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8 APPENDIX A: HISTORICAL PERSPECTIVE ON MEASUREMENT AND PREDICTION OF COMMUNITY RESPONSE TO TRANSPORTATION NOISE

Aircraft noise varies simultaneously in the amplitude, frequency, and temporal domains. During the course of a flyover as experienced in urban settings, aircraft noise levels may rise and fall as much as 30 dB (a factor of 1,000:1 in energy) in less than a minute, and their spectral content may change dramatically as an aircraft approaches and recedes from an observation point. Time histories of overflights as measured at various points on the ground can also depend heavily on geometric relationships between observation points and aircraft altitude, speed, flight path, direction of flight, operating mode, and even meteorological conditions. Considerable sophistication in noise measurement is required to yield noise metrics sensitive to all of this variability.

Complex acoustic measurements during the vacuum tube era, from the 1920s until the 1960s, were expensive and time consuming. As late as the 1960s, "narrow-band" (that is, one-third octave) analyses of analog field recordings of environmental sounds required a laboratory full of expensive instrumentation: tape loops, filter banks, stand-alone analyzers, graphic level recorders, and the like.

As minicomputer- and microprocessor-controlled acoustic instruments became popular and affordable in the 1960s and 1970s, it became increasingly feasible to measure and manipulate complex properties of environmental noise. In the last two decades, it has been economically feasible to automatically collect, analyze, and characterize essentially any property of environmental acoustic signals, on a large scale basis. Affordable and convenient digital instrumentation that can make and store arbitrarily complex acoustic measurements under field conditions is now commercially available.

Although instrumentation technology is no longer an obstacle to environmental acoustic measurement, other obstacles persist. The chief of these remains understanding what is worth measuring. Genuine, systematic, theory-based understanding of which acoustic properties (if any) of transportation noise determine its annoyance and sleep disturbance remains elusive.

8.1 Chronology of development of modern aircraft noise metrics

The earliest systematic attempts to characterize community reaction to aircraft noise antedate both widespread public exposure to jet engine noise, and the concept of "public annoyance". They evolved throughout the 1950s into the CNR (Community Noise Rating) system, which attempted to characterize adverse community reaction to aircraft noise on the basis of its overt (complaint and similar) consequences. Rosenblith *et al.* (1953) interpreted the findings of about 20 case studies of community reaction to aircraft noise in terms of "sporadic" through "widespread" complaints, "threats of community action," and "vigorous community action."

Determination of a CNR value required estimating a "noise level rank" from a set of idealized spectral shapes for community noise. These shapes were derived from laboratory findings about the loudness of sounds in different frequency bands. The noise level rank was modified (normalized to standard conditions) by site-specific factors such as ambient noise levels, time of day and year, tonal content, dynamic range of noise intrusions, and novelty of exposure. CNR-based assessment of community reaction to environmental noise required a detailed case study, and involved more-or-less arbitrary judgments about the detailed nature of noise exposure.

As Beranek (2008) notes, community reaction to the noise produced by B-707s equipped with JT3 engines was prompt and vigorous when commercial jet passenger service began in the U.S. in 1958. Within a year, the Port of New York Authority had sponsored development of a "Perceived Noise Level" frequency weighting (Kryter, 1959; Kryter and Pearsons, 1963), because the customary A-, B-, and C-frequency weighting networks were unable to account for the great differences in annoyance associated with exposure to propeller versus jet aircraft noise.

The distinctions between loudness and annoyance, and of the annoyance of narrowband (tonal) versus broadband noise that were eventually incorporated into PNL and similar aircraft noise measurements, were all inferred from individual annoyance judgments made by test subjects in laboratory studies. The first large-scale social survey of community noise exposure study (McKennell, 1963) was not conducted until 1961. The next two decades were a Golden Age in psychoacoustic research, from which a veritable alphabet soup of aircraft noise metrics emerged (as summarized by Schultz, 1972, and by Bennett and Pearsons, 1981). Most of these metrics were inferred from descriptive curve fits to the data of individual or small numbers of social surveys.

All of the readily-measured acoustic and operational characteristic of distributions of aircraft noise levels were considered for inclusion into noise metrics such as the Articulation Index, Noise Pollution Level, the Noise and Number Index, Isosophic Index, Noisiness Index, Total Noise Load, Equivalent Daytime Disturbance Number, and Noise Disturbance Level. Among the factors combined in various ways by these metrics were numbers of operations, maximum levels, variance of levels, time of day, rates of change of level, signal-to-noise ratios, and so forth.

EPA's 1974 Levels Document identified a family of equivalent energy metrics, normalized to durations ranging from one second (SEL) to a day (DNL), similar to those described in California's (1970) aircraft noise regulations (per Title 4, California Administrative Code, §5000 - §5080). DNL was identified by EPA not as a predictor of community reaction to environmental noise exposure, but rather as a summary measure that facilitated comparisons of exposure associated with a variety of noise sources in different settings.

8.2 Prediction of annoyance prevalence rates from descriptive dosage-response curves

Following Schultz's (1978) precedent, predictions of the prevalence of a consequential degree of annoyance due to transportation noise ("%HA") are routinely based on estimates of

DNL values. Since predictions are based solely upon a composite measure of time-weighted noise exposure - the simple product of level, number and duration - they tacitly assume that all three of these factors contribute equally to annoyance, and that nighttime noise exposure is ten times as potent as daytime noise exposure in creating annoyance. Basing predictions *solely* upon a cumulative, 24 hour measure of noise exposure also effectively denies any contributions of non-acoustic factors to annoyance prevalence rates.

FICON's (1992) report endorses a curve fit ($\%HA = 100/(1+e^{(11.13-0.141Ldn)})$) that Harris (Finegold, Harris, and von Gierke, 1994) developed by logistic regression to a selected sub-set of the data points compiled by Fidell, Barber, and Schultz (1991). The FICON curve is a purely descriptive, "one-size-fits-all" function that is used to predict response to all forms of transportation noise in all communities, without exception. When applied to prediction of the annoyance due to aircraft noise, it accounts for less than a fifth of the variance in the underlying data (Fidell and Silvati, 2004). In contrast, the aircraft-specific predictive function of Miedema and Vos (1998) accounts for more than twice as much of the variance in the association between aircraft noise exposure and the prevalence of annoyance as does FICON's prediction.

Both FICON's 1992 curve and that of Miedema and Vos (1998) are derived by generic statistical curve fitting methods. They are unsupported by any rationale derived from first principles, nor any other theoretical basis, and hence provide no explanation for the great variability of annoyance prevalence rates in communities with similar noise exposure levels.

FICON's predictive method nonetheless remains in routine use in the United States to justify transportation noise-related environmental policies and assessments. The uncertainty associated with FICON's method is so great, however, that when predictions of noise impacts are made for purposes of disclosing environmental noise effects of proposed airport projects, meaningful differences in annoyance prevalence rates often cannot be discerned among existing, no action, and alternative scenarios.

8.3 Method for predicting annoyance under consideration by ISO Working Group 45

It has long been understood that community response to transportation noise has both acoustic and non-acoustic determinants. DNL addresses only the acoustic determinants of annoyance, probably because the understanding and technology underlying acoustic measurement is much more advanced than that for quantifying the non-acoustic determinants of annoyance.[28] The decades-old quest for the Holy Grail of noise measurement (a purely acoustic metric that can accurately, precisely, and universally predict community response to noise exposure), although futile, has been spurred in no small part by the conviction of successive generations of acoustic engineers that advances in acoustic measurement technology will someday lead to success.

[28] The proliferation of noise metrics during the last half-century is traceable in large part to this imbalance of understanding.

ISO Working Group 45 is now considering an alternate approach to predicting the annoyance of transportation noise exposure for a revised international standard. This approach identifies a second, entirely non-acoustic parameter useful for predicting the prevalence of aircraft noise annoyance. The approach is developed from a recent examination of social survey findings from 43 field studies of the annoyance of aircraft noise conducted within the last half century has shown that annoyance prevalence rates within individual communities consistently grow at the same rate as effective (duration-adjusted) loudness, or in proportion to $(10^{DNL/10})^{0.3}$ (Fidell *et al.*, 2011). The annoyance growth functions are offset from one community to the next, however, based on the community's tolerance for aircraft noise. Fidell *et al.* have shown that these community-specific offsets can be expressed in a decibel-like index, a "Community Tolerance Level" (CTL). The CTL value for a community is simply a value of DNL above which half of the community is highly annoyed by aircraft noise exposure (and half if not).

Figure 8-1 shows the fits of half a dozen data sets of social survey findings to the predictive function.[29] Each of the data points represents a paired observation of a DNL value at an interviewing site with the percent of respondents highly annoyed by aircraft noise at the site. On average, the effective loudness function accounts for two-thirds of the variance in the association of observed and predicted annoyance prevalence rates, or about half again as much variance as that accounted for by the better of the purely descriptive dosage-effect relationships.

