AN ANALYSIS OF THE TECHNICAL BASIS OF FAA'S NOISE REGULATORY FRAMEWORK AND ITS APPLICATION TO THE O'HARE MODERNIZATION PROGRAM

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1 INTRODUCTION AND SUMMARY

1.1 Purpose of this Report

This report was prepared for the Suburban O'Hare Commission ("SOC"),[1] some of whose members have been overflown by substantially greater numbers of approach and departure operations following a recent runway re-alignment at Chicago's O'Hare International Airport (ORD). As shown in Figure 1, ORD's runways are being reconfigured as part of a project of runway and terminal modifications known as the O'Hare Modernization Program (OMP). The realignment is intended to increase airport capacity and reduce air traffic delays.

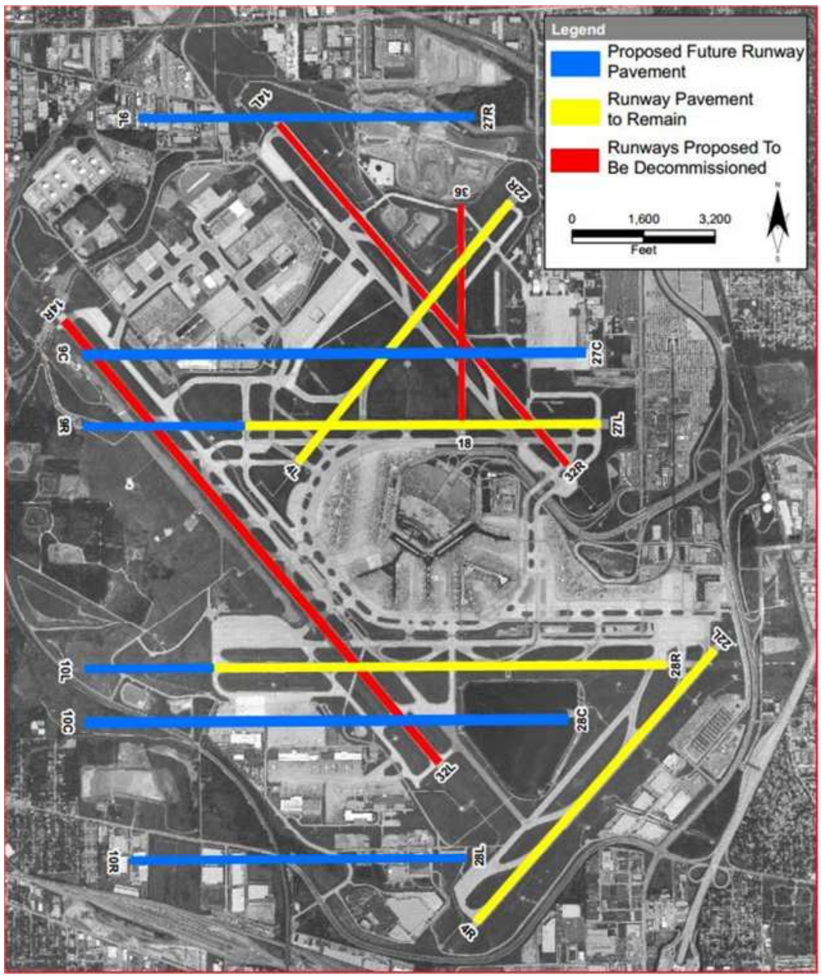

Figure 1: Planned runway re-configuration for ORD

(Source:https://www.faa.gov/airports/airport_development/omp/media/Chapter1_page51.pdf**)**

Predominantly east-west operations began at ORD in October of 2013, greatly increasing overflights of communities to the east and west of the airport with respect to air traffic patterns of prior decades. In some newly overflown areas, residents have complained about the effects of aircraft noise intrusions on their quality of life, despite prospective modeling that predicted

[1] SOC is a coalition of Chicago suburban communities including Addison, Bensenville, DuPage County, Elk Grove Village and Township, Elmhurst, Hanover Park, Itasca, Roselle, Wood Dale and Schiller Park.

actual noise exposure would not exceed a threshold considered by the Federal Aviation Administration ("FAA") as indicative of significant noise impact. Adverse community response to the new operational patterns at ORD has proved to be far greater than predicted by FAA's Environmental Impact Statement (EIS) for the OMP.

This analysis examines the history, data, derivation, and rationale for FAA's adoption of Day-Night Average Sound Level[2] as its preferred measure of aircraft noise exposure; and for FAA's selection of L_{dn} = 65 dB as its criterion of significant noise impact. The intent of the report is to provide SOC, other communities impacted by ORD aircraft noise, ORD-area residents, and interested public officials with an analysis of the scientific basis for:

1) FAA's selection of DNL as the noise metric for defining significant noise impact; and

2) FAA's selection of the L_{dn} = 65 dB value as a threshold of significant noise impact.

The report also examines the utility of noise metrics other than DNL for defining the significance of aircraft noise impacts, and describes modern methods for assessing aircraft noise impacts on communities.

1.2 Organization of Report

Chapter 2 of this report describes the framework of U.S. aircraft noise regulation. It also analyzes the adequacy of the technical rationale for FAA's use of L_{dn} = 65 dB as a definition of significant environmental impact of aircraft noise.

Chapter 3 reviews the utility of DNL as a measure of aircraft noise exposure. Chapter 4 provides improved estimates of noise impacts of the changes in aircraft noise exposure on ORD-vicinity communities. Chapter 5 recommends further actions intended to characterize community response to increases in aircraft noise exposure in communities to the east and west of ORD.

To the extent possible, the body of the report is written for readers with only a basic acquaintance with U.S. aircraft noise regulatory practice. Five Appendices contain supplemental information for readers interested in further technical detail.

1.3 Summary of Principal Findings

The 1979 Aircraft Safety and Noise Act (U.S. Public Law 101-193) required the U.S. Secretary of Transportation to

> (1) establish a single system of measuring noise, for which there is a highly reliable relationship between projected noise exposure and surveyed reactions of people to noise, to be uniformly applied in measuring the noise at airports and the areas surrounding such airports;

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[2] Day-Night Average Sound Level is a 24 hour measure of cumulative noise exposure. It is abbreviated in text as DNL, and represented symbolically in mathematical expressions as L_{dn}.

(2) establish a single system for determining the exposure of individuals to noise which results from the operations of an airport and which includes, but is not limited to, noise intensity, duration, frequency, and time of occurrence; and

(3) identify land uses which are normally compatible with various exposures of individuals to noise.

FAA complied with this Congressional mandate by adopting the "equivalent energy" family of noise metrics identified in EPA's 1974 "Levels Document" (see Appendix B) as its system of noise measurements, and by publishing its recommendations for compatible land uses in 1985, in Part 150 of the Federal Aviation Regulations.

1.3.1 *Basis for FAA selection of L_{dn} = 65 dB as a criterion of significant noise impact*

FAA's 1985 adoption of L_{dn} = 65 dB in Part 150 of the Federal Aviation Regulations to identify land uses incompatible with continued airport operation and expansion, and as a definition of significant noise impact, was *not* based on objective analysis or systematic scientific research.

FAA asserts that its L_{dn} = 65 dB criterion for participation in noise mitigation efforts is based on a 1992 relationship between noise exposure and the percentage of community residents highly annoyed by noise. Many subsequent studies have shown that the 65 dB value significantly understates the geographic extent, and hence the size of the population adversely impacted by aircraft noise. As explained further in this report, FAA's use of an annualized average DNL value of 65 dB has other flaws which render its definition of the significance of noise impact technically inaccurate.

To remain consistent with the current international scientific consensus (per the International Standards Organization's Standard 1996-1, "Description, measurement and assessment of environmental noise — Part 1: basic quantities and assessment procedures"), FAA must reduce its definition of significant noise impact by about an order of magnitude, to $L_{dn} \approx 55$ dB. Failure to do so will deprive populations of communities of average tolerance for aircraft noise of protection from exposure to highly annoying noise.

The noise exposure contours of the EIS for the OMP considerably understate the geographic extent of areas in communities and neighborhoods around ORD that are adversely impacted by aircraft noise. Full disclosure of these greater impacts in the EIS could have affected analyses of runway alignment alternatives in the EIS, and could affect ongoing decisions about future operations at ORD. Failure to acknowledge these greater impacts can exclude thousands of residents from eligibility for impact mitigation measures such as acoustic insulation.

1.3.2 *Varying tolerances of different communities for aircraft noise exposure*

FAA's interpretive criterion for the significance of aircraft noise exposure applies only to a hypothetical community of average tolerance for aircraft noise. In reality, communities differ considerably from one another in the prevalence of annoyance induced by the same levels of noise exposure. If FAA wishes its criterion of significant noise impact to apply with uniform effect in different communities, the criterion must reflect community-specific differences in tolerance for noise exposure.

ORD-vicinity communities newly exposed to high levels of aircraft overflights are almost certainly less tolerant than average of aircraft noise exposure. Numbers of unique noise complainant addresses lodged from ORD-vicinity communities have increased greatly since the latest runway opening at O'Hare in 2013. Even an L_{dn} = 55 dB criterion for significant noise impact underestimates the extent of the significantly noise impacted population in a community of lesser than average tolerance for noise exposure.

1.3.3 *Common mis-understandings of DNL as a noise metric*

DNL is a widely mis-understood and much-maligned measure of cumulative noise exposure. Much of the criticism that DNL attracts is technically ill-founded and mis-directed. Similar criticisms would almost certainly be directed against any other decibel-denominated system of units used in aircraft noise regulation. Criticism of DNL *per se* is, in effect, shooting at the wrong target. DNL is so highly correlated with all other measures of noise that are potentially useful for aircraft noise regulation that its ability to predict community response to noise exposure cannot differ greatly from that of other noise metrics. For example, some contend that CNEL (Community Noise Equivalent Level) is a more useful predictor of community response to aircraft noise than DNL. In reality, there is little meaningful difference in the predictability of community response to transportation noise, whether measured in units of CNEL, DENL, or DNL.

2 FRAMEWORK OF U.S. AIRCRAFT NOISE REGULATION

2.1 Purposes of Aircraft Noise Regulation, Measurement, and Prediction

Many discussions of airport/community controversies center on issues of aircraft noise exposure *per se*. Such close focus on noise exposure can obscure the fact that the underlying purpose for quantifying aircraft noise is *not* measurement for measurement's sake. Measurement of aircraft noise is only a means to an end. For regulatory purposes, aircraft noise is measured only to quantitatively predict its effects ("impacts") on noise-exposed populations. If aircraft noise did not disturb sleep, interfere with speech, and annoy people, few would find it worth the bother and considerable expense of measuring it in the first place. It follows that any noise metric which does not support useful prediction of community response cannot play a useful role in aircraft noise regulation.

For most practical purposes, aircraft noise regulation in the vicinity of airports nationwide is intended to protect some percentage of residential populations from exposure to highly annoying aircraft noise.[3] The generic questions that national regulatory bodies must answer are thus "How much noise is too much noise?", and "How can you tell?" FAA and other regulatory agencies have long sought objectively defensible answers to these questions, with only limited success.

2.2 Rationale for Aircraft Noise Regulation

FAA and other regulatory agencies routinely assert that their noise regulations are supported in some manner by formal technical analyses of statistical relationships between the prevalence of a consequential degrees of noise-induced annoyance in communities (percent highly annoyed, or "%HA") and a measure of cumulative noise exposure (such as DNL), expressed in units of decibels (dB).[4] "Dosage-response" relationships of this sort are commonly expressed as mathematical functions. This lends them the appearance, if not the substance, of accuracy, precision and scientific merit. Since FAA adopted DNL as its preferred measure of aircraft noise exposure, no other association of noise dose and noise effect has been as thoroughly investigated, nor based on as much empirical information.

