  Later reference: Zwicker and Fastl, "Psychoacoustics" - Facts and models. Edition Springer-Verlag, 1991.
1960s		
	Stevens' tone to noise ratio procedure	Stevens, Procedure for calculating loudness, Mark VI, JASA 33, p157-1585, 1961
	FAR 36 tone correction procedure	Similar to International Civil Aviation Organization, Aircraft noise, Annex 16 to the convention on International Civil Aviation, Montreal ICAO, 1972 and Little, Human response to jet engine noise, Noise Control 1, p11-13, 1961
	Little's tone relative to background procedure (1/24 bands)	J W Little, Human response to jet engine noise, Noise Control 1, p11-13, 1961.  J W Little and J E Mabry, Empirical comparisons of calculation procedures for estimating annoyance of jet aircraft flyovers, J. Sound Vib. 10, p71-80, 1969.
	Wells and Blazier's tonal identification procedure	Wells and Blazier, A procedure for computing the subjective reaction to complex noise, Proceedings 4 <sup>th</sup> ICA, Denmark, L24 1-4, 1962
	Kryter and Pearsons' tonal identification procedure	Kryter and Pearsons, Judged noisiness of a band of random noise containing an audible pure tone, JASA 38, p106-112, 1965.
	BS4142: 1967 reference curves	British Standards Institute, Method for rating industrial noise in a mixed residential and industrial area, BS 4142: 1967
	IALA audibility criterion	AIMS IALA, The definition and method of calculation of a nominal range and the usual range of a sound signal, supplement No 3, 1968
1970s		
	ISO R 1996 procedure	International Organization of Standards, Assessment of noise with respect to community response, ISO R1996, 1971.

Decade	Method	Key reference describing the principles of feature classification
	Low frequency noise methods	References by Geoff Leventhall and Bill Tempest (TBA)
	Speech communication methods	J M Steeneken, Speech communication and recognition, objective and subjective assessment methods : Speech Transmission Index and Rapid Speech Transmission Index (full reference not known).  Norm IEC 60268-16: 98 STI and RASTI.
1980s		
	Fisher's tonal correction procedure	Fisher PS, The assessment of industrial noise nuisance involving tonal character, MPhil dissertation, Open University 1982.
	ISO 1996 1/3 octave band procedure	International Organization of Standards, Description and measurement of environmental noise, ISO 1996, 1982
	Aures' procedure	Procedure for calculating the sensory euphony of arbitrary sound signals, Aures, Acustica 59 p130-141, 1985  An examination of Aures's model of tonality, Sound Quality Symposium, Dearborn, Michigan, August 2002
	ANSI S12.9 1/3 octave procedure	Quantities and procedures for description and measurement of environmental sound. Part 3: Short term measurements with an observer present
	ANSI S12.10 tone prominence rule	American National Standard, Methods for the measurement and designation of a noise emitted by computer and business equipment, 1985  Identifying prominent discrete tones in machine noise emissions using an FFT analyzer," M.A. Nobile, Proc. Inter-Noise 86, 1027-1032, July, 1986. (this introduced the FFT method that later went into the ISO 7779, ECMA-74, and ANSI S12.13 Tone-to-Noise Ratio Methods)
	ISO 1996 procedure	International Organization of Standards, Description and measurement of environmental noise, ISO 1996, 1982  Australian standards organization, AS 1055 (1997), Description and measurement of environmental noise.
1990 –2000s		
	BS4142: 1990 subjective definitions	British Standards Institute, Method for rating industrial noise in a mixed residential and industrial area, BS 4142: 1990
	ISVR/Robinson's tonal detection methodology	Annoyance due to discrete tones in broadband background noise: Part II Analysis, ISVR TR 202, University of Southampton 1992

Decade	Method	Key reference describing the principles of feature classification
	Sound power methods for assessing importance of tones and other features	TBA
	DIN 50377 procedure	DIN 50376 Publication declaration of sound power and tonality of wind turbines: German version prEN 50376
	Windfarm tonal noise identification procedure	The assessment and rating of noise from windfarms, The working group on noise from wind turbines, Final Report September 1996, ETSU for DTI.
	Pedersen and the Joint Nordic method	<p>Several key references from Pedersen 1978-1991 (not listed here).</p> <p>Earlier reference:</p> <p>Danish National Agency of Environmental Protection, Guideline No 6, Measurement of Environmental Noise from Industry, The Joint Nordic Method for the Evaluation of Tones in Broadband Noise, 1984</p> <p>M Sondergaard, T D Pedersen, J Kragh, Method for assessing tonality of wind turbines, DELTA report Acoustics and Vibration Dec 1999.</p> <p>Objective method of assessing the audibility of tones in noise, Joint Nordic Method Version 2, DELTA report AV 1952/99</p> <p>T D Pedersen, Method for assessing tonality of wind turbine noise, DELTA report AV 1940/99.</p> <p>T D Pedersen and M Sondergaard, Objective method for assessing the audibility of tones in noise, Proceedings of Internoise 2000.</p> <p>T D Pedersen and C L Fog, Optimisation of perceived product quality, Euronoise 98.</p>
	ISO/DIS 7779, ECMA 74 for computer and business equipment	<p>See also ICWG entries</p> <p>ISO 7779 Acoustics – Measurements of airborne noise emitted by computer and business equipment, first edition 1988-06-05.</p> <p>ECMA 74, Acoustics – Measurement of airborne noise emitted by information technology and telecommunications equipment: Annex D Identification and evaluation of prominence of discrete tones.</p>

