TECHNICAL SUPPORT FOR DAY/NIGHT AVERAGE SOUND LEVEL (DNL) REPLACEMENT METRIC RESEARCH

FINAL REPORT

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0 EXECUTIVE SUMMARY

Aircraft noise is measured so that its effects on people can be predicted and disclosed in environmental impact analyses and used for noise/land use planning. One particular noise metric, Day-Night Average Sound Level (DNL), is commonly used as the sole predictor of annoyance - the primary effect of noise on residential populations. DNL is not the only cause of annoyance with transportation noise, however, and the measure is poorly understood by the public. This report examines options for supplementing or replacing DNL as a predictor of aircraft noise impacts.

Section 1 reviews basics of transportation noise regulatory policy, introduces the customary approach to measuring aircraft noise, and identifies the major limitations of DNL. The information presented in this section is further explained and discussed in Appendices A and B. (Appendix C contains excerpts from a European analysis of similar matters, and Appendix D is an extended description of various aircraft noise metrics.)

Section 2 describes the logic for measurement of transportation noise, and the rationale necessary to predict noise effects from noise measurements. The section also contains information about limitations of the most commonly used frequency weighting for noise measurements (the A-weighting network), and about the unreliability of field measurements of noise that are not based on a time-integration of exposure.

Section 3 addresses a different matter – communication with the public about predictions of aircraft noise impacts. The discussion of this section indicates that the most effective means for reducing public confusion about acoustic jargon is to avoid it entirely. Rather than attempting to educate the public about decibel notation, for example, it is preferable to present contours of annoyance rather than of noise exposure. Similarly, although it may be necessary to describe anticipated changes in noise exposure in terms of noise metrics, it is preferable to display all other predicted noise impacts directly in terms of the impacts themselves.

A different noise metric can serve as an improved predictor of aircraft noise impacts only if it differs meaningfully from DNL. A "meaningful" difference between DNL and an alternate noise metrics requires a statistical correlation between DNL and the alternate noise metric that is smaller than about 0.7. Section 4 of this report shows that nearly all aircraft noise metrics correlate very highly with DNL. Most alternate noise metrics are thus unlikely to support more accurate or precise predictions of noise impacts than DNL. The only noise metrics that do not correlate highly with DNL, "Time Above" and "Number Above", share other limitations that limit their usefulness as predictors of noise effects.

Section 4 also includes a brief description of a systematic method for including non-acoustic influences on self-reports of annoyance. This "Community Tolerance Level" is currently under consideration by ISO for adoption in a revised international standard for characterizing transportation noise impacts.

Section 5 summarizes the European perspective on characterizing environmental noise and predicting its effects on people.

The report concludes with recommendations and conclusions consistent with the analyses described in Sections 3 and 4.

1 INTRODUCTION AND BACKGROUND

1.1 Purpose of this document

"A determination of whether the rationale for defining significant noise impact requires updating to better reflect current understandings of community annoyance caused by aircraft noise exposure" is a critical research need, according to the Office of Environment and Energy of the U.S. Federal Aviation Administration (FAA/AEE). As required by Volpe Purchase Order DTRT57-10-P-80191, this report describes:

1) supplemental or replacement noise metrics that could help to improve characterization of relationships between community annoyance and aircraft noise exposure;

2) noise metrics that are *not* likely to support such improvements;

3) metrics that could be used to predict sleep disturbance and speech interference;

4) extant information useful for calculating any or all such metrics; and

5) new information useful for calculating such metrics.

As described in Section 1.2, discussion of aircraft noise measurement in isolation is somewhat artificial, since the purposes for and nature of aircraft noise measurements are closely linked to prediction of aircraft noise impacts and to regulatory policy. Although the focus of this report is on noise measurement, portions unavoidably touch on the rationale for aircraft noise measurement and its policy implications.

1.2 Fundamental regulatory purpose for aircraft noise measurement

As many ways to measure transportation noise exist as reasons for making measurements. Bennett and Pearsons (1981, excerpted here and condensed in Section 11, Glossary) and Schultz (1982) describe many such metrics and reasons for noise measurements. Although it is easy to lose sight of the fact, aircraft noise is not measured for its own sake, but for the purpose of predicting its effects on individuals and communities. If aircraft noise did not annoy people and interfere with their speech and sleep, few would regard noise measurement as worth the effort.

Given the underlying purpose for transportation noise measurement, every noise metric expresses a tacit theory: that annoyance (and/or speech interference/sleep disturbance/hearing loss/community opposition to airport operation and expansion, *etc*.) is caused by and hence predictable from the measured acoustic quantity. Explicit acknowledgement of these tacit theories can improve understanding of some of the limitations of noise metrics for implementing regulatory policy decisions.