Dosage-response relationships derived by logistic regression[5] (*cf*. FICON, 1992, and Miedema and Oudshoorn, 2002), vary continuously in slope over their ranges, and lack obvious

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[3] FAA maintains that aircraft noise regulation is intended to protect public investment in airport infrastructure, but the major pragmatic benefit of such regulation is nonetheless its limitation of residential exposure to aircraft noise. The population protected from exposure to highly annoying aircraft noise is *not* a percentage of the entire residential population in the vicinity of an airport, but only of the population exposed to a specified noise exposure level. The percentage of an entire residential population near an airport actually protected from exposure to highly annoying aircraft noise depends on the geographic distribution of residences with respect to noise exposure contours.

[4] This assertion by FAA is the agency's stated response to Congressional direction to the Department of Transportation in the 1979 ASNA statute to adopt a noise measurement standard based on a "highly reliable relationship between projected noise exposure and surveyed reactions of individuals to noise."

[5] Logistic regression is a statistical procedure that produces a smooth, S-shaped approximation to the centroid of a cloud of data points. A dosage-response curve produced by univariate logistic regression is driven by the correlation

breakpoints (other than near their asymptotes, which are of little regulatory interest). They also predict annoyance prevalence rates only in "typical" – that is, nominally average – communities, not in any actual community. In reality, annoyance prevalence rates in different communities vary greatly for the same noise dose measured in units of DNL. Thus, NEPA-based environmental impact disclosures for specific projects in actual communities, as well as regulatory policies supposedly derived from regression-based dosage-response relationships, do not properly disclose the potential range in community annoyance, and therefore do not offer uniform protection from exposure to highly annoying noise in communities nationwide.

2.3 Measurement of Community Response to Aircraft Noise

The term "community response" has served since the late 1970s as an informal term for the percentage of a representative sample of noise-exposed residents who describe themselves as consequentially annoyed by aircraft noise (Schultz, 1978). This percentage has been measured directly in hundreds of field studies of community response to aircraft noise exposure since the first modern social survey of this kind was undertaken at London Heathrow Airport (McKennell, 1963). The International Standards Organization (2013) has since published a technical specification describing the design of social surveys intended to quantify community response to transportation noise. Some of the key aspects of the technical specification include a standardized organization and wording of questionnaire items about the annoyance of noise exposure, and requirements for contemporaneous measurement and/or prediction of survey respondents' residential aircraft noise exposure levels.

If not determined empirically in a field study, the prevalence of high annoyance in a community can also be predicted *via* a dosage-response relationship. As further described in Section 2.5.3 of this report, FAA relies on one such relationship, developed for the 1992 FICON report, to predict community response to aircraft noise. This statistical relationship is now known to be technically inaccurate. Appendix C describes the International Standards Organization's current methods for quantifying the relationship between transportation noise exposure and annoyance prevalence rates.

2.4 Legislative Direction for U.S. Aircraft Noise Regulation

FAA regulates aircraft noise in accordance with Congressional direction, as specified in Public Law 85-726, the much-amended 1958 legislation which originally established FAA as an independent agency. Subsequent legislation, notably including the Airport Safety and Noise Act of 1979 ("ASNA", Public Law 96-193) and the Airport Noise and Capacity Act of 1990 ("ANCA", Public Law 101-508), has provided considerable additional Congressional direction.[6]

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between a single predictor variable (*e.g.*, DNL) and a single predicted variable (*e.g.*, % highly annoyed). Such a regression analysis is purely descriptive, lacks any inherent explanatory value, and does not address *bona fide* differences from one community to the next in tolerance for noise exposure.

[6] For largely political rather than technical reasons, exceptions have been made to general regulatory practice for certain airports, notably, Jackson Hole Airport (JAC) in Teton County, WY. For its own reasons, FAA has also permitted some airports (*e.g.*, MSP) to use AIP funding to acoustically insulate homes within the 60 dB DNL contour. FAA has also made no effort to challenge pre-ANCA compulsory or *de facto* restrictions on aircraft operations at airports such as Long Beach (LGB), John Wayne (SNA), and Denver (DEN).

The "dual mandate" in FAA's original (1958) charter – to not only regulate civil aviation, but also to promote it – created an inherent conflict of interest for the agency. FAA interpreted its dual mandate as encouraging a regulatory environment steeply tilted in favor of aviation industry interests. According to a former Department of Transportation Inspector General, "[FAA's] job was to promote aviation, and what they did is protected carriers to keep them flying." The 1996 Federal Aviation Reauthorization Act[7] eliminated FAA's dual mandate by striking language instructing FAA to promote civil aeronautics.

2.5 Underlying Assumptions of FAA-Sanctioned Assessment of Community Response

FAA noise regulatory positions rest on several fundamental assumptions (*cf*. Fidell, 2003) that were re-affirmed in 1992 by the Federal Interagency Committee on Noise in its "FICON Report":

1) Annoyance is the most useful measure of the general adverse reaction of communities to aircraft noise exposure; the preferred measure of annoyance is the proportion of community residents who consider themselves highly annoyed by aircraft noise.

2) A particular measure of cumulative noise exposure (Day-Night Average Sound Level) is the most useful descriptor of community noise.

3) A dosage-response function developed by U.S. Air Force researchers in the early 1990s (FICON, 1992) can accurately and reliably transform cumulative noise exposure levels, expressed in units of Day-Night Average Sound Level, into *predicted* annoyance prevalence rates in communities.

4) A level of aircraft noise expressed in units of cumulative noise exposure as L_{dn} = 65 dB serves as a strict threshold separating significant from "insignificant" transportation noise impacts in all communities. Various forms of federal participation (*i.e*., funding) are available to mitigate only significant aircraft noise impacts, (*i.e.*, noise within the 65 DNL contour.)

These assumptions are discussed in the following subsections.

2.5.1 *Annoyance as the Preferred Measure of Aircraft Noise Environmental Impact*

This is the least technically controversial of the assumptions underlying FAA noise policy. Volume 2 (Section 3.2.2.1, pp. 3-3 *et seq*.) of FICON's 1992 report states that:

> "…the percent of the exposed population expected to be highly annoyed (%HA) [is] the most useful metric for characterizing or assessing noise impact on people", and that

[7] Public Law 104-264, Section 401 ("Elimination of Promotion"), http://www.gpo.gov/fdsys/pkg/PLAW-104publ264/pdf/PLAW-104publ264.pdf.

"…the updated 'Schultz curve'[8] remains the best available source of empirical dosage-effect information to predict community response to transportation noise."

FAA adopted this position by the early 1980s, in response to ASNA. The selection of community annoyance as the criterion for significant noise interference remains consistent with the international scientific consensus expressed in the recent revision of the International Standards Organization standard, "Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures" (ISO, 2015), and with the European Union's Environmental Noise Directive (European Commission, 2002).

It is helpful to recall that the nature of annoyance of interest to FAA is *not* the annoyance of individuals, nor of exposure to transient noise events (*i.e.*, individual overflights), but the community annoyance of cumulative, long term exposure to multiple noise events. DNL, FAA's noise metric of choice (described in the next sub-section) predicts the annoyance of a full day's worth of noise-induced annoyance.

Further, it is not any particular day's annoyance that is of concern to FAA, but a hypothetical annual average day.[9] It is implicit in FAA's annual average day basis for estimating DNL values that seasonal variations in opening and closing of windows in residences, as well as variations in airport operations (such as differences in hot and cold season aircraft performance, fleet mix, runway and flight path use, and so forth) are adequately addressed through reliance on annual average conditions.

2.5.2 *DNL as the Preferred Measure of Community Noise Exposure*

DNL was formally defined in the Environmental Protection Agency's "Levels Document" (EPA, 1974). FAA was unenthusiastic about the utility of the measure prior to ASNA's requirement for adoption of a single, universally applicable aircraft noise measurement system. FAA's position subsequently evolved to near-exclusive reliance on DNL for quantifying aircraft noise exposure and predicting its consequences. Although the noise metric is frequently denigrated in public challenges to environmental impact disclosure exercises and other public debates, it is consistent with national and international scientific consensus standards, such as American National Standard ANSI S12.9/Part 4 and ISO 1996-1.

In practice, DNL values used to assess annoyance prevalence rates in communities (see next sub-section) are more often predicted (prospectively modeled) ones, rather than actually measured ones. One of the major purposes for predicting annoyance prevalence rates in communities is to meet NEPA requirements for disclosure of anticipated future noise impacts. Not all airports have systems capable of credibly measuring aircraft noise exposure in surrounding communities in any event. At those which do, discrepancies in DNL values

[8] The so-called "Schultz curve" is an early dosage-response relationship (Schultz, 1978) linking transportation noise exposure to the prevalence of a consequential degree of annoyance in communities. The original analysis by Schultz has been revisited several times in subsequent decades, and is now obsolete.

[9] The fictional nature of an "annual average day" of noise exposure is particularly clear in noise modeling exercises. A hypothetical "annual average day" is one on which the wind simultaneously blows at eight knots directly down each of an airport's runways (regardless of their actual orientations), while the annual average fleet utilizes annual average runways and flight paths while flying to annual average destinations. No such day actually exists, of course, nor is the pattern of noise exposure produced on such a hypothetical day ever experienced in all airport-area communities.

between prospectively predicted and empirically measured values of DNL as large as several decibels are commonplace at some measurement sites.

2.5.3 *Accuracy and Precision of the FICON Dosage-Response Relationship*

The "FICON curve" was developed by two employees of the U.S. Air Force Aerospace Medical Research Laboratory, Drs. Stanley Harris and Henning von Gierke, in the early 1990s (Feingold *et al.*, 1994). The starting point for their analysis was a database of paired DNL values and prevalence rates of high annoyance with transportation noise that had been compiled by Fidell, Barber and Schultz in 1989. Harris and von Gierke opted to fit a single curve to annoyance prevalence rates observed for all forms of transportation noise (road, rail, and aircraft), after intentionally omitting some of the aircraft data points which, in their opinion, appeared to be unreliable.[10] Both of these analysis choices – combination of community response data to all forms of transportation noise, and omission of some of the seemingly more extreme aircraft noise data points – led to a dosage-response relationship which considerably underestimated the annoyance associated with exposure to aircraft noise (Fidell and Silvati, 2004).

Figure 2 shows FICON's 1992 dosage-response relationship, which FAA continues to regard as reliable and definitive. For example, Chapter 17 of FAA's "Airports Desk Reference" confidently asserts that:

> *"Past and present research by the Federal Interagency Committee on Noise (FICON) verified that the DNL metric provides an excellent correlation between the noise level an aircraft generates and community annoyance to that noise level."*

Such claims are little more than circular, self-referential assertions of truth by claimed authority, without regard for evidence, intellectual examination, or fact.

FAA's assertion elaborates on a similar claim in Section A150.1 of FAR Part 150 that DNL provides "a system of measuring noise at airports for which there is a highly reliable relationship between projected noise exposure and surveyed reactions of people to noise…." The claim is commonly but uncritically repeated in the boilerplate sections of FAR Part 150 studies and Master Planning exercises that individual airports prepare, such as those of the Port of Seattle (2004).

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[10] The omitted points included observations of annoyance prevalence rates made at Burbank Airport (Fidell *et al.*, 1985). With the advantage of another three decades of field measurements of aircraft noise-induced annoyance, these observations do not appear in hindsight to be as extreme as believed at the time by Harris and von Gierke. Subsequent field measurements of aircraft noise-induced annoyance have demonstrated adverse community response to aircraft noise at even lower levels of aircraft noise exposure than those excluded from analysis in preparing the FICON curve.