Decade	Method	Key reference describing the principles of feature classification
	Nobile's Prominence Ratio method	<p>See also Prominence ratio (below)</p> <p>A procedure for determining the Prominence Ratio of discrete tones in noise emissions," M.A. Nobile and G.R. Bienvenue, Proc. Noise-Con 91, 475-482, July, 1991. (Minor additions later made in: "Prominence Ratio method for discrete tones in noise: Computation of adjacent critical bands," Proc. Noise-Con 94, 729-734, May, 1994).</p> <p>Led to ANSI S1.13, "Measurement of sound pressure levels in air, Appendix A: Identification and evaluation of prominent discrete tones," December, 1995</p>
	ICWG Tone-to-Noise ratio and Prominence Ratio	<p>A comparison of two methods for the evaluation of prominent discrete tones – recommendations, Hellweg, Balant, Nobile, Proceedings of Internoise 2001</p> <p>Modification to procedures for determining prominent discrete tones, Robert D. Hellweg, Jr. Matthew A. Nobile</p> <p>Proc Internoise 2002</p> <p>Tone to noise ratio method published in: ISO 7779, "Acoustics--Measurement of airborne noise emitted by information technology and telecommunications equipment, Annex D: Identification of prominent discrete tones," second edition, 1999-08-01 (This is equivalent to ECMA-74 of the same name). Note: the next version of ISO 7779 (and ECMA-74) currently being drafted will have both the Tone-to-Noise Ratio and Prominence Ratio methods in it.</p>
	DIN 45681 procedure	<p>DIN 45681 – Acoustics – Detection of tonal components of noise and determination of a tone adjustment for the assessment of noise immissions, June 2002</p> <p>D Sagemuhl, L Schmidt: Revision of E DIN 45681 (Tonality), Proceedings of Internoise 2001.</p>
	Wind turbine - standard methods for measurement of noise	<p>88/166/FDIS, IEC 61400-11 Ed. 2, Wind turbine generator systems, Part 11: Acoustic noise measurement techniques, 2002.</p> <p>J Bass, A critical comparison of standard tonal analysis methodologies, report no. 502/res/2006, issue 1, 19 January 1999</p>

**Table 1b: List of methods used to describe impulsive features and the key references describing the principles of each method**

Decade	Method	Key reference describing the principles of feature classification
1970s		
	Proposed ISO / Berry and Robinson method for helicopter noise impulse correction	Berry et al 1979. The rating of helicopter noise, development of a proposed impulse correction. NPL Acoustics Report Ac93.
	Sonic boom methods	CHE Warren (RAE) and NASA reviews, with most recent NASA review as: Leatherwood, Jack D.; Sullivan, Brenda M.; Shepherd, Kevin P.; McCurdy, David A.; Brown, Sherilyn A.: "A summary of recent NASA studies of human response to sonic booms": Journal of the Acoustical Society of America, Vol. 111 (1), Pt. 2, pp. 586-598, Jan 2002.
1980s		
	CEC methods	Bisping 1989 Steady versus impulsive noise , spectral parameters and subjective ratings. Proc 13 <sup>th</sup> ICA 3, 143-146  R Bisping 1991 Spectral modeling of impulsive noise by Prony's method. Workshop on the effects of Impulse Noise, CEC Report d 11992-00157-8, Part A, 15-17  B. F. Berry and R. Bisping, CEC joint project on impulse noise: physical quantification methods. The 5th International Congress on Noise as a Public Health Problem, 1988, Stockholm. Proceedings, 1-6.
	Berry's impulse method	B F Berry, The evaluation of impulsive noise, NPL report Ac 111, September 1987  B. F. Berry, A. D. Wallis and A. Rozwadowski. The use of short-term $L_{Aeq}$ in the assessment of impulsive noise. Proc. Inst. of Acoustics, 1989, Vol. II, (9), 309-317.
	Zwicker methods involving loudness level statistics	B. F. Berry and E. Zwicker, 1986 Comparison of subjective evaluations of impulsive noise with objective measurements of the loudness-time function given by a loudness meter. Internoise 86, 1986, Cambridge USA. Proceedings, 821-824.  Later reference:  Zwicker and Fast, "Psychoacoustics" - Facts and models. Edition Springer-Verlag, 1991.
	ISO 1996 procedure	International Organization of Standards, Description and measurement of environmental noise, ISO 1996, 1982  Australian standards organization, AS 1055 (1997), Description and measurement of environmental noise.