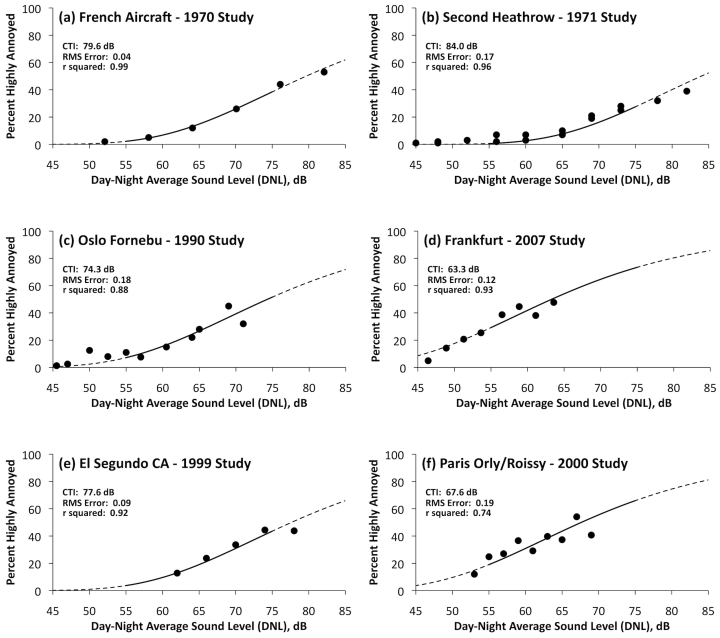

Figure 8-1. Fit of data from the indicated surveys to the effective loudness function.

[29] Note that the relationships displayed in Figure 8-1 are ***not*** descriptive curve fits derived by regression, but rather fits of data sets to an *a priori* prediction. The single predictive parameter of the relationships shown in Figure 8.1 is the value of CTL that yields the minimal root-mean-square error between the fixed predictive function and the social survey findings.

9 APPENDIX B : FEATURES OF CONTEMPORARY CIVIL AIRCRAFT NOISE METRICS

This appendix contains three tables which systematically characterize the attributes of transportation noise metrics developed during distinct technological eras. The first table addresses metrics developed during the 1960s or earlier, some of which remain in common use. Each of these metrics - other than loudness - can be measured with equipment no more sophisticated than an analog sound level meter, or an electromechanical distribution analyzer. The bottom half of the first table, addressing integrated noise metrics, is therefore largely empty. Metrics such as NNI (Noise and Number Index) are little used today. Metrics such as TA (time above a threshold) and NA (number above a threshold), date from a later era, but could have been measured with 1960s technology.

Table 2 addresses metrics developed mostly in the 1980s and 1990s that remain in use today. The table includes a family of temporally-integrated metrics, such as A-weighted sound exposure level (ASEL) and C-weighted equivalent level (CSEL). It also includes are integrated calculations, such as effective perceived noise level (EPNdB) and ratings such as day/night average sound level (DNL). Calculations of the more complex metrics were facilitated by standalone one-third octave band analyzers interfaced to laboratory minicomputers.

Table 3 suggests metrics whose calculations are facilitated by contemporary digital technology. Such metrics have the potential for serving as improvements or supplements to DNL. They include a family of time and frequency-dependent integrated metrics, and alternative ("interrupted" or threshold-sensitive) integration methods such as SENEL. Table 3 also acknowledges the potential for source-specific forms of noise ratings which could be based on categorical judgments about the annoyance of particular noise sources. Such metrics could distinguish the integrated annoyance of (for example) aircraft from that of trucks, cars, motorcycles, and trains. Such metrics could also take into consideration rates of occurrence and rates of responses to noise events, as described by Schomer and Wagner (1995).

Gray areas of the tables indicate items or quantities inapplicable to the time frame or metric class. Light blue coloring delineates metric classes; light purple shading highlights examples or notes; alternating salmon and almond coloring of rows is included simply for clarity; and yellow highlighting signifies a change in the frame of reference.

PAGE 1		1960's era, analog metrics									
Name	Metric Class	Directly Measured		Calculated				Rating	Time-dependent		Counting
	General Characteristics of the Metric	Single level	Spectrum of levels	Frequency	dependent	Amplitude and frequency dependent w/o masking	Amplitude and frequency dependent with masking	"Adjusted" calculation	Centiles	Time above	Number above
	Example	max A (slow)	C--octave bands	AI	SIL	PNL	Loudness ISO 532b	PNL-t	L10-A (1-s *slow*)	TA-C (1-s *slow*)	NA 70 A
Frequency weighting (choose 1)	OASPL			●	●						
	Z					●	●	●			
	C		●							●	
	A	●							●		●
Spectrum (if applicable choose 1)	Octave Bands		●		●						
	1/3 Octave Bands			●		●	● *	●			
	narrow bands										
Time detection (choose 1)	fast			●							●
	slow	●	●		●	●		●	●	●	
	1-s LEQ										
	other LEQ (Duration in s)										
Detection (choose 1)	maximum	●		●		●					●
	rms average		●		●		●	●	●	●	
	peak										
Integration (choose 1)	LEQ										
	LEQ + K*log(n) +f(level,number) [specify K and f]										
Summation (choose 1)	LOG2						●				
	LOG10					●		●			
Rating factors (choose all that apply; specify value)	Tone							●			
	Rattles										
	Impulse										
	Evening										
	Night										
	Weekend										
Expectations (all that apply)	Rural										
	New										
	PR										

Table 9-1. 1960's era analog noise metrics.

	1980s and 1990's era, Integrating-averaging Metrics								
	Metric Class	Directly Measured				Calculated			Rating
		Sound Exposure Level (SEL)		Equivalent Level (LEQ)					
	General Characteristics of the Metric	Single level	Spectrum of levels	Single level	Spectrum of levels	Frequency dependent	Amplitude and frequency dependent w/o masking	Amplitude and frequency dependent with masking	"Adjusted" calculation
	Example	CSEL (1-s LEQ)		1-hr ALEQ (1-s ALEQ)			EPNdB	Time-varying loudness	DENL
Frequency weighting (choose 1)	OASPL						●		
	Z		●		●			●	
	C	●							
	A			●					●
Spectrum (if applicable choose 1)	Octave Bands				●				
	1/3 Octave Bands		●				●		●
	narrow bands							● *	
Time detection (choose 1)	fast								
	slow						●		
	1-s LEQ	●	●				●		●
	other LEQ (Duration in s)			1 ms	10 - s			2 ms	
Detection (choose 1)	maximum								
	rms average		●	●	●		●	●	●
	peak								
Integration (choose 1)	LEQ	●		●	●		●		●
	LEQ + K*log(n) +f(level,number) [specify K and f]								
Summation (choose 1)	LOG2							●	
	LOG10						●		●
Rating factors (choose all that apply; specify value)	Tone								●
	Rattles								●
	Impulse								●
	Evening								5 ●
	Night								10 ●
	Weekend								5 ●
Expectations (all that apply)	Rural								●
	New								●
	PR								●

Table 9-2. 1980's and 1990's era integrating-averaging metrics.

	Integrating-averaging Ratings									
	Metric Class	**Directly Measured**		**Existing, Calculated Ratings**			**Potential, Calculated Ratings****			
	General Characteristics of the Metric	**"Standard" Sound Exposure Level**	**Thresholded Sound Exposure Level**	**DNL**	**DENL**	**NEF**	**Amplitude and frequency dependent w/o masking**	**Amplitude and frequency dependent with masking**	**DNL/DENL (using SENEL)**	**Categorical judgment and "number noticed"**
	Example/note	CSEL (1-s LEQ)	SENEL > 60				LL-SEL	Time-varying loudness	Using SENEL	Rate of response
Frequency weighting (choose 1)	OASPL					●				
	Z						●	●		
	C	●								
	A		●	●	●				●	●
Spectrum (if applicable choose 1)	Octave Bands									
	1/3 Octave Bands			●	●	●	●		●	
	narrow bands							● *		
Time detection (choose 1)	fast									
	slow					●				
	1-s LEQ	●	●	●	●				●	●
	other LEQ (Duration					0.5 s	50-100 ms	2 ms		
Detection (choose 1)	maximum									
	rms average		●	●	●	●	●	●	●	●
	peak									
Integration (choose 1)	LEQ	●		●	●	●	●	●	●	●
	LEQ + K*log(n)		1-s LEQ > 60						1-s LEQ > 60	
Summation (choose 1)	LOG2							●		
	LOG10			●	●	●	●		●	●
Rating factors (choose all that apply; specify value)	Tone			●	●	●	●		●	●
	Rattles			●	●		●		●	●
	Impulse			●	●		●		●	●
	Evening				5 ●					
	Night			10 ●	10 ●	16.67	10 ●		10 ●	10 ●
	Weekend			5 ●	5 ●		5 ●		5 ●	5 ●
Expectations (all that apply)	Rural			●	●		●		●	●
	New			●	●		●		●	●
	PR			●	●		●		●	●
Frame of Ref:	Indoors						●	●		

* Calculations may depart from one-third octaves below about 500 Hz because the critical bands of the ear are wider than a one-third ocatave-band filter .

** Conservatively, 100,000 rating variations

Table 9-3. Integrating averaging metrics.

10 APPENDIX C: EXCERPTS FROM EUROPEAN UNION 2005 "SOUND NOISE METRICS" REPORT

Community-level regulation of noise nuisance at European airports is a contentious issue that has been discussed for over a decade now. Against the backdrop of both 2002 noise Directives this study develops and assesses approaches to setting noise limits at larger EU airports. Harmonization of noise limit schemes within the Community may contribute to smooth functioning of the internal market. In this study, different degrees of harmonization are presented, but the pros and cons of the concept of uniformity in noise limiting schemes, though important issues, are not part of this study.