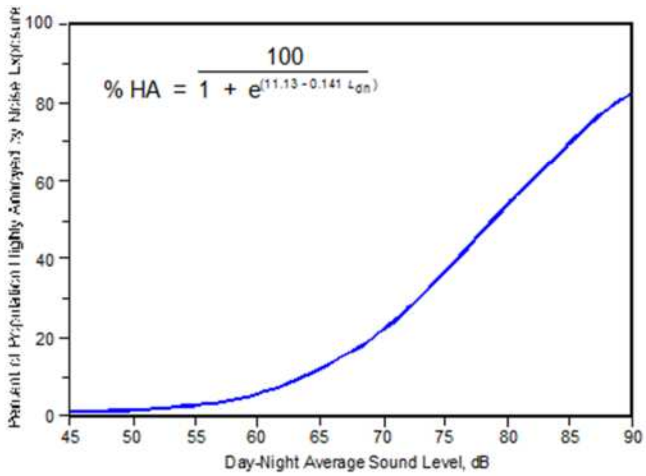

Figure 2: Dosage-response relationship developed by FICON (1992) and endorsed by FAA for predicting the prevalence of high annoyance in communities from cumulative noise exposure.

In reality, the FICON dosage-response relationship accounts for only about a fifth of the variance in the relationship between aircraft noise exposure and the prevalence of high annoyance in communities (Fidell and Silvati, 2004), and virtually none of the variance in the range of greatest regulatory interest – 55 dB $\leq L_{dn} \leq$ 65 dB (per Figure 6 of Fidell, 2003.) Figure 2 (above) is misleading because it does not display the data that FICON's relationship supposedly represents.

Figure 3 illustrates the enormous variability in annoyance prevalence rates of residential populations in different communities. Each of the 500+ open circles represents an empirical field measurement of the prevalence of aircraft noise-induced annoyance. Figure 4 shows that the FICON fitting function falls far short of the centroid of this cloud of data points. As such, it fails to explain or otherwise account for the great majority of the variability in the relationship. Mis-informed claims to the contrary are based on obsolete information and simplistic analyses.

The FICON dosage-response relationship is both obsolete and technically flawed in several ways. It is based on a limited set of dated field observations; fails to distinguish between the annoyance of aircraft, rail, and road noise; excludes data from certain surveys documenting high annoyance prevalence rates at modest noise exposure levels; and (as described in greater detail in Section 3 of this report) greatly underestimates the annoyance of aircraft noise exposure.

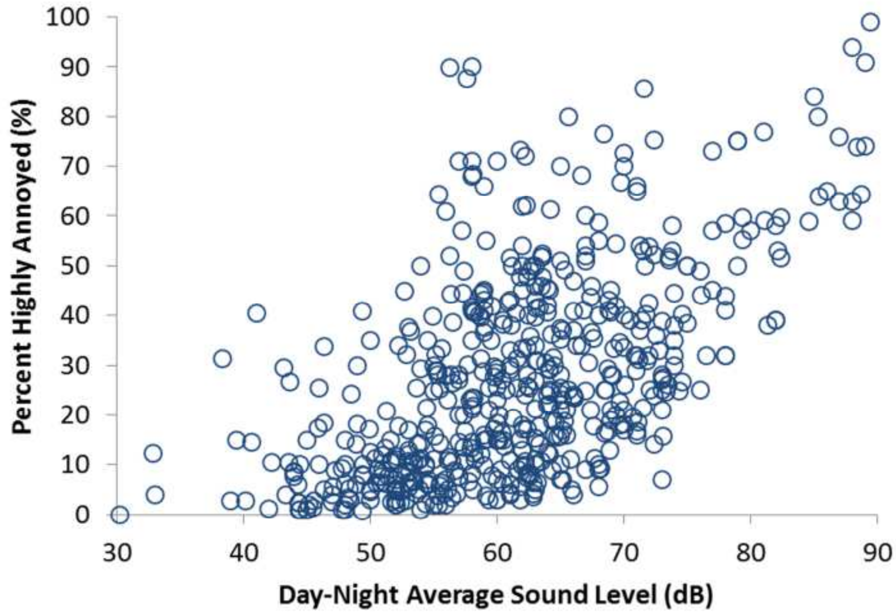

Figure 3: Illustration of the great variability in field measurements of aircraft noise-induced annoyance prevalence rates in approximately 550 communities.

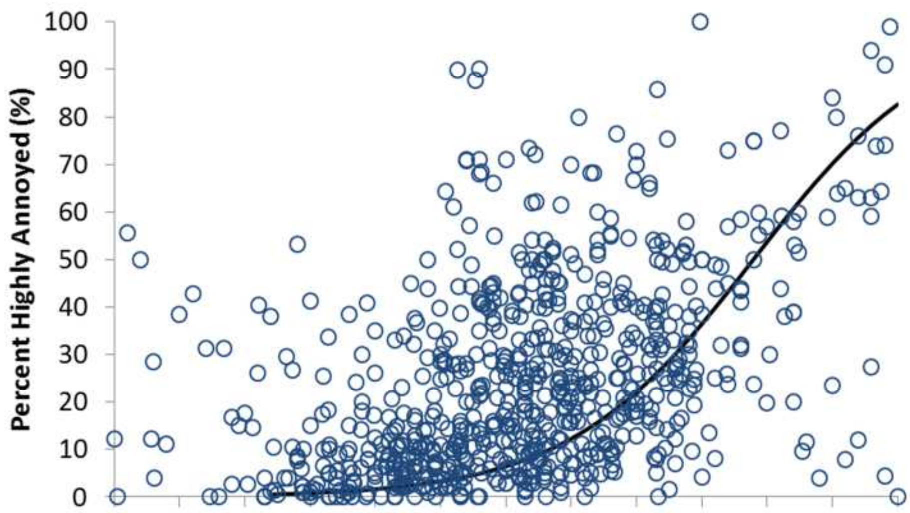

Figure 4: Summary of world-wide observations of the prevalence of all transportation noise-induced annoyance. The solid curve in the figure is a dosage-response relationship relied upon in the United States to predict annoyance prevalence rates in all communities to all transportation noise sources.

The FICON fitting relationship does not apply to any actual community, but only to a hypothetical community of nominally average tolerance for all transportation noise exposure.[11]

2.5.4 *Distinction of Significant from Insignificant Noise Impacts*

Judgments about the significance of noise impacts are critical for policy purposes. They affect, *inter alia*, NEPA-related disclosures and decisions about project alternatives, requirements for mitigating aircraft noise impacts, and subsequent eligibility for participation in airport-vicinity residential acoustic insulation and property purchase programs.

FAA does not use the term significance in its statistical sense, as a likelihood that an observation may have arisen by chance alone. As used by FAA, the term has *no* objective, systematic meaning other than as a policy threshold. For policy purposes, significance indicates only that the magnitude of predicted noise exposure exceeds L_{dn} = 65 dB.[12] Significance is dichotomous in FAA parlance – a noise impact is either significant or not significant. Significant noise impacts do not vary by degree for policy purposes, nor does the definition of significance of noise impacts vary from one community to the next, even though FAA acknowledges in its 1976 policy statement that "community responses to aircraft noise differ substantially [among communities]…."

A few moments' reflection reveals the lack of objective meaning of any claim that L_{dn} = 65 dB is a *scientifically* defensible definition of significant noise impact. No empirical, scientific study can be designed to determine the "correct" balance between conflicting societal interests. Such determinations self-evidently require value judgments about who should enjoy the benefits and who should bear the costs of satisfying demand for air transportation services. In the words of Kirsch (2015),

> *"Anyone who asserts that the FAA's [L_{dn} = 65 dB] standard for land use compatibility was established through an independent and objective scientific and technical exercise is either deceiving themselves or lacks a fundamental understanding of the relationship between science and public policy…. In the United States, all pollution standards are (or should be) based upon a technical/scientific foundation but the … decision as to an acceptable level is, ultimately a policy decision. There simply is no scientific or technical standard for what is acceptable: that is a policy decision."*

[11] The National Environmental Policy Act of 1969 (NEPA) requires disclosure of the expected environmental impacts of major federally-funded projects in specific communities. The fact that the FICON (1992) dosage-response relationship applies only to a hypothetical average community, rather than to any actual community, complicates its use in NEPA documents intended to disclose expected environmental impacts of aircraft noise exposure in actual communities affected by particular proposed actions. Appendix C describes how noise impact assessments may be conducted for specific communities, rather than for a hypothetical average community, by calculating a Community Tolerance Level value.

[12] FAA's "Policies and Procedures for Considering Environmental Impacts" (FAA Order 105.1E, 2004), for example, identifies L_{dn} = 65 dB as a strict noise exposure threshold for the purpose of defining a significant aircraft noise impact.

3 DNL AS A PREDICTOR OF COMMUNITY RESPONSE TO AIRCRAFT NOISE

Modern acoustic instrumentation can measure all aspects of aircraft noise, from the most obvious (sound pressure level, number, and duration of overflights) to the most subtle (rates of change of level, temporal variance, spectral complexity, *etc*.) Measurements can be made on time scales ranging from fractions of seconds to years, in narrow or wide bandwidths, in a variety of frequency weightings. Figure 5 (on the next page), adapted from Mestre *et al.* (2011), illustrates some common time scales and frequency weightings for aircraft noise measurement systems, represented by analogy to astronomical bodies orbiting an aircraft noise source.

The variety of alternative measurement systems can be bewildering unless it is recognized that each system of measurements reflects a tacit assumption that the aspect of aircraft noise to which it is most sensitive is the primary cause of annoyance. Such assumptions stem from beliefs dating to the 1950s:

1) that the findings of laboratory studies of the acoustic determinants of annoyance can be freely generalized to community settings; and

2) that annoyance with residential exposure aircraft noise exposure can be fully explained and accounted for in exclusively acoustic terms.

After decades of subsequent research, neither of these beliefs has proved correct.

A veritable alphabet soup of schemes intended to predict community response to aircraft noise arose starting as early as the 1950s. Many of these are described by Schultz (1972), Bennett and Pearsons (1981), and by Mestre *et al.* (2011). The findings of any one field study do not suffice to test hypotheses about the acoustic determinants of annoyance, however. Noise metrics which correlate well with social survey findings in an individual study often correlate poorly in other studies.[13] In the absence of a clear definition – let alone a substantial body of field measurements of community response to actual aircraft noise – it was difficult to determine the predictive worth of many of these metrics prior to the 1970s (*cf.* Kryter, 1984).

3.1 Early precursors to DNL

3.1.1 *Community Noise Rating (CNR)*

The first systematic efforts to predict community response to aircraft noise exposure were those of Rosenblith *et al*. (1953) and Stevens *et al.* (1955). As described by Fidell (2003), their "Community Noise Rating" approach to characterizing adverse community reaction to aircraft noise interpreted the findings of 20-odd case studies of community reaction to aircraft noise in terms of "sporadic" through "widespread" complaints, "threats of community action," and "vigorous community action." CNR values in airport neighborhoods were scaled from about 100 through 115, in decibel-equivalent units.

[13] This is due in large part to the limitations of purely correlational statistical analysis methods, such as multivariate regression, which are not based on causal relationships.