Decade	Method	Key reference describing the principles of feature classification
	Powell' s helicopter procedure	Powell CA, Subjective field study of response to impulsive helicopter noise, Report Number NASA -TP-1833 (1981).
1990s		
	BS 4142 subjective criteria	British Standards Institute, Method for rating industrial noise in a mixed residential and industrial area, BS 4142: 1990
	ISVR's impulse feature detection methodology	Ikeda and Flindell, Subjective listening tests of impulse noise annoyance, ISVR contract report 93/37, December 1993
	NPL and USAF onset rate methods	BF Berry, 1995 Towards a standardised descriptor of the impulsive noise caused by low-altitude military aircraft Proceedings of Internoise '95, Newport Beach, USA, July 1995, Vol II, 879-884
	ISO 1996 procedure	International Organization of Standards, Description and measurement of environmental noise, ISO 1996, 1982  Australian standards organization, AS 1055 (1997), Description and measurement of environmental noise.
	Vos's classification of shooting sounds (ASEL and CSEL)	Vos, J, On the annoyance caused by impulse sounds produced by small, medium-large, and large firearms. Journal of the Acoustical Society of America 109 (1), 244-253. (2001)  Vos, J, A- and C-weighted sound levels as predictors of the annoyance caused by shooting sounds, for various façade attenuation types. Journal of the Acoustical Society of America 113 (1), 336-347 (2003)  validation study:  Vos, J, Validation of a new procedure for rating shooting sounds with the help of field survey data. Acustica - Acta Acustica Vol. 85, Suppl. 1, S 144 (Abstract). 1999
	Wigner-Ville' s method	P. Flandrin, "Temps-Fréquence" - Traité des nouvelles technologies (Série traitement du signal). Edition Hermes. 1993.
2000s		
	Kerry et al's method for onset rate	G Kerry et al. A critical assessment of methods for calculating onset rate and their role in predicting acoustic reflex attenuation. Proc 17 <sup>th</sup> ICA Rome, 2002. CDROM, paper 6_08.pdf
	Pedersen's prominence method: Nordtest method	T D Pedersen, Objective method for measuring the prominence of impulsive sounds and for adjustment of LAeq, see proceedings of Internoise 2000 paper 304.

Decade	Method	Key reference describing the principles of feature classification
		<p>T D Pedersen, Objective method for measuring the prominence of impulsive sounds and for the adjustment of LAeq, Proceedings of Internoise 2001, The Hague.</p> <p>T D Pedersen, Nordtest method proposal (final version) 1 AV 1106/02, 2002-03-04 "Objective method for the measurement of prominence of impulsive sounds and for the adjustment of Leq". (Approved May 2002).</p> <p>H Andersson, T D Pedersen, Nordtest Project 1516-00, SP Rapport 2000:30, Round robin test of an objective method for the determination of the prominence of impulsive sounds and for the impulse adjustment of LAeq.</p> <p>Draft ISO/CD 1996 2, ISO TC 43/SC1/WG, Secretariat: DS Acoustics – description and measurement of environmental noise – Part 2: Determination of environmental noise levels, Annex E.</p> <p>T D Pedersen and C L Fog, Optimisation of perceived product quality, Euronoise 98.</p>
	ISO 1996 amendment based on enumerated categories	International Organization of Standards, Description and measurement of environmental noise, ISO 1996, amendment 2001

**Table 2a: Description of Methods for Tonal Features (see Table 1a for References)**

Method	Development and application of method	Principles of feature classification
Fletcher's equal loudness contours, 1953	An early procedure whereby a 1000 Hz tone was fixed in level and the test sound adjusted to give a loudness match. This was repeated for different frequencies of a sinusoidal test sound and equal loudness generated. The findings showed that the rate of growth of loudness differs for tones of different frequencies.	This is only an implied tonal classification procedure in that the relative loudness of the different frequency components in a sound changes as a function of the overall level.
Zwicker's tone to noise ratio, 1956-59	This procedure could be considered as a tone correction procedure in that it is designed to handle pure tones and combination of tones and noise, with respect to loudness. The work developed critical band theory based on loudness judgments.	The procedure handles tones on the basis of the principles of mutual inhibition that underpins Steven's procedure (below). A tone would be identified by a process based on the concept that noisiness differs from loudness. It incorporates an allowance for the effects of masking between tones and noise when heard simultaneously and was therefore considered a tone correction procedure with respect to loudness.
Steven's tone to noise ratio procedure, 1956-72	In 1970 Stevens circulated a proposal for a tone correction procedure to be used with his loudness calculation procedures. Based on Steven's 1956 work on the calculation of the loudness of a complex noise, this was an unpublished tone correction procedure to be used with Steven's loudness calculation procedures. It was based on the notion that the underestimation of the calculated perceived magnitude of the tone and noise complex arises because the auditory system analyses components in the complex as distinct sources and then, in effect, adds them together to obtain a total percept. This procedure differs from the FAR 36 and Kryter and Pearson's methods (see below) in a number of ways; (1) it includes the level of the band containing the tone, (2) it omits any dependence on the frequency of the tonal component, (3) and it includes a method for handling multiple components.	The procedure was developed to mimic the auditory system by using data on the masking of a pure tone by broadband noise. It assumed that the loudness of the partially masked tone summates with the loudness of the noise when the two are judged as a composite sound. It took into account that partial masking depends on the tone-to-noise ratio as well as the absolute level of the noise. No actual criterion to use for identifying the presence of a tonal component.
Little's tone relative to background procedure, 1961	Little's tests examined the judgment of the relative annoyance of broadband noises with added single tonal components and were carried out in the context of aircraft noise. The standard comparison sound was set at 100 dB and the difference between the overall spl and the noise-tone complex was measured when the two sounds were judged to be equally annoying. This difference (the Noise Factor) was determined for different levels of the tone relative to the background level in the appropriate 1/24-octave band.	Little concluded the following principles: that the capacity of a noise-tone complex to cause annoyance is related to the frequency and relative amplitude of the tone, annoyance equality between noises with and without added tones can be achieved by establishing the proper Noise Factor relationship between two spls, and the perceived noise level does not adequately assess the annoyance of noises containing tonal components.
Wells and Blazier's tonal identification procedure, 1956-62	This was a procedure used for computing the subjective reaction to complex noise. It was recognized that the successful use of approximately parallel contours to set criteria was limited to broadband spectra of similar shape and problems would be associated with applying this method to noise with tonal components. For broadband noise, a tangential contour was drawn in a manner similar to NR curves. To this level, a correction was proposed to take into account the	For noises with tonal components, an added process step was added into the procedure, the addition of a tone correction. The basis of this relied on the level of the tone above the 1/3 octave band level as being comparable with the level that the tone exceeds the critical band level. A ratio of bandwidth was therefore included in their mathematical expression for the tone correction. It was also recognized that annoyance potential was not identical to