The key question that has been answered is primarily in what way could noise limits be defined. Questions like at what level such limits should be set and what mitigation measures can be applied to reach these levels have not been answered here.

The aim of setting noise limits at airports is to limit or reduce noise around them.

Limitation of noise can serve the following two goals:

- Limitation of noise impacts on people.
- Spatial limitation of noise impacts.

A noise limiting scheme consists of:

- A noise indicator.
- A method for setting the noise limits (resulting in the levels of the limits).
- A monitoring mechanism.
- Enforcement procedures.

Currently, many different types of noise limitation schemes exist. Many European airports have developed their own system for limiting noise based on different noise indicators, noise limits and monitoring methods.

The scheme we propose is composed of the following elements:

A locally set limit to the absolute number of exposed people within several Lden contour zones, including a supplementary measure indicating the number of annoyed people.

Locally set limits to night time noise, based on two indicators:

- An indicator limiting the number of noisy events to which anyone is exposed during the night (NAx).

- A Person Events Index (PEI) limiting the total noise load per night.

Reporting requirements.

Locally set absolute limits to the number of exposed people within Lden contours

The first element of the proposed scheme is directed at limiting the absolute number of exposed people. It is a uniform noise indicator which adheres closely to current Community legislation. Though the indicator is uniform, thus increasing transparency and comparability, the levels of limits are determined locally.

By localizing the responsibility for setting limits to the number of exposed people, full account can be taken of the local situation. Local authorities are best equipped to do this, and also to balance the limits levels with land use issues. We propose a noise indicator based on exposure instead of one primarily based on noise emission or the adverse effects of noise (annoyance). Noise exposure relates directly to Directive 2002/49/EC and is also in line with environmental legislation in other fields. Noise exposure limits should be based on Lden contours, also advocated in the same Directive. Introducing a separate measure with a similar aim in mind would lead to confusion.

The scheme should limit the total number of exposed people within Lden contours, mainly because this most directly relates to the main problem of aircraft noise and provides a higher flexibility to airports than limiting noise exposure at a number of geographical 'reference' points on the ground. Special account can be taken of dwellings with noise insulation. A pragmatic approach would be to count these dwellings in a contour with a lower noise level. For monitoring, we suggest making primary use of calculated airport noise performance, because airport noise modeling allows a predictive approach and is well advanced, whereas reliable noise measurements are at best very labour intensive. Measurements could be used to validate calculations, to check whether aircraft certificated noise levels are accurate for in-service situations and whether best practice measures are being implemented.

Supplementary measure indicating the number of annoyed people

Using up to five noise level bands makes it hard to assess whether progress is being made. It is not clear how to appraise a reduction in one band and an increase in another. For this reason we strongly recommend using the following supplementary measure: the total number of annoyed people within the 55 dB(A) contour (*i.e.,* the lower boundary of the lowest band for which reporting requirements apply).

Based on established statistical noise-annoyance relationships for aircraft noise, the total number of annoyed people within each band can also be estimated. By summing the results for each band, an estimate of the total number of annoyed people is obtained.

This measure is not meant to provide an additional restriction, but might serve as a basis to determine limit levels for each particular band and to get insight into whether the airport is doing a good job or not with respect to noise limitation over the whole of the affected community.

Locally set limits to night time noise

Although the Lden measure does have a penalty factor for evening and night flights, this does not fully do justice to the specific problem of night noise. Peak noise levels are a better indicator than the LAeq based metrics, such as Lden. To have a good indication of the total noise exposure during the night and also provide certainty of protection to individuals, we propose to add two indicators:

- An NAx indicator to limit the number of noisy events to which any individual
- person is exposed, and

- A Person Event Index (PEI), giving a better indication of total noise exposure during the night than anNAx indicator. The PEI(x) sums the total number of instances where an individual is exposed to an aircraft noise event above a specified SEL value of x dB(A) for the night time period.

Internationally set limit based on the ratio of exposed area and some volume measure

To provide comparability between airports within the Community and to provide for reflection of the smooth functioning of the internal market, a relative indicator linking noise limits and transport volume should be part of the combined scheme. The indicators proposed above do not directly link the level of the noise limit with the transport volume.

We propose an internationally set limit defined by the exposed area per measure of transport volume. The underlying idea is that any two airports of a similar 'size' should produce broadly similar size noise contours, although they of course to some extent depend on runway layout. Noise contour size could be based on the total area within a simple 24 hour Leq contour. There may be exceptions where noise contour area is not so important, for example, an airport with contours stretching over the sea or other uninhabitable areas. It could also be appropriate to subtract the area of the airport itself from the airport's contour size. This may help to prevent the airports which cover larger areas being unfairly penalized. For defining a measure of transport volume some combination of distance and actual payload, such as Maximum Zero Fuel Weight (MZFW)5 seems the best option. Further research is necessary for this part of the combined scheme particularly into the robustness of the relationship between noise contour area and airport size in terms of transport volume. This would also identify any deterioration in the achievement of noise limit objectives with traffic growth.

Reporting requirements

The fourth element of the framework we propose consists of extensive requirements on reporting noise policy by the local authorities responsible for setting limits. Reporting should improve transparency and provide a clear picture of what is expected in the future to all

stakeholders, airlines and surrounding communities alike. This should provide a firm basis for corporate and personal planning, and that can itself help to limit annoyance.

We propose that airports should publish long term noise policy plans and associated forecasts, clearly stating their objectives and the proposed timescale for their achievement.

11 APPENDIX D: GLOSSARY

The following glossary of noise metrics was condensed from the following:

> Handbook of Aircraft Noise Metrics, Ricarda L. Bennett and Karl S. Pearsons,NASA Contractor Report 3406 N81-21871, Bolt Beranek and Newman Inc., prepared for Langley Research Center under Contract NASl-14611, 1981

In this condensed version only the metric definition, purpose and background are provided from the original text. The original document contains more background information and calculation procedure. Also, this condensed version was converted to text from using optical character recognition (OCR) software, so the reader is cautioned to refer to the original document for confirmation of the metric definition.

The metrics presented here are presented in the same order as in the original document as follows:

Frequency Weighted Metrics

1. A-Weighted Sound Level (SLA)
   A-2
2. B-Weighted Sound Level (SLB)
   A-4
3. C-Weighted Sound Level (SLC)
4. D-Weighted Sound Level (SLD)
5. E-Weighted Sound Level (SLE)

Computed Metrics

1. Perceived Noise Level (PNL)
2. Tone Corrected Perceived Noise Level (PNLT)

DURATION CORRECTED SINGLE EVENT METRICS

1. Effective Perceived Noise Level (EPNL)
2. Sound Exposure Level (SEL)
3. Single Event Noise Exposure Level(SENEL)

MULTIPLE EVENT METRICS

1. Statistical Sound Level (Lx)
2. Equivalent Continuous Sound Level(LEQ)
3. Hourly Noise Level (HNL)
4. Time Above Threshold (TA)
   a. Time Above Ambient (TAA)
   b. Time Audible (TAUD)
5. Composite Noise Rating (CNR)
6. Noise Exposure Forecast(NEF)
7. Day-Night Average Sound Level (DNL).

8. Community Noise Equivalent Level(CNEL)
9. Day-Evening-Night Average Sound Level (LDEN)
10. Noise and Number Index (NNI)
11. Weighted Equivalent Continuous Perceived Noise Level(WECPNL)
12. Australian Noise Index (ANEF)
13. Number of Events Above Threshold (NAx)
14. Kostens Units (K)

SPEECH COMMUNICATION METRICS

1. Articulation Index (AI)
2. Speech Interference Level(SIL).

INDEX (Alphabetical listing)

Title	Abbreviation	Symbol	Page
1. A-Weighted Sound Level	SLA	L_A	79
2. Articulation Index	AI	L_{AI}	107
3. B-Weighted Sound Level	SLB	L_B	81
4. C-Weighted Sound Level	SLC	L_C	82
5. Community Noise Equivalent Level	CNEL	L_{den}	102
6. Composite Noise Rating	CNR	L_{CNR}	97
7. D-Weighted Sound Level	SLD	L_D	83
8. Day-Night Average Sound Level	DNL	L_{dn}	100
9. E-Weighted Sound Level	SLE	L_E	84
10. Effective Perceived Noise Level	EPNL	L_{EPN}	88
11. Equivalent Continuous Sound Level	QL	L_{eq}	92
12. Hourly Noise Level	HNL	L_h	94
13. Noise and Number Index	NNI	L_{NNI}	103
14. Noise Exposure Forecast	NEF	L_{NEF}	99
15. Perceived Noise Level	PNL	L_{PN}	85
16. Sound Exposure Level	SEL	L_{AE}	88
17. Single Event Noise Exposure Level	SENEL	L_{AX}	89
18. Speech Interference Level	SIL	L_{SI}	109
19. Statistical Sound Level	L_X	L_X	90
20. Time Above Threshold	TA	TA	95
21. Tone Corrected Perceived Noise Level	PNLT	L_{TPN}	87
22. Weighted Equivalent Continuous Perceived Noise Level	WECPNL	L_{WECPN}	105

Frequency Weighted Metrics

TITLE: **A-WEIGHTED SOUND LEVEL**

ABBREVIATION: SLA

SYMBOL: LA

UNIT: Decibel (dB)[30]

GEOGRAPHICALUSAGE: International

DEFINITION: A-weighted sound level is sound pressure level modified to de-emphasize the low frequency portion of sounds. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound.