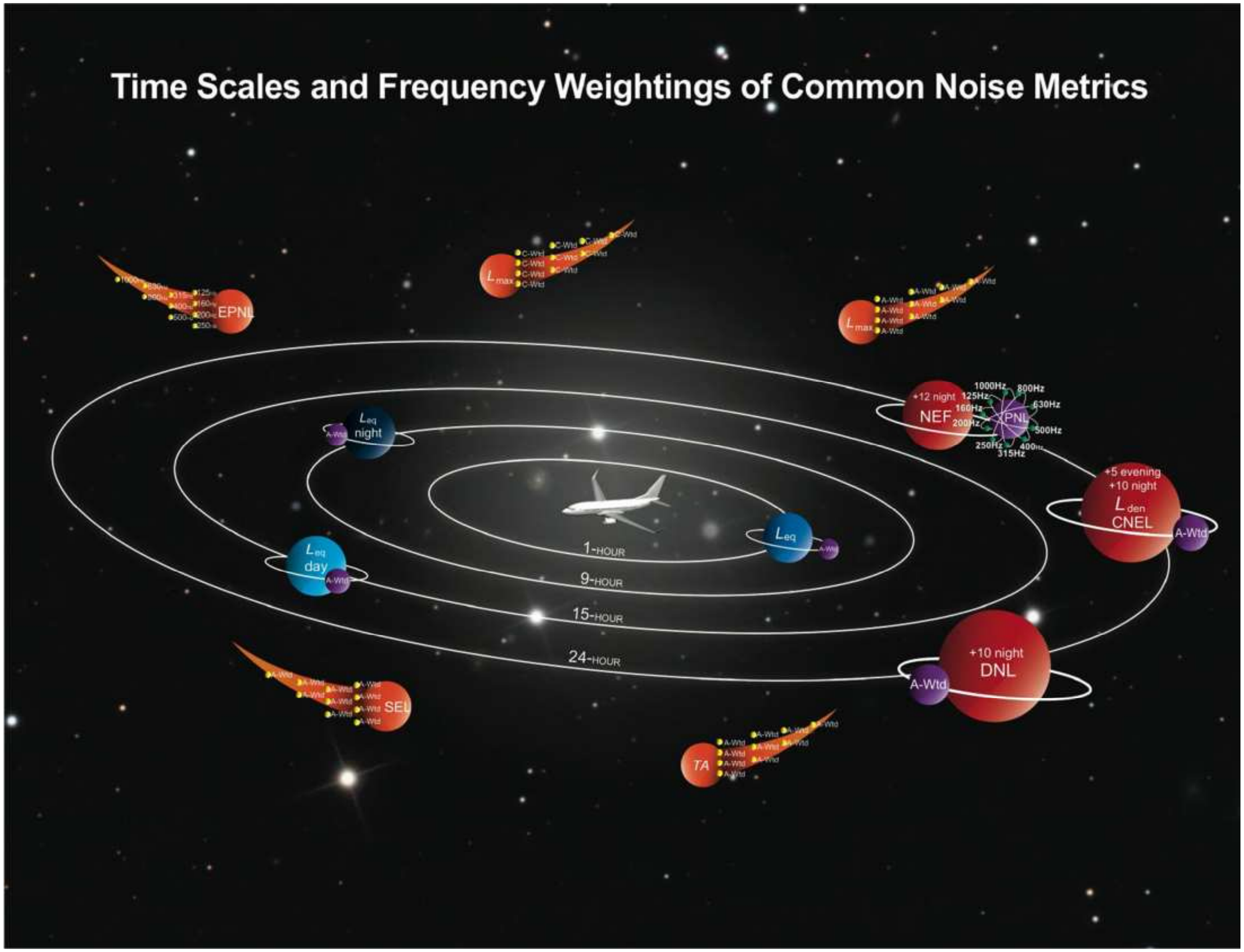

Figure 5: Common aircraft noise exposure metrics depicted as astronomical bodies orbiting a noise source, from Mestre *et al.*, 2011. The depiction emphasizes the various time scales and frequency weightings of different metrics.

A “Community Noise Rating” (CNR) value was determined by first estimating a “noise level rank” from a set of idealized spectral shapes for community noise. These shapes were developed from laboratory findings about the loudness of sounds in different frequency bands.[14] The noise level rank was 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. Each of these normalizations was accomplished by adding entirely *ad hoc* “correction factors” in increments of ± 5 dB.

CNR-based assessment of community reaction to environmental noise required a detailed case study, involved more-or-less arbitrary judgments about the detailed nature of noise exposure, and made no effort to account for the range of reactions associated with the same rating level. As seen in Figure 6 (taken directly from Galloway and Pietrasanta, 1963), the original CNR classification of community response distinguished three categories of severity of noise impact. Note further that community response was classified solely with respect to complaints (a behavior), not annoyance (an attitude).

Composite Noise Rating		Description of Community Response
Takeoffs and Landings	Runups	
Less than 100	Less than 80	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
100 to 115	80 to 95	Residents in the community may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	Individual reactions would likely include repeated, vigorous complaints and recourse to legal action. Concerted group action would be expected.

Figure 6: Three zones of severity of community response in the original Community Noise Rating System

3.1.2 *Noise Exposure Forecast (NEF)*

Following development of the Effective Perceived Noise Level (“EPNL”) metric in the late 1950s[15], CNR values were converted into NEF values as follows:

NEF = EPNL + 10 $\log_{10}$ [Number of daytime flight operations + 16.7 * (Number of night Time operations)] – 88 dB.

The constant 16.7 represents a 10 dB night penalty on the number of operations per hour (not the cumulative number of operations) when the ratio of 16 daytime hours to 9 nighttime

[14] CNR antedates development of the Perceived Noise Level scale, and so conducts its calculations on the notion of cumulative exposure to noise in an "equivalent 300-600 Hz octave band."

[15] Development of EPNL was a direct consequence of the community noise impact controversy surrounding the start of B-707 operations at New York Airports in 1958.

hours is taken into account. Both constants (16.7 and 88) in the above equation are entirely arbitrary, and based only on the experience and engineering judgment of Galloway and Pietrasanta. The constants were intended, respectively, to 1) weight night time flights ten times more heavily than day time flights, and 2) to avoid confusion between CNR and NEF values. In practice, the approximate relationship between NEF and CNR values was NEF = CNR – 72 dB.

On the basis of nothing more than field experience and engineering judgment, NEF values of 30 dB or less were believed to be suitable for aircraft noise exposure in areas of single family detached dwellings. NEF values between 30 and 40 dB were thought to be tolerable in neighborhoods of higher density housing, and NEF values in excess of NEF = 40 dB were thought of as suitable only for industrial and recreational purposes.[16]

When NEF values were supplanted by DNL values subsequent to publication of EPA's "Levels Document" in 1974, a further "correction" of 35 dB was added to NEF values to distinguish them from DNL values. All of the above "corrections," "adjustments," and constants were based on the personal opinions of acoustical consultants practicing in the 1950s through 1970s. None of their opinions were supported by any form of comprehensive, community-based, systematic, peer-reviewed, theory-based, or otherwise objective study or analysis.

3.2 DNL and the "Equal Energy" Hypothesis

DNL is the best known of the "equivalent energy" family of noise metrics. The tacit belief underlying use of DNL to predict community response to aircraft noise is known as the "equal energy hypothesis." This hypothesis holds that annoyance with aircraft noise exposure is equally determined by the number, duration, and acoustic energy of aircraft noise exposure. In other words, the hypothesis asserts that it is not simply the maximum level of an aircraft overflight that controls its annoyance, nor the duration of individual overflights, nor the numbers of overflights, but the multiplicative product of all three.

Because DNL directly expresses the simple product all of the primary factors (level, duration, and number) which can reasonably affect the annoyance of aircraft noise exposure, it is equally sensitive to all of them. Thus, if the number of aircraft operations increases by a factor of two (that is, by 3 dB, as explained in Appendix B), so does DNL. If the durations of aircraft overflights increase by a factor of two, DNL also increases by 3 dB. If the acoustic energy of individual aircraft overflights increases by 3 dB, so does DNL. In practice, this means that DNL is highly correlated with any sensible measure of aircraft noise.

Mestre *et al.* (2011) conducted an elaborate demonstration of the high correlation of DNL with virtually all other plausible measures of aircraft noise exposure. They used INM to model aircraft noise exposure at a notional one-runway airport served by a typical fleet of aircraft. They computed values of a variety of noise metrics at a closely spaced grid of points, and then computed a correlation matrix among all of the noise metric values.

The correlations between all other noise metrics and DNL were nearly perfect; so high, in fact, that DNL values varied from other noise metrics by little more than scale factors and constants. The very high correlations between DNL and other noise metrics mean that

[16] Beliefs about the suitability of aircraft noise exposure in outdoor recreational settings such as parks and wilderness areas have evolved greatly since, as evidenced by Public Law 100-91, the National Parks Overflight act of 1987.

mathematically, dosage-response relationship based on noise metrics other than DNL *cannot* explain any more variance in the relationship between DNL and the prevalence of high annoyance in airport neighborhoods than DNL already does.

The only aircraft noise metrics that were not nearly perfectly correlated with DNL were threshold-type metrics, such as numbers of events in excess of a sound level, and durations of exposure in excess of sound level. Such threshold-based noise metrics share an important limitation for regulatory purposes: their slopes are so steep that regulation based on them would be essentially dichotomous. As noted by Mestre *et al.* (2011), the values of time-above and number-above noise metrics "…are zero until a threshold is reached, after which they climb steeply until saturation is reached…. Once the threshold is exceeded, a small change in DNL can produce large changes in [*the noise metrics time- and number-above*]. The steep slope is an artifact of the logarithmic nature of DNL but the linear nature of TA and NA." In other words, the threshold-based metrics "time-above" and "number-above" are ill-suited for aircraft noise regulation, because they are insensitive to different degrees of aircraft noise over large portions of their ranges.

A further limitation of the threshold noise metrics for regulatory purposes is that they are sensitive to the composition of a fleet serving an airport. A fleet containing large numbers of, say, business or regional jets, but small numbers of larger jet transports, could produce the same values of a time-above noise metric as a fleet containing large numbers of much noisier four engine airliners, but very few smaller aircraft. Note also that INM calculations of metrics such as "time-above" and "number-above" are for informational purposes only, and not as predictors of community response.

DNL makes two further assumptions about the origins of annoyance with aircraft noise exposure. The first is that nighttime (10:00 PM through 7:00 AM) aircraft operations are an order of magnitude (10 dB) more annoying than aircraft operations at other times of day. The second assumption is that the optimal frequency weighting for predicting annoyance is the A-weighting network. It has been understood for several decades that the first of these assumptions is at best only approximately correct (*cf.* Fidell and Schultz, 1980). In practice, however, it matters little whether an aircraft noise metric assesses an 8 dB, 10 dB, or a 12 dB nighttime penalty. On a national basis, numbers of daytime operations dwarf numbers of nighttime operations, except at a small number of predominantly express delivery or air cargo airports.

Likewise, even though A-weighting of aircraft noise may not be an optimal approach to estimating its annoyance, it is probably good enough for most purposes. A low-frequency weighting network may be preferable for predicting annoyance in special cases (such as runway sideline and other airport-adjacent neighborhoods subjected to considerable ground run-up, thrust reverser, and start-of-takeoff roll noise). A loudness level weighting[17] would probably be preferable as well, but would yield only a minor improvement in the correlation of annoyance with exposure in most cases.

3.3 Use of DNL to Predict Prevalence of Noise-Induced Annoyance in Communities

The first systematic attempt to use of DNL to estimate the prevalence of a consequential degree of annoyance in communities was made by Schultz (1978). Schultz converted the noise

[17] The loudness of a sound varies with *both* frequency and absolute level. The A-weighting network does not vary with absolute sound pressure level.

measurement units of field studies available in the mid-1970s into units of DNL to conduct the first large-scale meta-analysis of the world-wide findings of social surveys on the annoyance of transportation noise. He included in his analysis all of the then-available information about transportation noise-induced annoyance, and produced a single fitting function for the combined data set. The relationship that Schultz derived was an informal ("eyeball"), rather than a statistical fit, described by an arbitrary third-order polynomial function.