Method	Development and application of method	Principles of feature classification
	distribution of energy, dependent on the number of 1/3 octave band levels within 5 dB of the rating curve assigned to the noise spectrum. The value of this correction being normalised and having values between about -6 and +7 dB. The method does not appear to have received any further attention.	detection and a corrected contour is calculated from corrected band levels.
Kryter and Pearsons' tonal identification procedure, 1963-65	In developing work on the judged noisiness of a band of random noise containing a tone, Kryter and Pearsons developed a pure tone correction procedure for Perceived Noise Level. This work was carried out in the context of aircraft noise. It differs from the FAR 36 method (see above) in that it first corrects the levels in each third octave band containing identified pure tones, and then calculates the Tone Corrected Perceived Noise Level.	The 'pure tone correction factor' was developed to modify the then existing methods for evaluating noisiness. Using 1/3 octave bands, tones 3 dB or more above adjacent 1/3 octave bands are identified as pure tones i.e. $T + N/AN$ must be greater than 3 dB ( $T$ = tone level, $N$ = noise level, $AN$ = intensity of the bands immediately adjacent to band containing the pure tone). There is a suggested method for smaller tone-to-noise ratios. The values of the tone corrections range from 0-14 dB. Pearsons recognized the difficulties of closely spaced tones and tones whose energy spread across adjacent bands. Extensions to the procedure based on 1/10 octave band levels were suggested.
BS4142: 1967 reference curves	This standard is used to predict the likelihood of complaint from residents living in the vicinity of an industrial noise source. The principle of intrusion is used whereby a rating level is compared against a background level. In calculating a rating level for the prediction, a 5 dB tonal penalty is used to correct for a noise that contains a distinguishable discrete continuous note (whine, hiss, screech, hum etc).	Appendix C of the 1967 version of this standard gives a description of additional measurements required to identify noise components likely to cause annoyance. This is primarily aimed at facilitating the identification of steps to be used to reduce the noise to an acceptable level. Tonal noise is addressed under this header. Octave band analysis is recommended. Levels are plotted against a set of reference curves specified in BS 4198 "Method for calculating loudness". The frequencies between which the plotted octave band spectrum protrudes into the highest of the zones defines the frequency band that is likely to contain the noise component(s) mainly responsible for the annoyance.
IALA audibility criterion. 1968	The International Association of Lighthouse Authorities (IALA) developed this method to assess the performance of fog signal emitters. In this guide, the audibility of a noise heard on board a ship is assessed. There is no description of the measurement procedure for the audibility of tones. However, the process of judging whether a sound is audible is based on spectral analysis into 'frequency groups'. The bandwidth of these groups appears to be based on critical bandwidths.	A probability of hearing a noise is based on the 50% audibility criterion. This depends on the difference between the spl of the noise and a just detectable (in 50% of cases) pure tone sound in a frequency group. This difference is set at 3 dB below 315 Hz and increases to 6 dB above 3150 Hz. Analysis therefore based on frequency groups derived from critical bands.
FAR 36 tone correction procedure, 1969	Procedure was introduced by the US Federal Aviation Administration in 1969 for noise certification of subsonic jet aircraft. A tone correction was included to take into account tonal components, in accordance with subjective judgments.	The presence of tones is confirmed in the cases where a correction is applied. This is where the band level is compared to a smoothed level (calculated from average adjacent bands) and where there is a difference of more than 3 dB, the presence of discrete tone is assumed. The value of a correction ranged from 0-6.67 dB. If more than one single tonal component is identified, only the largest penalty is applied to