PURPOSE: A-weighted sound level is used to approximate the relative "noisiness" or "annoyance" of many commonly occurring steady state or intermittent sounds. It is often employed in measuring outdoor community noise such as aircraft flyovers and vehicular traffic. However, for short impulsive
sounds, or sounds with very intense low frequency characteristics or with discrete tonal components, A-weighted sound level does not do an adequate job of accounting for people's subjective response and other more precise measures should be used.

BACKGROUND: A-weighted sound level was initially intended to be a convenient way to approximate subjectively judged loudness for measured sound levels between 24 and 55 dB. However, in practical usage it was found that A-weighted sound level correlated extremely well with human responses to many different sounds regardless of the levels.

This simple rating is a valid and reliable measure of many types of noise signals and is comparable to many of the more complex noise rating methods.
A-weighted sound level is also used as the basic frequency weighting for other measures such as the statistical measure Lx or for equivalent continuous level, (LEQ). In fact, sound level is understood to mean A-weighted sound level if no frequency weighting is specified.

An electrical network designed to provide the A-weighting has been conveniently incorporated into most sound level meters since approximately the late 1930's. This affords a simple direct method of measuring the A-level of a given noise signal. The resulting weighted spectrum is summed to obtain a single rating number.

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[30] It is often seen in the literature as dBA or dB(A). However, according to ANSI Y10.11-19?9, the correct unit is decibels without a modifier.

A-weighted sound level is widely accepted in both industrial and community noise control programs. It has been incorporated in many ordinances and regulations at both the state and federal level. And, it is often used in the rules and regulations published by several federal agencies including the Department of Labor (DOL), the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the Department of Housing and Urban Development (HUD).

TITLE: **B-WEIGHTED SOUND LEVELS**

ABBREVIATION: SLB

SYMBOL L_B

UNIT Decibel (dB)[31]

GEOGRAPHICAL USAGE: International

DEFINITION: B-weighted sound level is sound pressure level modified to de-emphasize the low frequency portion of sounds. It is one of several such weightings(A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound.

PURPOSE: B-weighted sound level was developed to approximate the relative loudness of medium level sounds. Currently SLB is not usually employed for noise measurement purposes.

BACKGROUND: In an effort to provide a better correlate with the loudness of sounds, three weighting networks were designed into sound level meters to modify sound pressure levels in accordance with equal loudness contours.

The B-weighting shown in Figure SLB-2 was one of the weighting networks used. The B-weighting network has the response characteristics that are approximately the inverse of the 70 phon equal loudness contour for pure tones. The B-weighting was to be used if the readings on the sound level meter were between 55 to 85 dB.

[31] It is often seen in the literature as dBB or dB(B). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

TITLE: C-WEIGHTED SOUND LEVEL

ABBREVIATION: SLC

SYMBOL: L_C

UNIT: Decibel (dB)[32]

GEOGRAPHICAL USAGE: International

DEFINITION: C-weighted sound level is sound pressure level modified to limit the low and high frequency portion of sounds. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound.

PURPOSE: The C-weighted sound level was developed to approximate the relative loudness level of high level sounds. Currently it is primarily used to approximate overall sound pressure level where the frequency range of interest is between 31.5 Hz and 8000 Hz. Frequency weightings are 3 dB or less in that range.

BACKGROUND: In an effort to provide a better correlate with the loudness of sounds, three weighting networks were designed into sound level meters to modify sound pressure levels in accordance with equal loudness contours.

The C-weighting is essentially flat and therefore provides a reasonable approximation for estimating the loudness level of high level sounds. Like the A-weighting and B-weighting, the C-weighting relates to the equal loudness contours. Specifically, it is the inverse of the 100 phon loudness contour. Initially the C-weighting was to be used If readings on the sound level meter were above 85 dB.

The C-weighting scale is fairly uniform in response from 31.5 Hz to 8000 Hz; It must be noted that the weighting factors will yield a slightly different result from measurements done with a linear scale which contains no corrections. However, if the sound level meter does not have a linear scale selection, it would be fairly safe to use the C-weighting as an estimate of the overall sound pressure level.

[32] It is often seen in the literature as dBC or dB(C). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

TITLE: D-WEIGHTED SOUND LEVEL

ABBREVIATION: SLD

SYMBOL: L_D

UNIT: Decibel (dB)[33]

GEOGRAPHICAL USAGE: International

DEFINITION: D-weighted sound level is sound pressure level modified to de-emphasize the low frequency and emphasize the high frequency portion of sounds. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound.

PURPOSE: D-weighted sound level was developed as a simple approximation of perceived noise level. Further, it was intended to be a more precise measure than A-weighted sound level to approximate the relative noisiness or annoyance of many commonly occurring sounds.

BACKGROUND: Because the calculation procedures for perceived noise level (PNL) is fairly complicated, it was thought that a similar more direct measure that would allow an immediate estimate of the effect of an aircraft flyover should be developed. This measure was initially designated as N-level and was to be incorporated into a sound level meter, like the A-, B-and C-weightings. The weighting network for this new measure was the inverse of the 40 noy contour developed by K. Kryter. However, the N-weighting, unlike A, B and C, had no reference at 1000 Hz. Thus the measurements made with the N-weighting had to be calibrated by determining N-level and PNL from several aircraft flyovers and
using the average difference for subsequent N-level measurements. Average N-levels were then, by definition, equal to PNL values.

To eliminate the uncertainty in the N-level, it was suggested that the inverse noy curve weighting be equal to 0 at 1000 Hz (similar to A, B and C), and the Technical Committee No. 29 (Electroacoustics) of the International Electrotechnlcal Commission (IEC/TC29) further suggested that the letter "D" be adopted to replace the "N". This recommendation has been implemented.

[33] It is often seen in the literature as dBD or dB(D). However, according to ANSI Yi0.i1-1979, the correct unit is decibels without a modifier.

TITLE: E-WEIGHTED SOUND LEVEL

ABBREVIATION: SLE

SYMBOL: LE

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: Limited

DEFINITION: E-weighted sound level is sound pressure level modified to de-emphasize the low frequency and emphasize the high frequency portion of a sound. This measure has been proposed as another attempt to approximate the human ear's response to sound in a manner very similar to D-weighted sound level.

PURPOSE: E-weighted sound level, in its proposed form, was designed to provide a close estimate to Stevens' (Ref. I) perceived level. It was designed to measure the noisiness or loudness of sounds such as aircraft flyovers.

BACKGROUND: The concept of E-weighted sound level was proposed by Stevens In his work on perceived level in 1972. He had found that sound measured with this "ear-weighted" frequency response was closely related (± 2 dB) to the perceived level calculated according to Stevens' Mark VII procedure. E-weighting reflects the basic 20 sone contour used In Mark VII with a standard reference band at 1000 Hz. The accuracy of the E-weighting to predict perceived level is particularly good for sounds of medium level. E-weighting is as yet a draft standard only recently published by the American National Standard Institute in August of 1978 for comments and criticism. No proposal was made in this draft to incorporate E-weighting as an addition to the American Standard sound level meter. It was merely specified as a frequency weighting which could be used with any general sound measurement system which has a flat frequency response over the frequency range of interest to the experimenter.

TITLE: PERCEIVED NOISE LEVEL

ABBREVIATION: PNL

SYMBOL: L_{PN}

UNIT: Decibel(dB)[34]

GEOGRAPHICAL USAGE: International

DEFINITION: Perceived noise level (PNL) is a rating of the noisiness of a sound calculated from acoustic measurements. It is computed from sound pressure levels measured in octave or one-third octave frequency bands. The PNL of a given sound is intended to be numerically equal to the level of an octave band of noise centered at 1000 Hz which is judged equally noisy to the given sound.

PURPOSE: PNL was developed as a method for ranking the noisiness of sounds of widely differing spectral character. It is used mainly for ranking the relative annoyance or disturbance caused by aircraft flyover noise.

BACKGROUND: Karl Kryter introduced the perceived noise level method when it was found that loudness level calculated by Stevens' method underestimated the Judged noisiness of Jet aircraft relative to that of reciprocating engine aircraft. The determination of PNL is patterned after Stevens' loudness level, except that equal noisiness curves were employed instead of equal loudness curves. Two sounds of equal noisiness mean that people would be willing to accept one sound as much as the other "occurring periodically 20-30 times during the day and night at their home". The equal noisiness curves shown in Figure PNL-2 were developed by determining the levels of equal noisiness of various bands of noise at different frequencies.

The unit noy is used for the scale of perceived noisiness. The numerical value of 1 noy was assigned to the perceived noisiness of an octave band of random noise centered at 1000 Hz and corresponding to a sound pressure level of 40 dB. Similarly, 2 noys corresponded to a sound pressure level of an octave band of random noise at 50 dB.

Thus, above the 1 noy value, an increase of l0 dB is equivalent to a doubling of the perceived noisiness as measured in noys, similar to the growth of loudness suggested by Stevens. Values less than 1 noy do not grow in the same manner, but again follow the same pattern as suggested by Stevens for the loudness measure.