As noted in Section 2.2, a number of other meta-analyses have since been completed, including those of Fidell *et al.*, 1989; Finegold *et al.* (1994); Miedema and Vos (1998), Miedema and Oudshoorn (2001), Fidell and Silvati (2004), and Fidell *et al.*, (2011). More recent meta-analyses have yielded transportation mode-specific fitting functions, produced by a variety of curve fitting methods. The most recent effort, described in Appendix H of ISO Standard 1996-1 (2015), is derived from first principles rather than as a statistical curve fitting exercise. As described in Appendix C, it also provides a well-defined, quantitative role for non-acoustic factors, in conjunction with DNL values, as a predictor of annoyance prevalence rates.

3.4 Common Mis-understandings of DNL

DNL is a widely mis-understood and widely mis-interpreted noise metric that is often distrusted by the public for a number of reasons. Mestre *et al*. (2011) point out that:

> A cumulative, 24 hour time-weighted annual average exposure 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 its units to 10log10 (86,400 seconds/day) are non-intuitive and poorly understood by non-technical audiences.
>
> Public understanding of prospective aircraft noise modeling and annual average day exposure contours, the context in which it often encounters DNL-based information, is weak. Prospective contours are inevitably speculative to some degree, since there are no facts about the future. The public nonetheless often confuses prospective noise contours with actual aircraft noise measurements, or with retrospective noise contours. Contours are also sometimes interpreted as step functions, and would be more reasonably depicted with shading rather than as sharp boundaries.
>
> The public does not fully appreciate the difference between DNL, a cumulative noise metric, and the interpretive criteria that FAA applies to DNL values for policy purposes. DNL is used in environmental impact disclosure documents as a required metric of noise exposure. The resultant focus on the metric in lieu of descriptive discussion of noise impacts is confusing and potentially misleading.

> DNL often suffers from a "shoot-the-messenger" reaction to unpopular policies that are expressed in units of decibels. This leads to a common criticism of DNL as a metric, rather than criticism of the manner in which noise exposure levels are interpreted for regulatory purposes.

3.5 Means for improving public communication of community noise impacts

The simplest solution to the problems of public confusion with DNL is to shift the focus of airport/community controversies away from noise exposure *per se*, back to where it belongs, on aircraft noise impacts. One way in which this may be accomplished is to label aircraft noise exposure contours in units of annoyance prevalence rates. Rather than labeling cumulative noise exposure contours in environmental impact disclosure documents in units of decibels, the same contours could be labeled in units of percentages of the population is highly annoyed by aircraft noise exposure.

Thus, for example, a set of noise exposure contours might show the decision makers for whom environmental impact disclosure documents are intended the areas within which 30%, 25%, 20%, 15%, 10%, and 5% of the residential population are highly annoyed by aircraft noise.

4 IMPROVED ESTIMATES OF AIRCRAFT NOISE ANNOYANCE IN ORD-VICINITY COMMUNITIES

Writing 44 years ago, Wyle (1971, p. 51) observed that inferences about noise impacts on communities in earlier times

> *"… were generally made in 5 dB intervals, since many of the initial relationships were based solely on the intuition of the authors, and it was considered difficult to assess the response to any greater degree of accuracy."*

Four decades later, it is no longer the case that estimates of noise impacts on communities must rely on crude, *ad hoc* interpretations of a sketchy noise effects literature, nor upon the intuitions of acoustical consultants. As described in Section 2.5.3, it is now apparent that the 1992 FICON dosage-response relationship on which FAA depends to transform aircraft noise exposure into the estimated prevalence of annoyance in communities considerably underestimates the actual prevalence of annoyance in most communities. Figure 7 illustrates the differences between FICON (1992) and the latest predictions of the prevalence of high annoyance due to aircraft noise exposure of Annex F of ISO Standard 1996-1.[18]

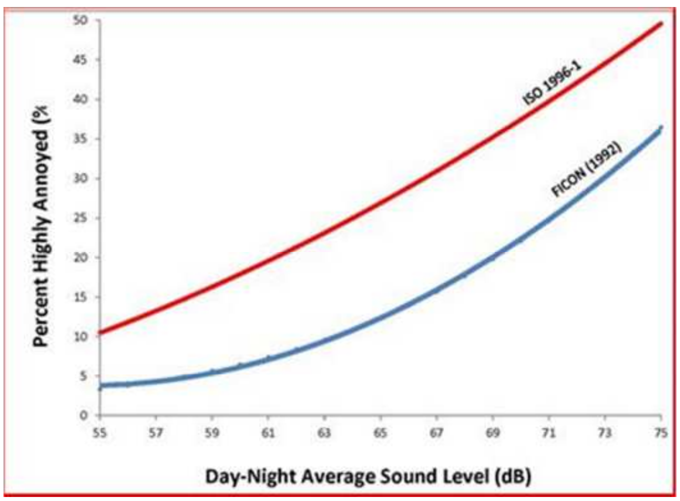

Figure 7: Graphic comparison of FICON (1992) and ISO (1996-1) predictions of aircraft noise-induced percentages of high annoyance for a community of average tolerance for aircraft noise.

At the same aircraft noise exposure levels, the modern (red) function shows considerably greater percentages of residential populations to be highly annoyed by aircraft noise exposure than the obsolete (blue) function.

Table 1 contains the same information as Figure 7, but in tabular form, for the case of a community of nominally average tolerance for noise exposure. The obsolete and incorrect

[18] The 2015 revision of ISO 1996-1 contains two dosage-response relationships for aircraft noise, one derived by conventional univariate regression methods, and one derived from first principles. For the special case of a community of nominally average tolerance for aircraft noise exposure, the two relationships are effectively identical.

FICON relationship indicates that about 12% of the population of a community of average tolerance for noise exposure is highly annoyed at an exposure level of L_{dn} = 65 dB. This indicates that FAA considers a significant aircraft noise impact to be one that consequentially annoys at least 12% of the residential population. Put another way, FICON's dosage-response relationship indicates that FAA's definition of significant aircraft noise impact of L_{dn} = 65 dB protects about 88% of the population from exposure to highly annoying aircraft noise.

Table 1. Tabular comparison of FICON and ISO predictions of aircraft noise-induced percentages of high annoyance for a community of average tolerance for aircraft noise.

Day-Night Average Sound Level, dB	% Highly Annoyed, *per* FICON (1992)	%Highly Annoyed, *per* ISO 1996-1
55 dB	3.3%	10.5%
56	3.8	11.9
57	4.3	13.3
58	5.0	14.7
59	5.7	16.3
60	6.5	17.9
61	7.4	19.5
62	8.4	21.3
63	9.6	23.1
64	10.9	25.0
65	12.3	26.9
66	13.9	28.9
67	15.7	30.9
68	17.6	33.2
69	19.8	35.2
70	22.1	37.5
71	24.6	39.8
72	27.3	42.1
73	30.2	44.5
74	33.3	47.0
75	36.5	49.5

Table 2 updates the DNL values which correspond to FAA's policy position to the current international scientific consensus standard. The cell entries in Table 2 display the equivalent DNL values required to protect the same population proportions from exposure to highly annoying noise for the obsolete (FICON) and current (ISO) dosage-response relationships. It is apparent from the rightmost column of Table 2 that FAA's L_{dn} = 65 dB definition of significant aircraft noise impact actually highly annoys about 27% of the population, not the 12.3% of the population that FICON predicts. Put another way, FAA's definition of significant aircraft noise protects only about 72% of the population from highly annoying aircraft noise exposure, not the 88% that FICON mistakenly estimates.

Table 2. DNL values for aircraft noise exposure that annoy equivalent percentages of residential populations, as predicted by FICON (1992) and by ISO 1996-1, Annex F

Predicted Percent of Population Highly Annoyed by Aircraft Noise	Percent of Population Protected from Exposure to Highly Annoying Aircraft Noise	Approximate DNL value (*per* FICON, 1992), decibels	Approximate DNL value (*per* ISO 1996-15), decibels
2%	98%	51.3 dB	46.3 dB
4	96	56.4	48.9
6	94	59.4	51.1
8	92	61.6	52.9
10	90	63.4	52.9
12	88	64.8	54.6
14	86	66.1	56.1
16	84	67.2	58.5
18	82	68.2	60.1
20	80	69.1	61.3
22	78	70	62.4
24	76	70.8	63.5
26	74	71.5	64.5
28	72	72.3	65.6
30	70	72.9	66.6
32	68	73.6	67.5
34	66	-	68.4
36	64	-	69.4
38	62	-	70.2
40	60	-	71.1
42	58	-	71.9
44	56	-	72.8
46	54	-	73.6
50	52	-	74.4

It is important to recall that the figures in Table 1 and Table 2 apply only to a special and rare case: a community of exactly average tolerance for noise exposure. Just as there are far more people who are either shorter or taller than average height than there are people of exactly average height, far more communities are either more or less tolerant of aircraft noise exposure than a hypothetical average community.

The great increase in numbers of unique aircraft noise complaints in ORD-vicinity communities since October, 2013 provides ample reason to believe that these communities are considerably *less* tolerant than average of aircraft noise exposure. This is the case even though it is well known that raw numbers of aircraft noise complaints can be artificially inflated by large numbers of robotically-filed complaints from small numbers of complainants.

Robotically-filed complaints are easily distinguished from non-robotically lodged complaints, however, and do not reasonably justify dismissing *all* complaints as spurious. Fidell *et al.* (2012) have shown that numbers of aircraft noise complaints per complainant follow Zipf's Law. The modal (most frequent) number of complaints per complainant at many airports is typically a small integer. Excluding from analysis hundreds or thousands of repetitive complaints from individual complainants has little effect on the modal number of complaints, because the number of such complainants is small. It is therefore unreasonable to dismiss complaints as unreliable indices of community response simply because many are generated by a few complainants.

The clear implication of the great increase in aircraft noise complaints since October of 2013 is that FAA's threshold of significant aircraft noise impact of L_{dn} = 65 dB highly annoys even more of the population than the 27% that it annoys in a community of average tolerance for aircraft noise as predicted by ISO 1996-15.[19]

The tolerance of communities for aircraft noise exposure can be measured empirically, as explained in Appendix C. Absent such direct field measurement, however, it is still possible to estimate the proportions of the residential populations of ORD-vicinity communities who are highly annoyed by aircraft noise from the new east-west runway orientations. It is also possible to estimate confidence intervals for predicted annoyance prevalence rates. This can be accomplished with respect to the variance of known distributions of tolerances for aircraft noise exposure, as explained by Fidell *et al.* (2014).

[19] The distinction between annoyance (an attitude) and complaints (a behavior) as indicators of community response to aircraft noise has in any event been rendered less important for regulatory purposes by a July 2013 D.C. Court of Appeals ruling. The ruling confirms that FAA has the authority to regulate flight paths on the basis of noise complaints, even with respect to areas outside the 65 dB DNL contour. In other words, the ruling indicates that FAA need not necessarily base its aircraft noise regulatory positions solely upon levels of aircraft noise exposure, but can also base them on documented aircraft noise complaints.

5 CONCLUDING COMMENTS

FAA identifies L_{dn} = 65 dB as a threshold of significant aircraft noise impact. This policy position relies on FICON's obsolete and flawed analysis of dated surveys that considerably underestimate the impact of aircraft noise on annoyance of communities. FAA's noise impact assessment methods do not reliably predict the adverse impact on ORD-vicinity communities of aircraft noise exposure following ORD's runway reconfiguration. At L_{dn} = 65 dB, the dosage-response relationship on which FAA depends to convert DNL values into estimates of the percentage of a community highly annoyed by aircraft noise underestimates the prevalence of aircraft noise-induced annoyance by more than a factor of two in an average community.