Method	Development and application of method	Principles of feature classification
		the perceived noise level.
ISO R 1996 procedure, 1971	ISO R 1996 (1971) describes procedures for the assessment of noise in terms of expected community response from most environmental noise sources except aircraft. The assessment is based on a comparison of the measured A-weighted noise level, corrected for duration and character, with the criterion based on background noise level. It stipulates a 5 dB(A) penalty be added to the measured level when audible tonal components (whine, screech or hum) are present. The standard has been superseded (see below).	Appendix Y of the standard gives details of frequency analysis for rating the noise and for cases where corrective measures to reduce noise nuisance may be required. The standard adopts a set of Noise Rating (NR) curves against which the measured spectrum of the noise can be compared. This allows the identification of the intrusive frequency bands. The analysis is based on octave bands analysis and sets a criterion based on NR values.
ISO 3891, 1978	ISO 3891 is a fairly complicated procedure using a perceived noise level (L <sub>p</sub> n) measurement scale (ISO 3891:1978), developed from Kryter and Pearsons, Little and FAR methods. It is used to set limits for new types of aircraft under agreed noise certification procedures. It uses a tone corrected perceived noise level for noise spectra showing pronounced irregularities such as a pure tones. The procedure uses as a basis the assumption that the perceived noise level of a given sound with a tonal component should be numerically equal to the sound pressure level of a reference sound that is judged by listeners to have the same perceived noisiness as the given sound.	<p>The tone correction is added to the perceived noise level whenever the 1/3 octave band containing the tone protrudes by more than 2.5 dB above the level of the non-tonal noise in the same 1/3 octave band. This can only in practice be estimated by taking the average level of the 1/3 octave bands on either side. The maximum value of the correction is 6.7 dB for frequencies in the range between 500 Hz and 5 kHz, and 3.3 dB for tones in the range from 6.3 kHz to 10 kHz and from 80 Hz to 400 Hz. The tone correction is defined as one third of the tone protrusion in dB in the middle frequency range and one sixth of the tone protrusions in dB in the other ranges, up to a maximum of 20 dB.</p> <p>The procedure does not clearly distinguish between generally irregular spectra and specific tone protrusion. This can potentially lead to falsely identifying a tonal component especially where 1/3 octave band analysis is too coarse to be able to reliably identify the presence or absence of subjectively identifiable tones. This deficiency is recognized in the standard by a note which attempts to eliminate spurious effects in the calculation of the tone corrected perceived noise level.</p>
Fisher's tonal correction procedure, 1982	This procedure arose from considering an extension to the ISO R 1996 procedure and a similar tone correction procedure to that proposed by Kryter and Pearsons. It recognizes the importance of tonal character in rating of community response to noise. Fisher proposed this new method after criticizing BS 4142 as underestimating the potential of noises having marked tonal character to give rise to complaints. He devised a system based on octave band analysis. This bandwidth was chosen since EHO department in the early eighties had been shown generally not to have any finer resolution capabilities. A basic rating level is determined from the NR curves. Octave band levels are used in terms of a L <sub>90</sub> level.	An annoying tone is defined as one being contained in the octave band which when plotted on the NR curves, sets the NR number and exceeds the arithmetical average of the adjacent octave bands. The value of the correction to be applied to the basic rating level is determined from the level difference between the band level of the octave band containing the annoying tone and the notionally smooth spectrum level. Tonal correction values from 0-6 dB are added, the actual value being dependent on frequency and an effective tone level (based on level differences). This procedure was evaluated using 40 case studies. It could be concluded that the proposed method actually performed no better than BS 4142 and ISO R 1996.
ISO 1996 1/3 octave band procedure, Part 1: 1982, Part 2: 1987,	This standard is in three parts. Part 1: 1982 (Basic quantities and procedures) refers to a possible need to make adjustments on occasions to the	The requirements for K1 are "If tonal components are essential characteristics of the sound within a specified time interval, an



Method	Development and application of method	Principles of feature classification
Part 3: 1987 (same as BS 7445; 1991)	measured noise levels in obtaining a rating level in terms of LAeq. Part 2 (Acquisition of data pertinent to land use) specifies a tonal adjustment, K1.	<p>adjustment may be applied, for that time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated".</p> <p>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 adjusted 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.</p>
Aures' procedure, 1985	In 1985 Aures proposed a method for the calculation of tonality that takes into account the frequency, bandwidth and level of all tonal components as well as taking into account the effect of noise.	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.
ANSI S12.9 1/3 octave procedure, 1988 (Re-affirmed 1993)	This is an American standard for the description and measurement of environmental noise. In describing environmental sounds, this standard sets out a test for the presence of a discrete tone.	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.
ANSI S12.10 tone prominence rule, 1985 (Re-affirmed 1990)	This is similar to ISO 7779 and DIN 45 635. This standard defines uniform methods for measuring and reporting the noise emitted by computer and business equipment. It describes procedures for determining the sound power produced by the equipment and for reporting the A-weighted sound pressure level at the operator's position. Although not an integral part of the standard, Appendix B gives a method for the identification of prominent discrete tones. No penalty is applied but any prominent tones identified according to the appendix B procedure can be reported.	<p>A discrete tone is defined as prominent if the spl of the tones exceed the spl of the masking noise in the critical band by more than 6 dB. This corresponds to a tone being prominent when it is more than 10 dB above the threshold of audibility.</p> <p>For multiple tones in a single critical band, only the primary tone is evaluated with the other tones treated as contributing to the masking noise level. For complex tones containing harmonics, only the component with the highest A-weighted sound pressure level is evaluated using the criterion.</p>