Validation tests for the perceived noise level using a variety of sounds indicated that the calculation procedure did not account for the effects of pure tones such as those often present in

[34] The unit for the scale of perceived noisiness is the noy, while the unit for perceived noise level is the decibel. It is seen in the literature as PNdB.

turbofan aircraft flyovers, nor did it take into consideration the effect of the duration of a sound, since it was mainly used to rank the judged noisiness for sounds of equal duration. For these reasons, further research was conducted which eventually provided tone corrected perceived noise level (PNLT) and effective perceived noise level (EPNL), which attempt to include the effects of pure tone and duration as indicated elsewhere in this Handbook.

The method uses octave or one-third octave band noise levels. However, for certain types of sounds that vary with time, the manner in which the octave or one-third octave band levels are determined is important. Originally, the band levels were determined as the maximum levels in each band under measurement regardless of the time In which they occurred. When calculated in this manner, the result is called composite PNL(PNLC). With the advent of computer calculations for perceived noise level, band levels are determined for each point in time and perceived noise levels calculated from these measurements. In both cases, maximum perceived noise levels are determined, but differences of as much as 2 dB are observed for the different techniques.

TITLE: TONE CORRECTED PERCEIVED NOISE LEVEL

ABBREVIATION: PNLT

SYMBOL: L_{TPN}

UNIT: Decibel (dB)*[35]

GEOGRAPHICAL USAGE: International

DEFINITION: Tone corrected perceived noise level is perceived noise level with the addition of a tone correction factor. This tone correction factor is intended to account for the added annoyance due to spectrum irregularity or discrete frequency components, such as tones.

PURPOSE: Tone corrected perceived noise level was developed to improve the noisiness assessment for those sounds with prominent discrete frequencies. Like perceived noise level, it is used in assessing the subjective response to single event aircraft fly-overs which commonly contain pure tones, such as in turbo-fan Jet aircraft. However, when aircraft noise is being evaluated, EPNL is more commonly employed because it takes duration as well as discrete frequency effects into accouter.

BACKGROUND: With the advent of turbo-fan Jet aircraft, it became evident that perceived noise level could not evaluate the effects of the pure tone "whine" that is sometimes present in the sound from these Jets. Therefore after developing the perceived noise level procedure, Kryter and Pearsons worked on a method which would compensate for these pure tones often heard in a Jet aircraft flyover. Several researchers developed various schemes for compensating for the additional noisiness of these discrete frequency components. After reviewing the various correction techniques, a tone-correction procedure was finally adopted by the Federal Aviation Administration and incorporated into the FAR Part 36 in 1969.

[35] The unit for the scale of perceived noisiness is the noy, while the unit for perceived noise level is the decibel. It is seen in the literature as PNdB.

TITLE: EFFECTIVE PERCEIVED NOISE LEVEL

ABBREVIATION: EPNL

SYMBOL: L_{EPN}

UNIT: Decibel (dB)[36]

GEOGRAPHICAL USAGE: International

DEFINITION: Effective perceived noise level is perceived noise level (PNL) of a single event adjusted for the added annoyance due to duration and for the presence of discrete frequencies (tones).

PURPOSE: Effective perceived noise level assesses the noisiness of a single noise event. Since EPNL takes into consideration both the tone and duration components of a noise, it is a convenient rating for measuring sub-sonic aircraft flyovers.The FAA has designated this rating scheme as the basis for its aircraft noise certification procedure.

BACKGROUND: Effective perceived noise level evolved in response to the new technological designs of Jet engines. Several individuals and sponsoring organizations worked independently and together on the development of this single number rating method which uses objective acoustic measurements to estimate the effective "noisiness" response to a single aircraft flyover. Finally, through Joint negotiations with FAA, ISO, and SAE, an ad hoc working committee (SAE A21) generated the procedure which computes effective perceived noise level.

The rationale for the development of this measure is based upon the results from several subjective judgment tests which indicated that as the duration of a sound or aircraft flyover increased, it was judged noisier. Further, the sounds with identifiable discrete tones were judged noisier than sounds without audible tonal components. Thus, it was evident that adjustment factors should be added to the perceived noise level rating to compensate for the perceived noisiness attributable to the signal time history and the presence of audible discrete frequency components.

Effective perceived noise level is calculated over the time history of a flyover at a time sequence (usually 0.5 sec. intervals) of tone-adjusted perceived noise levels which are calculated from one-third octave band noise spectra. The tone adjustments are determined from one-third octave band spectra by a procedure described under PNLT. The integration procedure results in adding 3 dB for each doubling of signal duration.

[36] The unit of effective perceived noise level is the decibel; it is commonly seen in literature as EPNdB.

TITLE: SOUND LEVEL EXPOSURE

ABBREVIATION: SEL

SYMBOL: LAE[37]

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Sound exposure level is energy averaged A-weighted sound level over a specified period of time or single event, with a reference duration of 1 second.

BACKGROUND: Sound exposure level was developed to provide a means of measuring both the duration and the sound level associated with a particular time period or event measured at a specific site. SEL was designed to include duration because it was found from the results of subjective noise studies that longer duration noises were judged more annoying than shorter duration noises. Thus, the SEL included the entire range of A-weighted sound levels over the period or event of interest. However, for practical purposes, when attempting to characterize an event such as an aircraft flyover by SEL, it is only necessary to measure the sound levels which are within l0 or 20 dB of the maximum A-level.

Relation to Single Event Noise Exposure Level (SENEL) (California)

SENEL is a special sub-set of SEL and was developed to be used exclusively in the California state airport regulations to limit excessively noisy aircraft operations. SENEL is calculated exactly like SEL but is based upon only the measured A-weighted sound levels above a threshold level. This threshold level is determined by some type of legislative or administrative action. A Federal court decision held that the Federal law pre-empted the State's power to regulate noisy aircraft operations with SENEL. The same decision noted that the airport proprietor's power to set noise limits was not affected. Conceivably, the individual proprietor, whether city or private, could still use a SENEL criteria to govern aircraft flyover noise.

[37] Sound exposure level is sometimes referred to as noise exposure (NEL).

TITLE: STATISTICAL SOUND LEVEL

SYMBOL: L_X

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: The statistical sound level is a descriptor of a noise environment measured In some time period. It is that noise level which is exceeded x percent of the time.

PURPOSE: Statistical sound level (often referred to as centile level) provides a means of assessing the fluctuating noise levels at a point of interest. For example, it is commonly used to characterize the noise at a community location that is exposed to vehicular traffic.

BACKGROUND: The sound levels in most communities fluctuate depending upon, among other things, the noise source, the time of day, or the season of the year. The noise level within an hour, for example, could fluctuate from very quiet to extremely loud. Therefore, a good way to describe the levels that are present during the day at a site, or the noise exposure of that site, is to use a statistical measure which takes the time varying characteristics of the sound into account. The measure, statistical sound level, or centile level, does just that by considering the proportion of time certain noise levels are exceeded.

The relationship between time and levels exceeded is represented as a cumulative distribution of sound levels as seen in Figure Lx-1. The curve in this figure shows what percent of the observation period each level is exceeded. The time period can be any length, but typically it is for 1 hour or more. Further, the sound levels can be measured using various weighting factors, but usually A-weighted sound level is used.

Common practice has dictated that L10, L50, and L90 are most often used as statistical descriptors of the noise environment to designate levels exceeded l0 percent, 50 percent and 90 percent of the time. However, it should be noted that any other centile levels can be used such as L1 (1 percent) to L99 (99 percent). The sound pressure level exceeded 10 percent of the time, expressed as L10, gives an approximate measure of high level and short duration noises. A measure of the median sound level is L50 and represents the level exceeded 50 percent of the time. The background ambient level is estimated by L90 which is the sound level exceeded 90 percent of the time. The choice of L90 to represent the ambient noise and L10 as the dividing line for the peak levels is somewhat arbitrary. Other countries, such as Australia, have chosen instead to designate L95 and L5 as background and peak levels.

The difference between L10 – L9O indicates range within which the noise levels spend 80 percent of the time. The standard deviation of the noise levels over the defined time period is a common measure of the statistical fluctuation.

Statistical sound level measures serve as the basis for other measures which were developed to examine how the fluctuating noise relates to subjective annoyance. The traffic noise index (TNI)

and noise pollution level (NPL) are both ratings which require a knowledge of statistical parameters such as the 90, 50, and l0 percent levels of cumulative distribution.

Highway traffic noise most often lends itself to a statistical distribution type measure. Early criteria used for highway noise are expressed in terms of L_{10} values. In high density traffic situations the statistical distribution of sound levels can be represented by a Gaussian distribution. The L_{10} value can be estimated by the median (L50) and the standard deviation of the noise levels (s), and is given by:

TITLE: EQUIVALENT CONTINUOUS SOUND LEVEL

ABBREVIATION: QL[38]

SYMBOL: LA_{eq}

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Equivalent continuous sound level is the level of the A-weighted sound energy averaged over a specified period of time.

PURPOSE: Equivalent continuous sound level was developed to provide a measure of time varying or fluctuating noise. It has proven to be an effective tool for assessing people's reactions to aircraft and vehicular traffic noise. It also correlates well with the degree of annoyance, hearing loss, speech and sleep interference that is generated by different levels of noise exposure.