FAA's current threshold for significant noise impact (L_{dn} = 65 dB) is not based on a "highly reliable relationship between noise exposure and surveyed reactions of individuals to noise." They agency's current, demonstrably incorrect, rationale is inconsistent with the latest international technical consensus standard for assessment of population-level transportation noise impacts. If FAA's wishes to base its policy positions on objective scientific evidence, and to maintain consistency with the rationale established by its prior dosage-response analyses, then this definition of significant noise impact will have to change.

FAA's limitation of regulatory and financial relief for noise damages to properties within the 65 dB DNL contour is also inconsistent with a July 2013 D.C. Court of Appeals ruling confirming that FAA has the authority to regulate flight paths on the basis of noise complaints outside the 65 dB DNL contour.

The 2001 Data Quality Act (U.S. Public Law 106-554) requires that federal agencies maximize the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by the agency. To comply with this mandate, FAA regulatory positions with respect to aircraft noise effects will have to be updated to reflect the current international technical consensus about the prevalence of aircraft noise-induced annoyance. For FAA to maintain consistency with the contemporary objective scientific information – information that FAA acknowledges should provide the technical support and justification that it cites as a basis of its current regulatory framework – any such updating carries the strong implication that the agency's policy on the significance of noise exposure must also change.

Merely updating the definition of significant aircraft noise impact on a community of hypothetically *average* tolerance for noise exposure implies a reduction of about an order of magnitude (10 dB) in community-compatible aircraft noise exposure levels, from L_{dn} = 65 dB to approximately L_{dn} = 55 dB. For the sake of nationwide uniformity of regulatory effect, however, an even greater reduction in the definition of significant noise impact is necessary in communities of less-than-average tolerance for aircraft noise exposure.

The actual tolerance of a particular community for exposure to aircraft noise can be empirically quantified by means of a social survey, as explained in Appendix C. Such a social survey would permit estimation of a CTL value for ORD-vicinity communities that would permit better-informed decisions to be made about the significance of noise impacts resulting from ORD's runway reconfiguration project. It would also permit systematic and specific application of policy-based decisions about the percentage of a community that deserves protection from exposure to highly annoying aircraft noise to ORD-vicinity communities.

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7 GLOSSARY OF ABBREVIATIONS AND SYMBOLS

AIP: Airport Improvement Program

ANCA: **U.S. Airport Noise and Capacity Act of 1990 (Public Law 101-508)**

ANSI: American National Standards Insitute

ASNA: U.S. Airport Safety and Noise Act of 1979 (Public Law 96-193)

CTL: Community Tolerance Level. CTL is the value of DNL at which half of a community is highly annoyed by transportation noise exposure, and half is not.

CNEL: Community Noise Equivalent Level, a California state law noise metric similar to the European Union's Day-Evening Night Sound Level noise metric.

CNR: Community Noise Rating

CTL: Community Tolerance Level

DENL: Day-Evening-Night Average Sound Level

DNL: Day-Night Average Sound Level

EIS: Environmental Impact Statement

FAA: Federal Aviation Administration

FAR: Federal Aviation Regulation

FICAN: Federal Interagency Committee on Aircraft Noise, 1993 successor to FICON

FICON: Federal Interagency Committee on Noise, 1980 – 1992, successor to FICUN

FICUN: Federal Interagency Committee on Urban Noise, 1979-1980

ICAO: United Nations International Civil Aviation Organization

INM: Integrated Noise Model

ISO: International Standards Organization

L_{ct}: Mathematical symbol for Community Tolerance Level

L_{dn}: Mathematical symbol for Day-Night Average Sound Level

L_{den}: Mathematical symbol for Day-Evening-Night Sound Level

NA: INM abbreviation for the "Time Above" noise metric

NEF: Noise Exposure Forecast

NEPA: National Environmental Policy Act of 1969 [42 U.S.C. 4321 *et seq*.]

OMP: O'Hare Modernization Program

ONAC: EPA Office of Noise Abatement and Control

ORD: O'Hare International Airport

SEL: Sound exposure level, an EPA-endorsed integrated energy metric of sound normalized to a 1-second duration. (See also SENEL)

SENEL: Single event noise exposure level, a unit developed by the California Department of Aeronautics to compare the equivalent energy of individual aircraft overflights.

TA: INM abbreviation for the "time above" noise metric

%HA: The percentage of community residents who describe themselves a highly annoyed by transportation noise exposure.

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9 APPENDIX A: CHRONOLOGY OF MAJOR U.S. AIRCRAFT NOISE RESEARCH AND REGULATORY DEVELOPMENTS

This Appendix summarizes the evolution of U.S. aircraft noise regulation since the establishment of FAA as an independent agency within the Department of Transportation in 1958. Increases in aircraft noise exposure that accompanied the introduction into service of military and civil jet aircraft in the 1950s were accompanied by increasing public concern with aircraft noise effects on individuals and communities, and by a concomitant increase in legislative concern. Prior to the application of modern social survey methods to measurement of community response to aircraft noise in the early 1960s, however, understandings of aircraft noise effects in residential neighborhoods were limited to anecdotal case studies. Likewise, prior to the development of integrating sound level meters and other digital analysis techniques in the late 1960s, technical understandings of aircraft noise exposure were considerably more limited.

The following subsections describe developments in federal legislation, noise measurement technology, and technical understandings of community response to transportation noise during several distinct periods.

9.1.1 *Post-World War II Period – Start of Commercial Jet Service*

The U.S. Air Force and Navy initially became concerned about the habitability of military housing following the introduction of jet aircraft to military bases during the late 1940s and 1950s. The Air Force (particularly the Aerospace Medical Research Laboratory at the then-Wright Development Center, now Wright-Patterson Air Force Base) and other federal agencies sponsored considerable research during this time period which set the pattern for subsequent civil regulatory policies (*cf.* Ades *et al.*, 1953; Rosenblith *et al.*, 1953; Stevens *et al.*, 1955; Galloway and Pietrasanta, 1963; and BBN, 1967).

This early research was directed not only to measurement, modeling and understanding of aircraft engine and flight noise, but also to noise effects on individuals and communities. The early research led to development of environmental noise modeling and community noise assessment tools such as the Noise Exposure Forecast and the Composite Noise Rating systems.

9.1.2 *Start of Commercial Jet Service – Passage of Noise Control Act of 1972*

Commercial jet service began in the United States in 1958, the same year that the Federal Aviation Act (P.L. 85-226) established the modern FAA. The first large scale social survey of community response to aircraft noise was conducted at London Heathrow Airport in 1961 (McKennell, 1963).

The Effective and Tone-Corrected Perceived Noise Level noise metrics of FAR Part 36 were also developed in this time period to represent the frequency-weighted noisiness, rather than the broadband acoustic energy, of sounds.[20] Adoption of these metrics were part of the fallout of the Port of New York Authority's studies of the noisiness of Pan American Boeing 707

[20] The original publication of FAR Part 36 was in 1969, more than a decade after the start of commercial jet service in the U.S. Much of this delay was attributed at the time to the deliberate haste necessary to resolve technical questions about aircraft noise measurement – even though the U.S. Air Force and the Port of New York Authority had completed much of the relevant research prior to the start of commercial jet service. Civil aviation escaped meaningful noise regulation throughout this decade, in part due to FAA's early Congressional direction to promote civil aeronautics.

jets (Fidell, 2014). The Port had established a policy in 1951 of prohibiting operations at its airports by any aircraft that were noisier on takeoff and landing than existing four engine, propeller-driven passenger aircraft. Aircraft manufacturers had interpreted the Port's policy as "no greater overall sound pressure level."

The Port Authority concluded that B-707 overflights at altitudes comparable to those at which the aircraft would overfly homes near New York's (then) Idlewild Airport (now JFK) were intolerably noisy, and that the B-707 would be not be permitted to operate at Port Authority airports. It was estimated that jet noise would have to be reduced by 15 dB to be judged no more annoying than the noise of large, four engine propeller aircraft. This early research provided the impetus for many subsequent technical and regulatory developments.

The U.S. Air Force began development of the "NOISEMAP" computer software in the late 1960s. This software permitted the first routine construction of aircraft noise exposure contours. NOISEMAP inspired FAA to develop its own Integrated Noise Model ("INM") in the 1970s. Independent analyses were also conducted in the late 1960s by the California Department of Aeronautics (Wyle, 1971), leading to development of a system of integrated energy units (including SENEL and CNEL, later modified by EPA/ONAC into today's SEL and DNL noise metrics).

One of the more systematic approaches to quantifying aircraft noise during this era was adopted for California's airport noise regulations (Wyle, 1971). California's "Community Noise Equivalent Level" (CNEL) noise metric was based on a 24-hour summation of individual equivalent energy measures of individual aircraft noise events during day, evening, and night time periods. Noise events occurring during these three periods were characterized by their total acoustic energy, normalized to one second durations as Single Event Noise Exposure Level (SENEL) values. Before summing to yield a CNEL value, these SENEL values were assigned arbitrary "penalties" of 0, 5, and 10 dB, respectively, depending on their time of occurrence.

The Office of Noise Abatement and Control ("ONAC") of the U.S. Environmental Protection Agency explicitly recognized the California system:

> *"…one of the most important measures of environmental noise in terms of the effects of noise on man is the Energy Mean Noise Level, L_{eq}, which by definition is the level of the steady state continuous noise having the same energy as the actual time-varying noise" (von Gierke, 1973).*

In the same EPA report, von Gierke also noted that "to achieve an environment in which no more than 20%, of the population are expected to be highly annoyed and no more than 2% actually to complain of noise, the outdoor day-night average sound level should be less than 60 decibels.[21] Higher noise levels must be considered to be annoying to an appreciable part of the population, and consequently to interfere directly with their health and welfare."

[21] von Gierke's estimate of the prevalence of annoyance with aircraft noise at L_{dn} = 65 dB is within about one decibel of the ISO 1996-1 estimate (see Table 2). It was remarkably prescient for its time, and at odds with the later 1992 FICON dosage-response relationship, on which FAA continues to rely today.

9.1.3 *Noise Control Act of 1972 – 1979 Airport Safety and Noise Act*

Passage of the Noise Control Act of 1972 (Public Law 92-574), and creation of EPA's Office of Noise Abatement and Control, was the catalyst for much progress in the analysis and understanding of transportation noise effects. Two of ONAC's better-known publications were von Gierke's 1973 report on characterizing noise impact criteria in units of cumulative noise exposure, and EPA's 1974 "Levels of Noise Exposure Requisite to Protect Public Health and Safety with an Adequate Margin of Safety."

These early 1970s documents were followed by FAA's 1976 noise policy publication, which acknowledged the nationwide severity of the aircraft noise problem: "…aircraft noise adversely affects a significant portion of the nation's population." The prevalence of a consequential degree of noise-induced annoyance in a community eventually became the standard measure of transportation noise impact several years after Schultz's (1978) synthesis of a relationship between noise exposure and annoyance.

9.1.4 *Airport Safety and Noise Act – FICUN Report*

The 1979 Airport Safety and Noise Act ("ASNA") was the first federal legislation specifically addressing airport noise compatibility. ASNA required the Secretary of Transportation to "establish a single system for measuring noise that… has a highly reliable relationship between projected noise exposure and surveyed reactions of individuals to noise." Congressional mandates can direct executive branch agencies, but do not create objective facts or statistical relationships. If factors in addition to noise exposure are required to reliably predict the "surveyed reactions of individuals to noise," it is not within either Congress's or FAA's powers to mandate or create a relationship based on noise exposure alone.