Method	Development and application of method	Principles of feature classification
BS4142: 1990 subjective definitions	This standard was amended in 1975, 1980 and 1982. This revision was to bring it into line with ISO 1996 with the adoption of LAeq as the descriptor for the specific noise level. The assessment still uses a rating level, which includes a correction for character, but the standard does not include an objective method for identifying a tone.	A 5dB penalty is added to the specific noise if it contains a distinguishable, discrete, continuous note (whine, hiss, screech, hum etc) i.e. a subjective judgment of tonal character.
ISVR/Robinson's tonal detection methodology, 1992	This method was developed from work to experimentally develop a quantitative formula for overall tonal penalty (using sensation level of a tone). It is limited to discrete tones in steady broadband background noise.	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 centered on the tone frequency). It uses 1/24 octave band analysis in order to derive the levels in the approximate critical band).
DIN 50377 procedure	A German standard on the declaration of sound power and tonality of wind turbines	Not yet determined
Windfarm tonal noise identification procedure, ETSU 1996.	This is a framework for the measurement and assessment of wind farm noise based on the Joint Nordic Method for non-stationary tones (see below). It sets out a method for the assessment of tones. An approach is adopted which presents a sliding scale of penalties from 0 to 5 dB based on tone level audibility of sensation levels of 2 to 6.5 dB+ above an audibility criterion.	<p>The tonal identification process is based on the prominence criteria of the Joint Nordic Method for non stationary tones (see below). There are number of embellishments to this method which include more detailed prescriptive techniques for tone identification and for specifying averaging periods.</p> <p>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.</p> <p>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.</p>
The Joint Nordic Method, version 1 1984, version 2, 1999	<p>This is a guideline from the Danish National Agency of Environmental Protection relating to the measurement of environmental noise from industry. It is often referred to as the Joint Nordic Method for the Evaluation of Tones in Broadband Noise.</p> <p>Following several investigations, proficiency tests and practical experience, version 2 updated version 1 to overcome some identified problems. The key differences were:</p> <ul style="list-style-type: none"> <li>The revised method is based on an A-weighted spectrum of the sound pressure level measured</li> </ul>	<p>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.</p> <p>Version 1 of this method applies a 5 dB penalty to an incident noise when a tone is deemed</p>



Method	Development and application of method	Principles of feature classification
	<p>with a long averaging time (at least one minute).</p> <ul style="list-style-type: none"> <li>• Stationary and non-stationary conditions are in principle treated the same way.</li> <li>• A graduated 0-6 dB penalty replaces the 5 dB on/off penalty.</li> <li>• 4. Precise definitions of tone and masking noise levels are included to facilitate automation.</li> </ul>	<p>prominent using an objective test method whereas 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 and defined as:</p> <p>Version 1 defines a method for the analysis of tones in non-stationary conditions, e.g. where the level or frequency of the tone is varying. This procedure applies a Hanning correction to the measured level of the masking noise. This is to correct for the effective analysis bandwidth of the frequency analyser being wider than the frequency resolution. Version 1 deals with non stationary tones by suggesting that the highest level of the tone is found by varying the five highest tone levels from a number of individual spectra.</p>
<p>Tone-to-noise ratio and prominence ratio (see references for ISO 7779, ECMA 74 for computer and business equipment, Nobile's PR, ICWG entries), 1988-2001</p>	<p>ANSI 12.10 tone to noise ratio led to an FFT method developed by Nobile, which later went into ISO 7779, ECMA 74, and ANSI 1.13 tone to noise ratio methods. Both of the methods are published in ANSI S1.13</p>	<p>Tone to noise ratio: 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 centered 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.</p> <p>Prominence ratio: 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.</p>
<p>DIN 45681 procedure, 2002</p>	<p>A German standard on the detection of tonal components of noise and the determination of a tone adjustment for the assessment of noise immissions.</p>	<p>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 <math>a_v</math>, (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 <math>a_v</math> are recomputed. The powers of all tones within the critical band are added to</p> <p>the total tone power. The maximum level difference <math>DL = TNR - a_v</math> for all detected tones is taken as the result. A tone penalty between 0 and 6 dB can be computed from DL. The</p>



Method	Development and application of method	Principles of feature classification
		maximum penalty of 6 dB is given for DL greater than 12 dB.
Wind turbine - standard methods for measurement of noise, IEC 61400-11:2002, 2002	This standard provides guidance in the measurement, analysis and reporting of complex acoustic emissions from wind turbine generator systems.	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 ( $\Delta L_k$ ) 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 $\Delta L_k$ and the frequency dependent audibility criteria (formula given).