1.3 Graphic representation of customary aircraft noise measurement systems

Figure 1-1 illustrates some of the customary physical dimensions of noise metrics. The figure analogizes common single event and cumulative aircraft noise metrics to a system of bodies (distinct noise metrics) orbiting a noise source. The distances from the noise source to the orbits of noise metrics in Figure 1-1 represent the measurement time scales. The color coding of the bodies (and the satellites orbiting them) represent their various frequency weightings. Measures with momentary or variable measurement periods cross orbital paths of the other metrics.[1]

1.4 Dominance of A-weighted equivalent energy metrics in aircraft noise measurement

For both technical and other reasons, the family of A-weighted equivalent energy metrics that was first fully described in the U.S. Environmental Protection Agency's (EPA) 1974 "Levels Document" has remained dominant in aircraft noise regulatory analyses for the last several decades[2]. Total acoustic energy is readily and consistently measurable on time scales from milliseconds to days; combines all of the primary characteristics of aircraft noise (level, duration, and number) into a single-valued index; is conveniently manipulated (at least by acousticians); and demands only one appealingly simple assumption - the so-called "equal energy hypothesis" - about the origins of annoyance. This assumption is that level in decibel units, logarithm base 10 of duration, and logarithm base 10 of the time weighted number of noise events are directly interchangeable, and hence, equally important determinants of annoyance.[3]

Federal Aviation Regulation (FAR) Part 36 measurements are an exception to the general dominance of A-weighted metrics for aircraft noise measurement. Aircraft noise measurements under Part 36 are made in units of Effective Perceived Noise Level (EPNL). The source-based measurements, made under highly controlled conditions at specific points, are expressly intended to verify compliance with aircraft noise emission standards, characterize aircraft noise emissions for acoustic modeling and related purposes, and historically have had no specific role in prediction of population-level noise impacts.

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[1] Appendix B includes three spreadsheets that characterize (1) metrics from the 1960s and 1970s that remain in common use; (2) integrating metrics from the 1980s, 1990s, and 2000s; and (3) some calculations and ratings that may be of future interest.

[2] Note that California had adopted the cumulative noise metric Community Noise Equivalent Level, CNEL, a metric that differs from DNL only by the inclusion of an evening time weighting, in 1970 (California Administrative Code, Title 21, Subchapter 6, "Noise Standards.").

[3] As noted by Fidell (2003), the empirical evidence in favor of this hypothesis is not definitive, but the theory that people integrate the acoustic energy of noise events in precisely the same manner that a sound level meter does has historically been appealing, both for its simplicity and for want of demonstrably superior hypotheses.