BACKGROUND: Equivalent continuous sound level is one of the ratings which addresses the problem of measuring a time varying noise. It is a single number descriptor that quantifies the combination of noise magnitude, duration, and frequency response of the ear. This is achieved by averaging (that is, converting decibel levels to relative sound power, averaging, and then changing back into resultant levels in decibels) A-weighted sound level over stated period of time. This has also been called 'energy averaging' the sound levels.

This concept of energy averaging or integrating over time is the basis of equivalent continuous sound level. This is defined as the A-weighted sound level of a constant or steady state sound which contains the acoustical energy equivalent to the actual fluctuating noise existing at the location over the observation period.

Equivalent continuous sound level may be calculated for any desired time period such as 24 hours, 8 hours, 1 hour, daytime, or nighttime. It is often seen In the literature as $L_{eq}(24)$, $L_{eq}(8)$, $L_{eq}(1\ )$, L_d and L_n, respectively. It is essential to always indicate the time period over which equivalent sound level

Equivalent continuous sound level is familiar to scientists in the United States and in Europe. In 1957, it was used in the original U.S. Air Force Planning Guide for noise from aircraft operations. It was also referred to in the 1955 report on criteria for short term exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation on "Hazardous Noise Exposure".

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[38] Equivalent continuous sound level is also referred to as average sound level. ANSI, in proposed terminology, will symbolize average sound level or equivalent continuous sound level at L_T, where T is the time period over which the average is taken; previously it was symbolized as $L_{eq}(T)$.

In 1965 it was used in Germany as a rating to evaluate the impact of aircraft noise upon the communities near airports. Other countries such as Austria, East and West Germany, and Sweden have recognized its applicability for assessing the subjective effects of time varying noises of all kinds, including street traffic, railroad traffic, canal and river ship traffic, aircraft, industrial operations, playground, etc.

Equivalent continuous sound level is the primary metric for several more complex noise ratings. Notably it is used in community noise equivalent level (CNEL) in the form of hourly noise level which is L_{eq}. Likewise, QL is the fundamental metric for day-night average sound level (DNL). DNL, like CNEL, has a weighting adjustment for sound levels occurring during different hours of the day.

TITLE: HOURLY NOISE LEVEL

ABBREVIATION: HNL

SYMBOL: L_h

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: State of California

DEFINITION: Hourly noise level is the level of the mean-square A-weighted sound pressure over an hour period.

PURPOSE: Hourly noise level is used to characterize the time varying noise environment on an hourly basis.

BACKGROUND: Hourly noise level is identical to equivalent continuous sound level (QL) for an hourly period. HNL can be calculated for 1 hour or more and identified by 1HNL (L_{lh}) or 2HNL (L_{2h}). If HNL is computed for different time periods within a day, they are referred to in literature as HNLD (L_{hd}), HNLE (L_{he}) and HNLN (L_{hn}) (Ref. 1). Hourly noise level is the basis for one of the computational formulas for California's community noise equivalent level (CNEL).

TITLE: TIME ABOVE THRESHOLD

ABBREVIATION: TA

SYMBOL: TA

UNIT: Minutes

GEOGRAPHICAL USAGE: United States

DEFINITION: Time above threshold is the time of noise exposure above some pre-selected threshold of A-weighted sound level. For comparison purposes both the threshold level and the observational period must be stated.

PURPOSE: The time above threshold method was designed as a means of describing the noise exposure at locations of interest using units of measure (minutes) that could be comprehended by non-acoustics as well as acoustic experts.

BACKGROUND: The time above threshold method was initially incorporated into an approach called Aircraft Sound Description System (ASDS) developed by the Federal Aviation Administration (FAA) as part of an effort to provide an objective approach for describing aircraft sound levels at geographical locations around an airport. The ASDS concept used two means to carry out this approach: l) the time above a specified threshold (TA), and 2) the situation index (SI). The time above threshold rating accounted for both the A-weighted sound levels of the aircraft events and the time that the sound levels were in excess of a specified 85 dB threshold value.The second aspect of the ASDS method, the situation index, provided a description of the noise exposure in terms of the amount of geographical area that was affected by the noise, and was expressed in units of acres-per-minute.

The ASDS method as a whole was not widely accepted. That part of the method dealing with the situation index concept was eliminated but the time above threshold rating was retained and incorporated by the FAA into the Integrated Noise Model (INM) computer program. This program is used in airport planning whenever it is necessary to consider the environmental impact. The threshold levels for time above in the INM program are specified from 65 to 115 dB in 10 dB increments. The standard observational time periods are 24 hours, evening (1900-2200) and night (2200-0700).

Time above threshold method provides information on the direct effects of noise generating activities such as aircraft flyovers. It enables one to obtain useful information on the total duration of a potentially interfering sound in order to analyze the effects on speech, sleep, or television viewing or determine the number of times during the day in which the interference occurs and the duration of each interference. The information on duration and intensity of sound that become fused into a single number cumulative rating (e.g., noise exposure forecast) can be differentiated by the time above threshold method.

The TA describes the noise exposure experienced at a specified geographical location; however, it is not correlated with estimates of community reaction for noise events above a certain threshold. Instead, the FAA emphasized the objective basis of TA and has not sponsored any research to qualify or interpret these numerical values in order to predict people's subjective annoyance reactions.

TITLE: COMPOSITE NOISE RATING FOR AIRCRAFT

ABBREVIATION: CNR

SYMBOL: L_{CNR}

UNIT: DECIBEL (dB)

GEOGRAPHICAL USAGE: UNITED STATES

DEFINITION: Composite noise rating is a calculated rating based upon perceived noise level of all events occurring within a 24-hour period. Adjustments are made for time of day, type of aircraft, and numbers of aircraft operations occurring over an annual period. Two composite noise ratings are calculated: one for flight and one for run-up aircraft operations.

PURPOSE: Composite noise rating is a method used for rating the noise exposure from aircraft operations and for estimating community reactions. This measure takes into consideration noise associated with both ground run-up and airborne operations in an attempt to predict community response.

BACKGROUND: Tracing the development of CNR over the years provides an insight into the evolution of a single measure which could be used to estimate human reactions to specific noise sources. CNR was the forerunner to other community noise prediction measures, but today is no longer used and has essentially been replaced by day-night average sound level (DNL).

The 1952 CNR and the later 1955 version was designed to predict community reaction to any noise source not exclusively aircraft noise. This
CNR method contained a series of rating curves plotted approximately 5 dB apart and labeled with letters (a through m) as a means of identifying the level rank of the measured noise source in question. After the level rank of a noise was determined from these curves, it was adjusted for the effects of community background level, time of day and how often the noise occurred, the presence of pure tone components, impulse noise characteristics, the previous noise exposure history of the community, and the season of the year. Each of these adjustments had an associated 'correction number' which raised or lowered the level rank of the measured noise.

The 1957 CNR procedure focused on predicting the effects of aircraft ground run-ups and flight operations on the adjacent community without the necessity of field measurements. In this modification of CNR, Stevens and Pietrasanta attempted to describe the physical nature of the noise source itself. They found that in most instances the equivalent level for the 300 to 600 Hz frequency band of an aircraft flyover controlled the level rank referred to in the earlier CNR version.

The correction factor for tone and impulse characteristics of the aircraft noise source was eliminated from the 1957 version of CNR because they were not present or rarely occurred in these particular types of military aircraft. However, an effective duration correction for the time-varying attributes of an aircraft flyover was added. The time of day (modified into three periods:

0600-1800; 1800-2300; 2300-0600), seasons of the year, and background corrections consistent with the previous CNR method were retained. Certain sociological correction factors were carried over from the 1952 CNR and refined, such as characterization of the neighborhood (i.e., suburban, urban, or rural) and emphasis on the community's previous noise exposure and current predisposition towards the airbase.

Stevens and Pietransanta also developed a technique which would allow the prediction of a noise rating and corresponding community reaction given the information on the operational characteristics of the aircraft. They, along with Galloway, developed two sets of basic L_{eq}(300-600 Hz) contours, one for ground run-ups and the other for airborne operations. A table was also developed which would allow for modification of these contours depending upon the specific aircraft under consideration. The contours could then be combined and overlaid on a map of the air base to determine the L_{eq} (300-600 Hz) at any point on the base.

A subcommittee of the Committee on Hearing and Bioacoustics of the National Academy of Science/National Research Council recommended that CNR be rewritten to incorporate a new psychoacoustic measure called perceived noise level (PNL). And, in 1963, Galloway and Pietrasanta produced "Land Use Planning with Respect to Aircraft Noise". This time the contours were based upon maximum PNL instead of L_{eq} (300-600 Hz). And the noise contours were produced for both takeoff and approach conditions as well as ground run-ups for different aircraft classified on the basis of aircraft type, engine type, and performance.

The 1963-1964 CNR, like the previous versions, contained adjustments which took into consideration the factors that affected community reaction to the total airport operations. The total duration of noise over a specific period of time was accounted for by considering the number of aircraft operation of each class of aircraft on each runway. The time of day correction factor was modified to require only two time periods (0700-2200 and 2200-0700) instead of the previous three time periods (Tables CNR-1 and CNR-2). And in contrast to the 1957 CNR calculation procedure, the 1963 CNR eliminated the seasonal corrections, and contained no adjustment for background noise levels nor community attitude towards the aircraft flyover operations. It was decided that such attitudinal assessments were difficult to quantify and at best would merely cloud the results.