**Table 2b: Description of Methods for Impulsive Features (see Table 1b for References)**

Method	Development and application of method	Principles of feature classification
Proposed ISO / Berry and Robinson method for helicopter noise impulse correction	Developed as part of proposed ICAO Helicopter Noise Certification procedure. The A-weighted signal is sampled at 5kHz, and then the time-series is processed to calculate the quantity $I =$ the variance of individual sample amplitudes around the 0.5 second mean value.	Linear transformation proposed relating Relative subjective annoyance level to $10\log I$ .
CEC methods – Bisping	EC Impulse project [ see Rice in JSV 1996 ] examined a variety of possible methods. As well as Berry /NPL method described below, Bisping of University of Dusseldorf proposed a method based on Prony spectral analysis of 10ms time segments	Visual inspection of 3 dimensional plots of relative amplitude, frequency and time for signals of known classification as “ Impulsive” etc
Berry’s impulse method	During a 3 year contract for the then Dept of the Environment , Berry explored a number of methods all of which involved processing the time-series of values of short-term LAeq, with 10ms time windows. Descriptors such as Saliency, Standard deviation and Increment were used . The overall conclusion of CEC work was that Increment was optimum. This is defined as the maximum positive difference between successive values of $L_{Aeq, 10ms}$	Correlation of physical descriptor with relative annoyance level based on judgements of a range of recorded and synthesised noises.
Zwicker methods involving loudness level statistics	Zwicker’s original method for loudness calculation had been extended in 19XX to cover time-varying loudness. Using a digital hardware version of the loudness meter the quantity $N_{20}$ – the loudness exceeded for 20% of the time – was calculated.	Comparisons made of values of $N_{20}$ for simulated impulse noises of with various durations and repetition rates, with trends in subjective judgements. [Note. Fastl later worked with $N_5$ ]
BS 4142 subjective criteria	BS4142:1997 states “ Apply a 5dB correction if one or more of the following features occur etc...the noise contains distinct impulses [bangs, clicks clatters or thumps] “.	Purely subjective assessment of whether impulse feature is present or not.
ISVR’s impulse feature detection methodology	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.	Sensation level related to experimentally observed masked threshold levels.

Method	Development and application of method	Principles of feature classification
<p>Pedersen's prominence method</p>	<p>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.</p> <p>Predicted Prominence P is then calculated as:</p> $P = 3 \cdot \log[\text{onset rate}] + 2 \cdot \log[\text{level difference}]$ <p>Where there are a number of impulses in a 30 minute period the highest value of P is used.</p> <p>An adjustment <math>K_i</math> is then calculated from P as follows;</p> $K_i = 1.8 \cdot (P - 5), \text{ for } P > 5, \quad K_i = 0 \text{ for } P \leq 5$	<p>Adjustment based on a Round Robin listening test.</p>
<p>ISO 1996</p>	<p>ISO 1996-2 : 1987 states..."Clause 4.1.4 Impulse adjustment K2.</p> <p>If impulse is an essential characteristic of a sound within a specified time interval, an adjustment may be applied, for this time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated."</p> <p>A Note refers to the possible use of the I time-weighting and to the use of C-weighting for large amplitude noise, in some countries.</p>	<p>Subjective judgement of presence of impulse characteristic.</p>
<p>ISO 1996 amendment based on enumerated categories</p>	<p>Addendum 1 of 1997 to ISO 1996-2 introduced the concept of 3 categories of impulsive sound defined by knowledge of the actual source of the noise.</p> <p><b>Highly impulsive sound</b> : a sound from one of the following enumerated sources – small arms fire, metal hammering etc etc.</p> <p><b>High-energy impulsive sound</b>: quarry and mining explosions, sonic booms, explosive industrial circuit breakers.</p> <p><b>Ordinary impulsive sounds</b>: an impulsive sound that is not a highly impulsive sound or a high energy impulsive sound, eg near-by high speed train.</p> <p>NOTE. These categories have been continued into the newly completed ISO FDIS 1996-1. 2003. The revised ISO 1996-2, currently being voted on at the DIS stage, states – " There is no generally accepted method to detect impulsive sound using objective measurements". It then refers to ISO 1996-1.</p>	<p>Value of the Impulse adjustment dependent on which category the source is in.</p>