In response to ASNA, FAA adopted the family of integrated energy noise metrics described in EPA's 1974 "Levels Document": sound exposure level (SEL) for single events, L_{eq} for cumulative exposure over arbitrary time periods, and Day-Night Average Sound Level (DNL) for 24 hour periods. As explained in Sections 3.1.1 and 3.1.2 and Appendix D, pre-existing interpretive criteria for aircraft noise impacts, originally expressed in units of CNR and NEF, were then transformed into units of DNL (Galloway, 2015).

Six years after the passage of ASNA, FAA implemented its provisions in FAR Part 150. FAR Part 150 contains no detailed information about the origins of FAA's land use compatibility recommendations, nor any rationale for defining the significance of noise impacts, in support of the DNL values displayed in Table 1 in Appendix A.

FICUN (the Federal Interagency Committee on Urban Noise), a self-organized group of federal agencies with interests in transportation noise but no explicit congressional charter to coordinate their policies, published a report in 1980 containing guidelines for land use planning and control. The FICUN (1980) report warned readers that unspecified federal agencies "have published policies and/or guidance on noise and land use" for purposes such as carrying out "public law mandates to protect the public health and welfare" and "to serve as the basis for grant approvals." Although the report noted that the guidelines did not consider the needs of communities for development, local zoning officials could be forgiven for mistaking the federal "recommendations" as all but compulsory. The language unambiguously suggests that federal authorities strongly discouraged certain land uses in neighborhoods near airports, and required building features such as noise insulation in some noise-exposed neighborhoods. The FICUN report provided no systematic rationale whatsoever for its recommendations.

FAR Part 150, published in final form in 1985, consolidated essentially all of the land use compatibility recommendations of the FICUN (1980) report into Table 1 of its Appendix A. A footnote to the table,[22] however, indicated that FAA's recommendations are subordinate to those of local authorities' judgments about the appropriateness of land uses. Part 150 elaborated further on FICUN's recommendations in several ways. For example, it was more specific than FICUN about the annualization of noise exposure criteria. Aircraft noise exposure modeling for civil airports was to be accomplished on an annual average day basis, not (as is still customary in Department of Defense noise modeling) on an average busy day basis. This specification minimizes the influence on predicted exposure levels of weekly and seasonal peaks in airport activity and prevailing wind directions, and of weather-related changes in aircraft performance.[23]

Part 150 also exempted from classification as "incompatible" any land use which generated more noise than aircraft overflights: "No land use has to be identified as noncompatible if the self-generated noise from that use and/or the ambient noise from other nonairacraft and nonairport uses is equal to or greater than the noise from aircraft and airport sources." In other words, Part 150 insists that aircraft noise exposure must exceed all other sources of environmental noise in a neighborhood, even if, decibel-for-decibel, aircraft noise is more annoying than other forms of noise exposure. In combination with the annualization of aircraft noise quantification, this exemption can be problematic in residential areas of moderate population density that are intermittently exposed to overflights.

According to Suter (1991), the Airport Noise and Capacity Act of 1990 (ANCA) was intended "to remove the issue of airport noise … as the principal barrier to airport expansion by "increasing federal control over local airports, and by doing away with the favorite whipping boy of the airlines, the 'patchwork quilt' of local noise rules." The aviation industry (and in particular, night air cargo operators)[24] were deeply concerned in the late 1980s by the agreement made by the proprietor of Stapleton Airport in Denver to facilitate construction of a new airport in adjacent Adams County. The City and County of Denver had to annex 45 square miles of the adjoining county, and agree to pay Adams County half a million dollars if DNL values in the future at any of 100 noise measurement points identified in an Inter-Governmental Agreement exceeded aircraft noise levels hitherto produced by Stapleton Airport.[25]

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[22] "The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses."

[23] Aircraft departing airports in hot summer weather may overfly communities at lower altitudes than in cold winter weather.

[24] Recall that DNL penalizes noise generated between 10 PM and 7 AM by 10 dB with respect to noise generated during the day, as shown in Figure 11.

[25] Following lengthy rounds of litigation in which Denver repeatedly lost appeals of judicial rulings against it, the Colorado Supreme Court confirmed Denver's obligation to pay Adams county tens of millions of dollars in fees for its subsequent violations of the Inter-Governmental Agreement.

ANCA's provisions were designed to forestall any further impediments of this sort on airport expansion. Suter (1991) notes that the bill was passed without the benefit of any public hearings; that public input was not sought; and that industry lobbyists were closely involved in drafting and approving its language. FAR Part 161, the implementing regulation for ANCA, imposes Kafka-esque requirements on airports seeking FAA approval for operational restrictions.

9.1.5 *FICON Report*

FICUN disbanded shortly after producing its 1980 report. FICON, the Federal Interagency Committee on Noise, was formed in December of 1990 to review the manner in which noise impacts are determined and described and the extent of impacts outside of DNL 65 dB that should be reviewed in a NEPA document. Additional information about community response to aircraft noise had been collected, and dosage-response analysis of the sort pioneered by Schultz (1978) had gained increasing acceptance in the decade since publication of the FICUN report.

FICON's August, 1992 report broke little new ground. The dosage-response relationship that FICON endorsed again failed to recognize any form of source specificity in community response to transportation noise. FICON re-confirmed and extended the land use recommendations of the FICUN report, again without supplying any systematic rationale for them. FICON did recognize circumstances in which transportation noise impacts at levels below L_{dn} = 65 dB could be examined for NEPA-related purposes, but did not modify its definition of significant noise impact.[26]

FICON also rejected the use of complaints as a basis for assessing noise impacts, on the curious grounds that "Annoyance can exist without complaints and, conversely, complaints may exist without high levels of annoyance."[27] As noted by Fidell (2003), however, "…it is equally true that high levels of annoyance can exist at low levels of noise exposure, and low levels of annoyance can exist at high levels of noise exposure. The lack of a strong or simple relationship between noise exposure and its effects is neither a consistent nor a persuasive rationale for ignoring noise complaints in policy analyses." For purposes of predicting community response to aircraft noise, a variable (such as complaint rates) that lacks a strong correlation with annoyance is in fact desirable, because it may explain variability in relationships between noise exposure and adverse community response apart from that which can be attributed to annoyance prevalence rates.

9.1.6 *Post-FICON – present*

FAA regulatory policy has not substantively changed since the FICON report. A new embodiment of the FICUN and FICON groups, the Federal Interagency Committee on Aircraft

[26] Pages 3-5 and 3-6 of the FICON report identify these circumstances as increases of 3 dB in aircraft noise exposure at levels below L_{dn} = 65 dB, and of 1.5 dB in aircraft noise exposure at levels in excess of L_{dn} = 65 dB.

[27] More recently, the U.S. Court of Appeals in Washington, D.C. has ruled that FAA does, in fact, have the authority to regulate aircraft noise and flight paths on the basis of documented complaints.

Noise, was formed in 1993. Like its predecessors, FICAN is self-organized, and lacks any Congressional charter.

Major advances in prediction of community response to transportation noise have continued, however, with little regard for policy positions taken by U.S. regulatory agencies. European interest in assessing transportation noise impacts, which had lagged U.S. interest in earlier decades, increased considerably in the 1990s. Miedema and Vos (1998), for example, published persuasive arguments for greater annoyance prevalence rates at similar exposure levels for aircraft noise than for that of road and rail noise. By 2002, the European Union had adopted a European Noise Directive that recognized major differences in community response to aircraft and other transportation noise.

FAA published a draft 2000 policy statement in the Federal Register which included observations that "Based upon local factors, local jurisdictions may take a more comprehensive approach to aviation noise exposure below DNL 65" and that "Some communities are more noise sensitive than others." These observations do not seem to have affected subsequent FAA noise regulatory policy, however.

Working Group 45 of the International Standards Organization's Technical Committee 43 began a lengthy review of its 1996-1 standard ("Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures") about five years ago.[28] As part of its updating and revision of the standard, ISO has adopted several positions concerning the prediction of community response to transportation noise which conflict with those of FICON (1992).

More specifically, the revised 1996-1 standard indicates that community response to aircraft noise exposure differs from community response to road and rail noise. Whereas the dosage-response relationship in the FICON report did not distinguish between the annoyance of aircraft and other transportation noise sources, the ISO standard now indicates that decibel-for-decibel, aircraft noise is more annoying than road and rail noise (see Chapter 4). The dosage-response relationship for aircraft noise endorsed by ISO is now essentially identical to that of the European Union's Environmental Noise Directive.

The ISO standard also endorsed Community Tolerance Level (CTL) analysis, as described by Fidell *et al.* (2011). The research on which CTL analysis is based was funded by FAA through DOT's Volpe Transportation Systems Center. CTL analysis explains half again as much variance in the relationship between cumulative noise exposure (as measured by DNL) and the prevalence of aircraft noise-induced high annoyance in communities. It does so by explicitly accounting for community-specific differences in response to noise exposure, as described in Appendix B.

FAA's reliance on the dosage-response relationship in the FICON report for predicting community response to aircraft noise exposure is now in conflict with the international scientific consensus. FAA will very likely be compelled to modify its technical position on the prediction of community response to aircraft noise. Whether it will also modify its policy judgments remains to be seen.

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[28] The revised standard is currently in the final stage of editorial proofreading, and is to be published shortly without any further technical changes.

10 APPENDIX B: SOME BASICS OF DECIBEL NOTATION AND RELATIONSHIPS AMONG NOISE METRICS

10.1 Linear vs. Logarithmic Measurement Scales

Measurement scales can make it convenient to express measured quantities in either absolute units, or as ratios. The former type of scale is usually referred to as “additive” or “linear”; the latter type of scale is usually referred to as “multiplicative” or “ratio.” The type of measurement scale used to express quantities of interest depends in part on the range of measurements to be made. Consider how *in*convenient it would be for traffic signs to warn drivers that the next highway exit is 126,720 inches (2 miles) ahead, or that their destination city is 6,336,000 inches (100 miles) distant.

Familiar sounds can vary simultaneously and enormously in frequency and sound level. The sound pressure of a sound that is barely audible can be 1,000,000,000,000 – twelve orders of magnitude – smaller than that of a sound that is painfully loud. A measurement scale that preserve *ratios* of sound pressures, rather than absolute units, is much more convenient for aircraft noise measurement over the enormous range of sounds levels to be expressed. For purposes of measuring aircraft noise, it is much more convenient to express sound pressures as ratios; for example, by indicating that an overflight creates a million or a billion times more acoustic energy than a very faint sound.

Measurement scales with which the public is most familiar preserve absolute differences in magnitude, rather than *ratios* of differences. Because ratios are conveniently expressed in logarithmic notation, a brief review of the basics of logarithms is helpful. The notation $\log_{10}(100) = 2$ is simply a way to say that raising 10 (the base of the logarithm, shown as a subscript) to the second power (10^2) yields 100. Likewise, $\log_{10}(1{,}000{,}000) = 6$ means that 10 raised to the sixth power (10^6) is 1,000,000, and so forth. Figure 8 illustrates the relationships among ratios, powers of ten, and decibel notation.

Measuring quantities in units of ratios implies a comparison between a sound of interest (in the numerator of the comparison) and a reference sound of a known magnitude (in the denominator). The sound pressure of the reference in the denominator is by convention extremely small.[29] Even this much pressure is too big for many purposes, and so is divided by ten to yield a “*deci*bel.” A decibel is just 10 times the $\log_{10}$ of a ratio, of the form 10 $\log_{10}$ (sound pressure of interest/reference sound pressure).