Remember that the CNR values for airborne and run-up operations are treated separately. However before they can be computed, the 'partial' CNRs must be determined for each type and class of aircraft and for runway utilization with appropriate time of day adjustments. The 'partial' CNRs are then combined to yield a final CNR value for flight and a CNR for run-up operations. These final CNR results are then correlated with descriptions of expected community reaction.

TITLE: NOISE EXPOSURE FORECAST

ABBREVIATION: NEF

SYMBOL: LNEF

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Noise exposure forecast is a rating based upon effective perceived noise level measurements taken over a 24 hour period. Adjustments are made for time of day and for the daily number of aircraft operations averaged over an annual period.

PURPOSE: Noise exposure forecast is used to estimate community reaction to the noise resulting from aircraft operations. The NEF levels at various locations in a community adjacent to an airport act as guidelines for establishing compatible land use development and zoning regulations.

BACKGROUND: Noise exposure forecast was developed as an improvement on the 1963-1964 composite noise rating (CNR) measure but was to apply to civilian and not military aircraft. However, like CNR it is no longer currently used by airport or community planners in the United States and has been replaced by day-night average sound level (DNL).

A brief comparison of CNR and NEF is useful to gain an historical perspective over these types of single number community noise measures. Both measures account for the number of aircraft operations. However, NEF uses effective perceived noise level as its basic metric which allows a better assessment of the tone and duration components associated with turbofan aircraft flyovers. The EPNL computations are more involved than the method found in CNR. Therefore, computer techniques are required to analyze the discrete tone and duration parameters at each time interval in a flyover time pattern.

NEF also incorporates a time of day adjustment, dividing the hours into two periods (0700-2200 and 2200-0700), the same as CNR. It is interesting to note that this correction factor in NEF adds 12.2 dB to the measured levels of the nighttime events. That is because the multiplier of the number of nighttime events is 16.67. Compare this report to the correction factor of only i0 dB used in community noise equivalent level (CNEL) and day-night average sound level (DNL) for the same purpose, namely, to estimate the increased annoyance associated with nighttime aircraft operations.

As was done with CNR, NEF results are correlated with community reactions to noise from aircraft operations. Guided by the responses associated with CNR values, in particular, the boundaries between categories of CNR 100 and 115, a new set of response categories was developed for the NEF values.

TITLE: DAY-NIGHT AVERAGE SOUND LEVEL

ABBREVIATION: DNL

SYMBOL: Ldn

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Day-night average sound level is energy averaged A-weighted sound level over a 24-hour period with a l0 dB adjustment added to the sound levels between 2200 and 0700. This time weighting is applied in an effort to account for the assumed increased sensitivity to noise intrusions during the nighttime hours.

PURPOSE: Day-night average sound level is a single number descriptor that is used to predict community reaction to noise exposure from aircraft and road traffic. This measure is used for evaluating the total community noise environment. It provides guidelines for assessing compatible land uses and zoning recommendations.

BACKGROUND: Day-night average sound level assesses the physical sound environment by taking into account both the sound levels and the number of noise producing events. The physical characteristics of sound such as the level, frequency components, and duration are measured with A-weighted sound level averaged on an energy basis over a stated period of time. This is referred to as equivalent continuous sound level (abbreviated as QL and symbolized as L_{eq}) and is defined as the constant level of sound during a specified time period that is equivalent to the same amount of sound energy as the actual time-varying sound signal. These two sounds of 'equal energy' both have the same average or equivalent sound levels.

Day-night average sound level is based upon equivalent continuous sound level and enhanced by an adjustment factor for nighttime noise disturbances. Results from community complaint surveys have indicated that the same noise environment may be considered by people as more annoying during the night time than during the day time. It is reasonable to assume that high level noises are more detectable inside the home, and consequently more annoying at night, due to a combination of lower exterior background noise levels, decreased activity inside the home, and raised expectations for rest and relaxation. In order to account for this presumed annoyance generated by intrusive noises, an adjustment factor of 10 decibels is applied (between 10 p.m. and 7 a.m.) to all nighttime noise levels. Essentially, this 10 decibel penalty characterizes the nighttime noise events as being noisier than actually measured. Day-night average sound level is calculated for 24 hours, but it can be computed for a longer time period such as a week or a year. It is recommended that the day-night average sound level be averaged over a yearly period in order to estimate the long term environmental impact. In such a case it is abbreviated as YDNL and symbolized as L_{dny}.

DNL is widely accepted as an effective environmental descriptor by many agencies at both the federal and state government level. It is recommended by the Environmental Protection Agency

as the primary measure for community noise exposure. The National Research Council Committee on Hearing, Bioacoustlcs and Biomechanics (CHABA) also favors DNL as one of the fundamental measures for assessing a noise environment potentially requiring an Environmental Impact Statement. The Department of Defense uses DNL in describing the noise exposure in the vicinity of military air bases; and it is one of the noise measures used by the Federal Aviation Administration (FAA) in describing the noise environment around airports. The Department of Housing and Urban Development (HUD) revised its noise policy regulations and recommended that DNL be used as the criterion measure to protect people in the community from excessive noise.

TITLE: COMMUNITY NOISE EQUIVALENT LEVEL

ABBREVIATION: CNEL

SYMBOL: L_{den}

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: State of California

DEFINITION: Community noise equivalent level is a 24-hour noise rating which is based upon A-weighted sound level. Two separate adjustment factors are added to the sound levels measured during the evening and the nighttime periods in an attempt to account for the assumed increased annoyance caused by noise during these hours.

PURPOSE: Community noise equivalent level is used to estimate community reaction to noise exposure resulting from aircraft operations. CNEL ratings for various locations in a community adjacent to an airport provide guidelines for making recommendations or to determine compatible land use development, and zoning regulations.

BACKGROUND: Community noise equivalent level like DNL seems to be an appropriate measure for land use compatibility planning because it takes into consideration the magnitude and the durations of the noise events as well as the frequency of occurrence. Like DNL it weights some time periods in the 24 hour day differently than others in an attempt to estimate peoples' annoyance to noise during the nighttime hours. A 5 decibel adjustment is added to the sound levels measured between the hours of 7 p.m. to 10 p.m. and a 10 decibel adjustment is added to the levels measured between 10 p.m. and 7 a.m.

CNEL can be calculated on a daily, weekly, or yearly basis. It is most often employed as an annual rating for purposes of assessing the impact of aircraft noise exposure. Given the necessary information, such as sound levels and number of events, CNEL contours can be drawn to establish a geographical reference for community noise exposure levels.

CNEL was introduced as one of the regulatory measures incorporated into the California Noise Standards. The regulation imposes a CNEL of 65 dB on noise from new airports and for military airports being converted to civilian use. The 65 CNEL limitation for existing civilian airports took effect on January 1, 1986.

An effort was made to related measured values of CNEL to observed community reactions by adding correction factors to measured CNEL to obtain what one report referred to as 'normalized' CNEL. This normalization procedure with some modifications is similar to the Rosenblith and Stevens method developed for Composite Noise Rating. However, normalized CNEL is rarely used to assess community reactions to certain levels and we recommend that only measured CNEL be used.

TITLE: NOISE AND NUMBER INDEX

ABBREVIATION: NNI

SYMBOL: L_{NNI}

UNIT: Decibel (dB)[39]

GEOGRAPHICAL USAGE: United Kingdom

DEFINITION: Noise and number index is based upon the average maximum perceived noise level for aircraft over-flights occurring within a time period.

PURPOSE: The noise and number index was developed as the appropriate measure to be used in Great Britain for assessing the effects of aircraft noise exposure on community reactions.

BACKGROUND: The Noise and Number Index was one of the outcomes of an extensive study concerning aircraft noise conducted in the vicinity of London's Heathrow Airport. This study combined physical measurements made of the noise exposure
at 85 locations within 10 miles of Heathrow with results from interviews of 2000 people living in this same area. The noise level measurements were reported in terms of a statistical distribution of level and time. The social survey questionnaire focused on peoples' reaction to their immediate living environment taking into consideration the influence of the airport as well as other sociological variables.

NNI was an attempt to describe the total noise exposure at a site, and it used as its basic metric peak perceived noise level. Consequently, there is neither an allowance for the duration of the individual aircraft events nor for pure tones which conceivably could be present in jet aircraft flyovers.

According to Schultz the concept of background noise is implicitly included in NNI by the stipulation that the adjustment for the number of aircraft events be the "number of aircraft flyovers heard" during the specified time period. However, typically only those aircraft with $L_{PN} > 80$ which occur within a time period are considered.

In determining the effect of the number of flyovers, it was estimated that doubling the number of events was equivalent to increasing the noise level by 4.5 dB. Therefore, the factor of 15 was used in the term $15 \log_{10} N$ to adjust for the number of events. The constant 80 is subtracted because it was concluded in the original survey that there was zero annoyance response when the aircraft noise levels were less than 80 dB (PNdB). In fact, in the Heathrow study the lowest aircraft level considered was 84 dB (PNdB).

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[39] It has been suggested that the unit should be PNdB because the primary metric in NNI is perceived noise level. However, like PNL, it was decided that the unit would be the decibel.