**Table 3a: Comparison of Methods for Tonal Features (see Table 1a for References)**

Method	Level of Sophistication	Representation of capabilities of ear	Describes sensory level of feature or extent of adverse response
Fletchers equal loudness, 1953	Subjective judgments of loudness	Early investigation of loudness processing capabilities	Not developed enough for either
Zwicker's tone to noise ratio, 1956-59	1/3 octave bands	Early representation of critical band theory	Does not attempt to judge adverse response
Steven's tone to noise ratio, 1956-72	1/3 octave bands	Early representation of critical band theory	Does not attempt to judge adverse response
Little's tone relative to background procedure, 1961	1/24 octave band analysis	Not specifically	Overall method aimed at determining annoyance (adverse response)
Wells and Blazier's tonal identification procedure, 1956-62	1/3 octave band analysis	Not specifically	Overall method aimed at computing subjective reaction (adverse response)
Kryter and Pearsons' tonal identification procedure, 1963-65	Octave, 1/3 octave and 1/10 octave band analysis	Not specially although frequency bandwidth used for analysis is recommended to be less than critical bandwidth	Overall method aimed at judgments of noisiness (possibly an adverse response)
BS4142: 1967 reference curves	Octave band analysis	Not specifically	Tonal corrections included in a rating level used to determine extent of an adverse response
IALA audibility criterion, 1968	Analysis into 'frequency groups' based on critical bands	Analysis into critical bands. Just detectable levels of noise also used.	Based on audibility only (i.e. sensory level rather than adverse response)
FAR 36 tone correction procedure, 1969	1/3 octave band analysis	Not specifically	Range of correction suggests that it describes extent of adverse response
ISO R 1996 procedure, 1971	Octave band analysis	No	Tonal corrections included in a rating level (suggesting an adverse response)
ISO 3891	1/3 octave band analysis	No	Correction applied to a perceived noise level (related to adverse response), does not compute sensory level of feature
Fisher's tonal correction, procedure, 1982	Octave band analysis	No	Tonal corrections included in a rating level used to determine extent of an adverse response

Method	Level of Sophistication	Representation of capabilities of ear	Describes sensory level of feature or extent of adverse response
ISO 1996 1/3 octave band procedure, 1982-1987 (BS 7445: 1991)	1/3 octave band analysis	No	Tonal corrections included in a rating level (suggesting an adverse response)
Aures' procedure, 1985	Narrow band analysis	Critical bands take into account	Procedure computes the perceived tonality so it relates to the sensory level of the tonal feature only
ANSI S12.9 1/3 octave procedure, 1988	1/3 octave band analysis	Not specifically	Identification of a prominent tone only, not related to extent of adverse response
ANSI S12.10 tone prominence rule, 1993	Narrow bands to determine critical bands levels	Masking and critical band theory taken into account	Identification of a prominent tone only, not related to extent of adverse response
BS 4142: 1990 subjective definitions, 1990	Subjective	No	Tonal corrections included in a rating level used to determine extent of an adverse response
ISVR/Robinson's tonal detection methodology, 1992	1/24 octave bands	Masking and critical band theory taken into account	Describes the sensation level (sensory level) which is related to the calculation of a penalty (indication of adverse response)
Windfarm tonal noise identification procedure, ETSU 1996.	Narrow bands to determine critical bands levels	Masking and critical band theory taken into account	Describes the sensory level of tone which is related to the calculation of a penalty (indication of adverse response)
The Joint Nordic Method, version 1 1984, version 2, 1999	Narrow bands to determine critical bands levels	Masking and critical band theory taken into account	Describes the sensory level of tone which is related to the calculation of a penalty (indication of adverse response)
Tone-to-noise ratio and prominence ratio (see references for ISO 7779, ECMA 74 for computer and business equipment, Nobile's PR, ICWG entries), 1988-2001	Narrow bands to determine critical band levels	Masking and critical band theory taken into account	Sensory level is described by the TNR and PR values, and the standards relate these to penalties (in terms of an adverse response)
DIN 45681 procedure, 2002	Narrow bands to determine critical band levels	Masking and critical band theory taken into account	Describes the sensation level (sensory level) which is related to the calculation of a penalty (indication of adverse response)
Wind turbine - standard methods for measurement of noise, IEC 61400-	Narrow bands	Masking and critical band theory taken into account	Sensory level only

Method	Level of Sophistication	Representation of capabilities of ear	Describes sensory level of feature or extent of adverse response
112002, 2002			

**Table 3b: Comparison of Methods for Impulsive Features (see Table 1b for References)**

Method	Level of Sophistication	Representation of capabilities of ear	Describes sensory level of feature or extent of adverse response
Proposed ISO /Berry and Robinson method for helicopter noise impulse correction	Requires digital sampling of signal and calculation of time-series statistics	none	Extent of adverse response
CEC methods - Bisping	Complex spectral calculation	none	Sensory level implied
Berry's impulse method	Requires short-term LAeq measurement and calculations on time-series	none	Extent of adverse response
Zwicker methods involving loudness level statistics	Zwicker method involves frequency analysis into critical bands and complex algorithms for masking and loudness summation	Close representation based on many psychoacoustic experiments	Can do both
BS 4142 subjective criteria	No objective analysis	Listener decides if impulsive	Listener judges
ISVR's impulse feature detection methodology	FFT analysis on 80 msec time windows	none	Sensory level of feature
Pedersen's prominence method	Detection of onsets, where level changes more than 10 dB per second, and calculation of onset rate and level difference	none	Extent of adverse response by way of sliding scale of correction
ISO 1996	No objective analysis	none	neither
ISO 1996 –2 amendment based on enumerated categories	No objective analysis	None – uses categories of noise source	Multi-level correction – implies differential adverse response/annoyance