Time Scales and Frequency Weightings of Common Noise Metrics

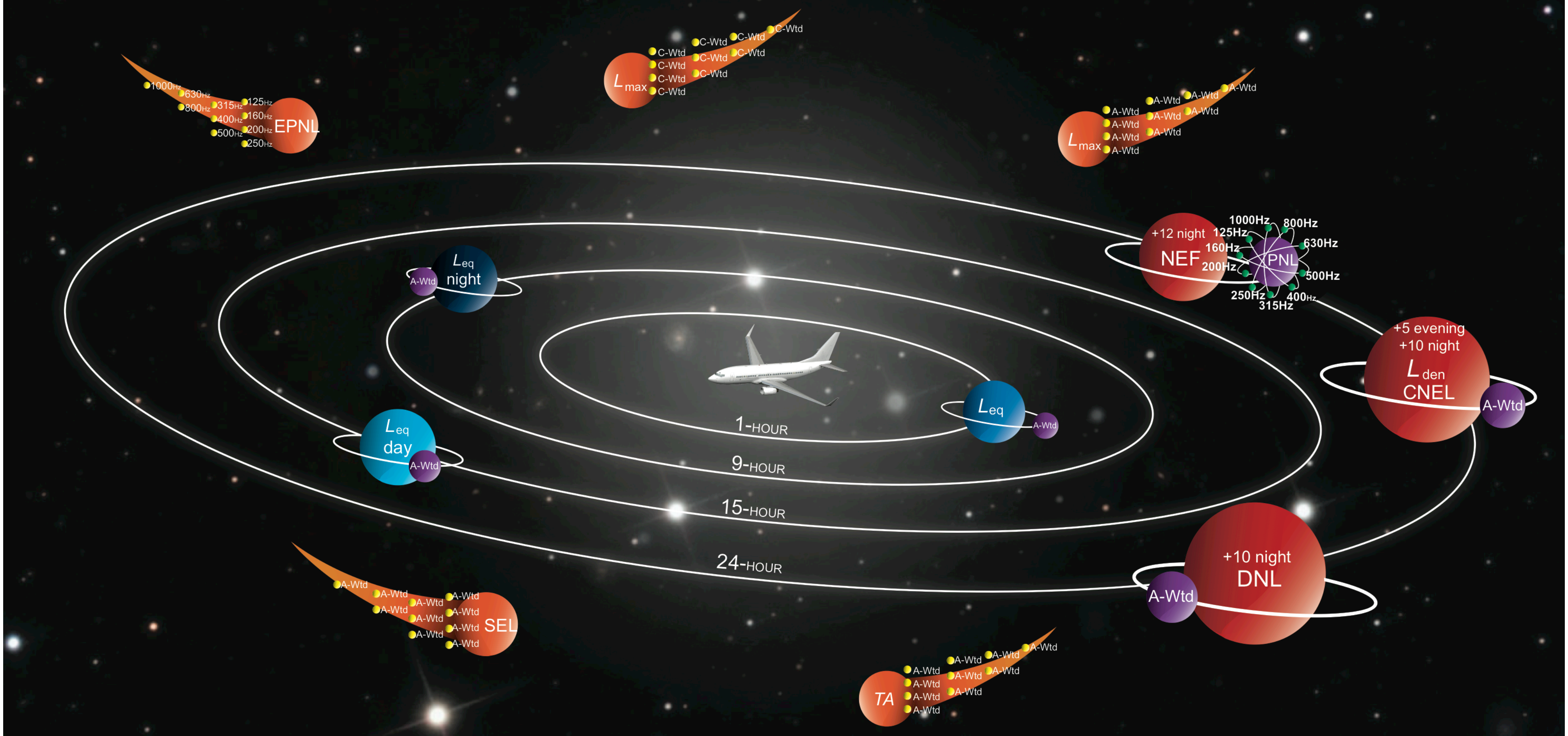

Figure 1-1. Schematic representation of common noise metrics

1.5 Current role of DNL in prediction of annoyance due to transportation noise

Day-Night Average Sound Level is an A- and time-weighted average sound level normalized to a 24 hour period. DNL was initially intended by EPA (1974) as an expedient means for quantifying and comparing transportation noise resulting from disparate sets of operations (for example, of operations of differing aircraft fleets at different airports, of noise exposure created by surface and air transportation, *etc*.). Schultz's (1978) use of DNL as the predictor variable was the first major synthesis of a relationship between environmental noise and annoyance prevalence rates and gained acceptance by the early 1980s. After FAA received Congressional direction to adopt a noise metric (Aviation Safety and Noise Abatement Act, 1978), the DNL metric was retroactively identified as the logical basis for U.S. aircraft noise regulatory policy.

In its 1992 report, the U.S. Federal Interagency Committee on Noise (FICON) declares that annoyance is its preferred "summary measure of the general adverse reaction of people to noise," and endorses "the percentage of the area population characterized as 'highly annoyed' by long-term exposure to noise" as its preferred measure of annoyance. FAA currently relies on annualized Day/Night Average Sound Level (abbreviated DNL in text and represented symbolically in mathematical expressions as L_{dn}) as its primary metric for quantifying cumulative exposure to aircraft noise.

FAA cites $L_{\mathrm{dn}} = 65$ dB as a guideline for defining compatible land use in the vicinity of an airport (FAR Part 150, "Noise Control and Compatibility Planning For Airports"), and as part of the definition of a threshold for defining a significant noise impact (FAR Order 1050-1E, "Environmental Impacts: Policies and Procedures," as follows:

> *14.3 SIGNIFICANT IMPACT THRESHOLDS. A significant noise impact would occur if analysis shows that the proposed action will cause noise sensitive areas to experience an increase in noise of DNL 1.5 dB or more at or above DNL 65 dB noise exposure when compared to the no action alternative for the same timeframe.*

When the $L_{\mathrm{dn}} = 65$ dB threshold of significance is exceeded, FAA policy permits, but does not require, further analysis to lower noise levels as follows:

> *14.4c. In accordance with the 1992 FICON (Federal Interagency Committee on Noise) recommendations, examination of noise levels between DNL 65 and 60 dB should be done if determined to be appropriate after application of the FICON screening procedure (FICON p.3-5). If screening shows that noise sensitive areas at or above DNL 65 dB will have an increase of DNL 1.5 dB or more, further analysis should be conducted to identify noise-sensitive areas between DNL 60-65 dB having an increase of DNL 3 dB or more due to the proposed action. The potential for mitigating noise in those areas should be considered, including consideration of the same range of mitigation options available at DNL 65 dB and higher and eligibility for federal funding.*

> *This is not to be interpreted as a commitment to fund or otherwise implement mitigation measures in any particular area. (FICON p. 3-7).*

When the L_{dn} = 65 dB threshold of significance is exceeded the FAA policy permits, but does not require further analysis using supplemental noise metrics as appropriate to the situation:

> *14.5a. The Federal Interagency Committee on Noise (FICON) report, "Federal Agency Review of Selected Airport Noise Analysis Issues," dated August 1992, concluded that the Day- Night Average Sound Level (DNL) is the recommended metric and should continue to be used as the primary metric for aircraft noise exposure. However, DNL analysis may optionally be supplemented on a case-by-case basis to characterize specific noise effects. Because of the diversity of situations, the variety of supplemental metrics available, and the limitations of individual supplemental metrics, the FICON report concluded that the use of supplemental metrics to analyze noise should remain at the discretion of individual agencies.*

FAA uses L_{dn} = 65 dB as a boundary for determining a significant noise impact with respect to an exposure-response curve which relates DNL to a nominal percentage of the population that is predicted to be "Highly Annoyed". The percent of the population predicted by the 1992 FICON curve to be highly annoyed at this exposure level is 12.3%.

1.6 Pragmatic limitations of DNL

Despite DNL's dominance as a metric underlying transportation noise policy, it is ill-understood, misinterpreted and distrusted by the public for a number of reasons:

> A cumulative, 24 hour time-weighted average level is an abstract concept, far removed from common experience. A quantity of noise exposure expressed in units of DNL cannot be directly experienced by casual observation in the same sense that the maximum sound level of a single noise event can be heard.
>
> Even though DNL values reflect all of the noise energy occurring during a 24-hour period, its very name (Day-Night *Average* Sound Level) is commonly misconstrued as implying that the measure is somehow insensitive to high level noise events.
>
> The logarithmic arithmetic necessary to manipulate DNL values, and the normalization of the decibel notation of the units to 10log(86,400 seconds/day) are non-intuitive for non-technical audiences.[4]

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[4] Efforts to express acoustic quantities such as DNL in linear units, such as pascal-square seconds or "pasques", have not been widely accepted.

> Public understanding of prospective aircraft noise modeling and annual average day exposure contours - the context in which the public generally encounters DNL-based information - is weak at best.
>
> DNL is required for use in environmental impact disclosure documents as the required metric of noise exposure. The subsequent focus on the metric in lieu of descriptive discussion of noise impacts is confusing and potentially misleading.
>
> The public does not fully understand the linkages between DNL and interpretive criteria based on predicted noise exposure levels. In particular, the rationale for identifying $L_{\mathrm{dn}} = 65$ dB as a threshold of significant noise impact is opaque.
>
> The metric often suffers from a "shoot-the-messenger" reaction to unpopular policies that are expressed in units of DNL. This leads to a common criticism of DNL as a metric in lieu of criticism of the manner in which DNL is used.

Quite apart from the difficulty the public experiences in grasping the concept of a time-weighted average sound exposure level expressed in decibel notation, DNL has another major practical limitation. It doesn't work particularly well as a predictor of aircraft noise impacts. FICON's 1992 relationship accounts for less than a fifth of the variance in the association between aircraft noise exposure and the prevalence of high annoyance in communities (Fidell, 2003; Fidell and Silvati, 2004). As discussed in greater detail in Section 4.8, this limitation is due in part to the fact that DNL is oblivious to the non-acoustic determinants of annoyance; in part to the expedient (non-theory based) formulation of the FICON exposure-response curve; and in part to random errors of measurement of both exposure and community response to aircraft noise exposure.

1.7 Distinction between "supplemental" and "alternative" noise metrics

For the above and other reasons, alternative and supplemental noise metrics have long been sought to complement or even replace DNL in aircraft noise impact assessments. An important distinction is drawn for current purposes between "alternative" and "supplemental" noise metrics. In the current context, a "supplemental" noise metric is one that can in some way improve public understanding of the manner in which aircraft noise is characterized. In itself, public understanding of forecasted changes in aircraft noise in environmental impact disclosure documents does not advance the state of the art of predicting community reaction to aircraft noise exposure. In contrast, an "alternative" noise metric is one that can actually improve the ability to predict aircraft noise *impacts*.

The distinction between improving public understanding on the one hand, and improving the predictability of noise impacts on the other, is an important one for present purposes. *Supplemental* metrics may correlate well or poorly with DNL, because their goal is merely to improve communication with the public.[5] Thus, for example, a noise metric expressed in linear units rather than in logarithmic (decibel) form might, in principle, be more readily grasped by the public than one expressed in decibel notation, even though it might not be any more effective than DNL as a predictor of noise impacts. Likewise, the public may find counts of numbers of times per day that aircraft noise intrusions exceed some threshold more intuitively appealing than DNL values, even though no means are available for transforming such counts into predictions of community response to aircraft noise.

Logically and statistically, however, *alternative* metrics should **not** correlate well with DNL, because if they did, they would offer little (if any) improvement in accuracy or precision of prediction of aircraft noise impacts.

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[5] A recent U.S. Department of Defense publication (DNWG, 2009) discusses such supplemental metrics at length.