The analyses of the social survey resulted in the identification of 58 socio-psychological variables which in turn were used to develop a scale representing
a continuous measure of annoyance. The noise measurements initially defined 14 parameters which were later reduced to two factors: average peak (maximum) noise level and number of aircraft heard in the day or nighttime periods. In a final step, the annoyance scale and the two physical correlates were combined in an attempt to predict the effect of aircraft noise and frequency operations on people's annoyance reactions.

Additional results from the social survey were further analyzed and correlated with the noise and number index to determine people's reactions to aircraft noise in comparison with their reactions to other sources of dissatisfaction in their living environment. These results were analyzed in an attempt to estimate the point at which the noise exposure became unreasonable.

TITLE: WEIGHTED EQUIVALENT CONTINUOUS PERCEIVED NOISE LEVEL

ABBREVIATION: WECPNL

SYMBOL: L_{WECPN}

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Weighted equivalent continuous perceived noise level is a cumulative rating scheme which is based upon effective perceived noise level (EPNL). The adjustments incorporated into this measure account for some of the variables associated with aircraft noise such as discrete tonal frequencies, as well as time of day and season of the year.

PURPOSE: Weighted equivalent continuous perceived noise level was developed to assess the total noise exposure from aircraft noise. It is not often used in the United States and is not as widely accepted as the noise exposure forecast (NEF) measure. The principal use is in ICAO analyses.

BACKGROUND: In a 1969 winter meeting of the International Civil Aviation Organization (ICAO), several seminars were held concerning aircraft noise. One of the agreements reached at this meeting was the adoption of ICAO reference units for total noise exposure from aircraft noise. This measure was designed to take into consideration the number of aircraft events, the occurrence of the events during the day or night periods, and the effect of the time of the year.

Like the noise exposure forecast rating (NEF), weighted continuous equivalent perceived noise level (WECPNL) was based upon the effective perceived noise level (EPNL) of each flyover. The EPNL value for each event was summed together on an energy basis and then normalized to l0 sec. to achieve a 'total noise exposure level' (TNEL). The various TNELs could then be converted to 'equivalent continuous perceived noise level' (ECPNL) for different noise exposure time periods. This conversion was necessary to achieve the 'weighted equivalent continuous perceived noise level' which used ECPNL for different periods in a 24-hour day.

The aircraft levels measured in the evening or night hours were 'corrected' or penalized in the sense that 5 or l0 dB was added to the ECPNL. The rational for this adjustment was that aircraft flyovers heard at night are judged more annoying than the same flyovers heard during the day. If WECPNL was calculated on the basis of a two period 24 hour day, there was a 10 dB adjustment for the levels during the night period (2200 to 0700). WECPNL could also be calculated for a three period day. In this case there was a 5 dB correction for the evening hours (1900 to 2200) and a l0 dB correction for the nighttime hours (2200 to 0700).

WECPNL also included what was termed a seasonal correction. This was an adjustment for the noise reduction achieved inside the home assuming the windows were closed during the winter, as opposed to open. (Hopefully this window condition corresponds to the correct season of the

year.) Thus, if WECPNL was computed for the months during the summer, there would be a 5 dB added adjustment.

TITLE: ARTICULATION INDEX

ABBREVIATION: AI

UNIT: None

GEOGRAPHICAL USAGE: United States

DEFINITION: Articulation index is a calculated measure which weights the difference between the speech signal and the background masking noise in an effort to estimate the proportion of normal speech signal that is available to a listener for communication purposes. The results for AI range from 0 to 1.O where 1.0 is equated with lO0-percent speech intelligibility.

PURPOSE: Articulation index can be used to estimate how much the background noise found in an environment or communication system will interfere with speech communication as measured by speech intelligibility tests.

BACKGROUND: The articulation index was initially conceived by French and Steinberg and later modified by K. Kryter. In turn, Kryter's version of AI is the basis of the American National Standard (ANSI) which provides a detailed account of the computational procedures for AI. Conceptually, the AI calculation method is relatively straight forward. However, as a practical matter it is difficult for the ordinary person to interpret in order to evaluate an environment where speech communication would take place.

AI is based upon determining how much of the speech spectrum is masked by the background noise present during normal intercourse between a talker and listener. In order to make this determination the frequency range of the speech spectrum is divided into bands (in the range of approximately 200 to 7000 Hz). Then the difference between the average speech level in these bands and the average noise level in the comparable bands for the background noise is computed. These differences first are weighted and then combined to yield a single index number which can be compared to an estimated amount of speech intelligibility present for a specified environment of interest.

Historically, there are two methods for computing AI. The original procedure advocated by French and Steinberg examines the speech to noise ratio in 20 contiguous frequency bands (frequency range of 200-6100 Hz) which for equal signal to noise ratios contribute equally to intelligibility. The second method analyzes the speech to noise ratio for octave or third octave bands and applies various weighting factors to account for the relative contribution of each band to speech intelligibility.

It is interesting to note several caveats that should be considered when using AI. It is not advisable to use AI as a measure for estimating the effectiveness of a communication system or environment where female talkers or children are involved because AI was based upon, and has been principally validated against, intelligibility tests using male talkers and trained listeners.

This should be a consideration when interpreting AI results for those situations where female talkers or children are present such as typical home or work environments.

Further, while AI is an adequate predictor of speech intelligibility in a steady-state ambient background, it is not effective in predicting the intelligibility of speech in the presence of fluctuating noise levels. However, the Standard does list some provisions for determining the effect of noise having a definite off-on duty cycle. Caution should be exercised in situations where there might be reduced speech intelligibility due to reverberant room acoustics, varying vocal effort of the speaker, or multiple transmission paths.

TITLE: SPEECH INTERFERENCE LEVEL

ABBREVIATION: SIL

SYMBOL: L_{SI}

UNIT: Decibel (dB)

GEOGRAPHICAL USAGE: International

DEFINITION: Speech interference level is the arithmetic average of the sound pressure levels in the four octave bands centered at the frequencies 500, 1000, 2000, and 4000 Hz of the interfering noise in question.

PURPOSE: Speech interference level is a useful measure for determining the necessary vocal effort for face-to face communication. This measure has also been recommended as a means for estimating speech intelligibility in an environment with various background noises by rank ordering the noises according to their speech interference level.

BACKGROUND: Speech interference level appears to be a compromise between simple A-weighted sound level and the more complicated calculation procedure Articulation Index (AI) in predicting the speech masking ability of a large variety of background noises. SIL was initially developed by Beranek in 1947 in an effort to formulate a simplified method of estimating the quality of speech communication for aircraft passengers. This method provided an approximation of the general masking quality of the background noise. However, unlike A-weighted sound level, SIL ignored the contributions of the low and high frequencies in the noise spectrum in terms of their potential speech interference effect.

When SIL was first introduced, it was defined as the arithmetic average of the sound pressure levels in the octave bands identified as 600-1200, 1200-2400, and 2400-4800 Hz. Later new preferred octave band designations, referred to as the preferred speech interference level (PSIL), replaced the old octave band method and was calculated from the average sound pressure level in three preferred octave bands centered at 500, 1000, and 2000 Hz.

The ANSI standard advocates four octave bands (referred to as the 4-Band Method) centered at 500, 1000, 2000, and 4000 Hz as the best method of estimating the masking capability of the background noise.

In order to distinguish among the many different versions for calculating SIL, a precise nomenclature was developed. For example, if the old octave band method is used then the SIL is identified by the abbreviation SIL (0.85, 1.7, 3.4). In turn, the preferred speech interference level method includes the notation SIL (0.5, 1, 2, 4). It is recommended that this type of notation be used if there is an opportunity for confusion as to which octave bands were used to compute SIL.

The ANSI standard ($3.14-1977, refers to two applications of SIL. The obvious situation to apply SIL is in determining the quality of face-to-face communication. The parameters to

consider include speech interference level as well as talker-to-listener distance and voice level required for "Just reliable communication". The ANSI standard defines "Just reliable communication" as a 70-percent speech intelligibility score for monosyllabic words.

Intuitively one can conclude that, for most environmental conditions, as the distance between the speaker and listener increase, the voice level necessary for just reliable communication must also increase. The information summarized here was developed by Webster for voice levels measured outdoors. The four voice levels are identified as normal, raised, very loud, and shout. There is approximately a 6 decibel difference in level between each category of voice level.

It must be noted that the relationships are only approximations of speech efforts. Other variables such as familiarity with speech material, the listener's interest in hearing the talker, visual cues, and the noise characteristics in the environment, among others, all influence the speech levels necessary for just reliable communication. SIL is not an adequate predictor of speech intelligibility if the background noise is not steady state or it contains discrete frequency components.

The ANSI standard also recommended using SIL as a method to rank order potentially interfering noises for the purpose of determining speech intelligibility. The application of this concept is based upon the rationale that noises with the same SIL reduce speech intelligibility by approximately the same amount. Thus two noises with the same SIL result will yield approximately the same speech intelligibility factor.

The ANSI standard formulated a rough guide for deriving which noises are potentially more interfering to speech intelligibility. If the SIL results for one of two noises is 5 dB or greater than the other noise, then it is assumed that the first noise is probably more destructive of speech intelligibility. Conversely, if the two noises differ by less than 5 decibels in their SIL results, then both noises are assumed to be equally disruptive of speech intelligibility.