Logarithmic arithmetic differs from linear arithmetic because exponents are not additive. Adding one million (one followed by six zeroes) to one million yields two million, not a million million (a trillion, or 1 followed by twelve zeroes; that is, 1,000,000,000,000), just as adding 10^6 and 10^6 yields $2*10^6$, ***not*** 10^{12}. Similarly, adding 60 dB to 80 dB does not yield 140 dB, but only little more than 80 dB – just as the sum of a million and a billion (1,000,000 and 100,000,000) is a number only slightly greater than a billion.

[29] The reference pressure for sounds measured in air is 20 μPa – twenty millionths of a Pascal. A Pascal is defined as a Newton per square meter, and a Newton is the force required to accelerate one kilogram by one meter per second.) In English units, the reference sound pressure is about twenty *millionths* of a pound per square inch.

Ratio	Example	Power of 10	10 log (decibel) Notation
1:1		0	0 dB
10:1		1	10 dB
100:1		2	20 dB
1,000:1		3	30 dB
10,000:1		4	40 dB

Figure 8: Illustration of relationships among ratios, powers of ten, and decibels. (Recall that any number raised to the zero power, such as 10^0 is, by definition 1.)

Likewise, adding 60 dB and 60 dB yields only 63 dB, *not* 120 dB. This is because $\log_{10}(2) = 0.3$ (ten raised to the 0.3 power, or $10^{0.3}$, is 2.) By extension, two doublings of 3 dB, such as the addition of (60 dB + 60 dB = 63 dB) to (60 dB + 60 dB = 63 dB) = 66 dB. In other words, the decibel sum of four identical noises, each at a level of 60 dB, yields only 66 dB, *not* 240 dB.

10.2 Summation of Sound Exposure Levels to Calculate DNL values

A DNL value for aircraft noise exposure may be thought of as a summation of the sound exposure levels of multiple individual aircraft overflights. The concept of a sound exposure level (SEL) is illustrated Figure 9. Like a DNL value, an SEL value is sensitive to all of the acoustic energy occurring over a specified time period.[30] In effect, an SEL measurement "squeezes" all of the aircraft noise measured over the course of an overflight into a one second time period. This means that SEL values for overflights lasting more than one second are greater numerically than the maximum level actually observed during the course of the overflight.

[30] In the case of an SEL value, the time period is one second. In the case of a DNL value, the time period is 24 hours, further divided into 15 hour "daytime" and 9 hour "nighttime" time periods.

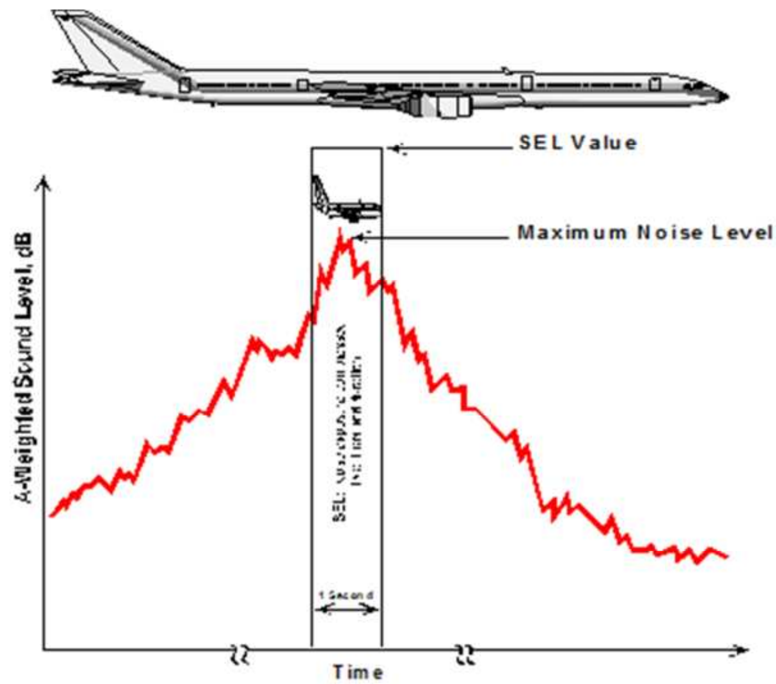

Figure 9: Illustration of concept of a sound exposure level

Sums of SEL values follow the rules for logarithmic addition described above. Thus, the SEL created by two identical aircraft overflights occurring at precisely the same time will result in an SEL value measured at the same point on the ground that is 3 dB greater than that created by a single overflight. The SEL created by four identical aircraft overflights occurring at precisely the same time will result in an SEL value 6 dB greater than that of a single overflight; and so forth. The sum of multiple SEL values yields an "equivalent energy" metric, represented symbolically in mathematical expressions as L_{eq}.

Because DNL is normalized to a 24 hour time period, the simple sum of SELs (which are normalized to a one second time period) must be adjusted by the number of seconds in a day. The number of seconds in a day (86,400, or 60 seconds x 60 minutes x 24 hours) equals 49.4 dB when represented in logarithmic notation as $10 \log_{10}$ (86,400). This value must therefore be subtracted from a day's summation of SEL values. Thus, a single daytime noise event with an SEL of 100 dB creates a DNL value of 50.6 dB. The sum of the SELs of two noise events, each of 100 dB, is 3 dB greater, so two such noise events in the course of a day create a DNL of 53.6 dB, and so forth.

If a noise event occurs during night time (10 pm to 7 AM) hours, 10 dB is added to its SEL. Thus, a single night time noise event with an actual SEL of 100 dB creates a DNL of 60.6 dB, not 50.6 dB. Two night time noise events would likewise sum to a DNL value of 63.6 dB.

A simple summation of SEL values of multiple overflights over the course of a day therefore yields a 24 hour equivalent level, typically represented symbolically as $L_{eq(24)}$. $L_{eq(24)}$ values differ from DNL and CNEL values, however, because various weighting factors are added to numbers of noise events occurring at various times of day. The notion is illustrated in Figure 10 and Figure 11.

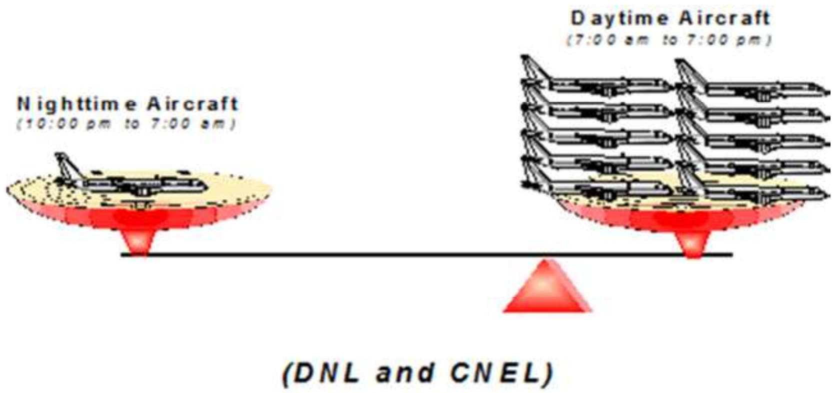

Figure 10: For calculations of DNL and CNEL values, a single nighttime aircraft operation is assumed to produce ten times as much noise energy as ten daytime aircraft operations.

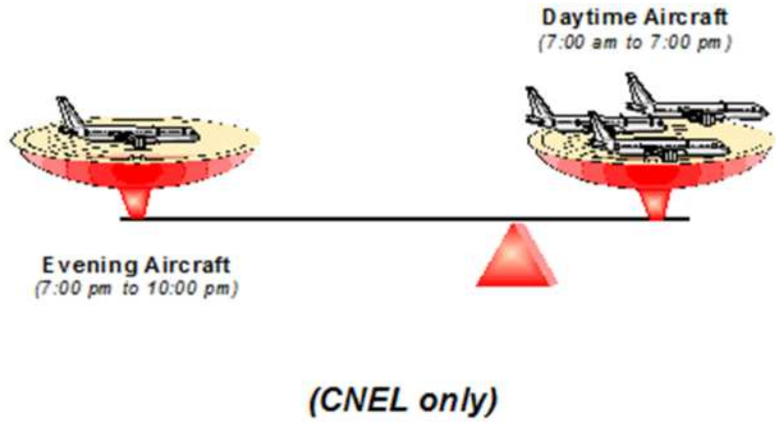

Figure 11: For calculation of CNEL values, a single evening aircraft operation is assumed to produce five times as much noise energy as three daytime aircraft operations.

In practice, DNL and CNEL values for aircraft noise exposure differ little – typically by 2 dB or less – because numbers of night time aircraft operations are a small fraction of daytime operations at most airports. (A European noise metric, known as L_{den} with slightly different definitions of penalties for noise created during some hours of the day, also differs slightly from both CNEL and DNL.) Numeric values of CNEL, DNEL, and DNL measures of aircraft noise are typically negligible for most practical purposes.

11 APPENDIX C: MODERN PREDICTION OF ANNOYANCE PREVALENCE RATES IN AIRPORT COMMUNITIES

The body of this report omits certain technical detail to facilitate general understanding of its contents. This Appendix contains additional detail. Portions of the text of the Appendix paraphrase that of Mestre *et al.* (2012) and of Fidell *et al.* (2014).

Fidell *et al*. (2011) and Schomer *et al.* (2012) have recently shown that a first-principles approach to explaining differences in community response to noise accounts for appreciably more variance in the association between transportation noise exposure and annoyance prevalence rates than purely descriptive (univariate regression-based) analyses (Wilson *et al.*, 2013). The additional variance is explained by a second independent variable, the Community Tolerance Level (abbreviated CTL, and represented symbolically in equations as L_{ct}).

The CTL approach follows from the observation that the rate of growth of community annoyance with transportation noise exposure closely resembles the rate of growth of loudness with sound level. A CTL value is an estimate of the DNL value at which half of a community describes itself as highly annoyed by transportation noise exposure. The range of CTL values derived from social survey measurements of reactions to aircraft noise in 44 communities extends over three orders of magnitude (from roughly 55 dB $\leq L_{ct} \leq$ 85 dB), equivalent to a factor of about 1000:1 in community-specific tolerance for aircraft noise exposure. - if one considers road (69 dB $\leq L_{ct} \leq$ 92 dB) and rail (61 dB $\leq L_{ct} \leq$ 92 dB) studies as well (Schomer *et al.*, 2012) The range of CTL values for all transportation sources extends over a range of 37 dB - a factor of about 5000:1 in energy (55 dB < All L_{CT} < 92 dB).

Annoyance prevalence rates in CTL analyses are predicted as

$$\text{Percent (Highly Annoyed)} = e^{-(A/m)}, \qquad \text{(Eq. C-1)}$$

where A is a scalar, non-acoustic decision criterion originally described by Fidell et al. (1988),

m is an estimated noise dose, calculated as

$$m = (10^{(DNL/10)})^{0.3} \qquad \text{(Eq. C- 2)}$$

and CTL is calculated from A as follows:

$$CTL = 33.3 \log_{10} A + 5.32 \qquad \text{(Eq. C-3)}$$

The value of A, a non-acoustic decision criterion, and hence of CTL, reflects the non-dose-related factors which influence annoyance prevalence rates in a community.

The value of A in a given community is that which minimizes the root-mean-square error between predicted (per Eq. 1) and empirically measured annoyance prevalence rates (Green and Fidell, 1991; Fidell *et al.*, 2011). Since m is just a transform of DNL, a quantitative estimate of the tolerance parameter, A, can be derived from knowledge of %HA and DNL at an interviewing site. The algebraic derivation of A from Eqs. C-1 and C-2 is straightforward. It begins by taking the natural logarithm of both sides of Eq. C-1, and substituting the definition of m (from Eq. C-2), yielding

$$-\ln [p(HA] = A/(10^{(DNL/10)})^{0.3} \quad \text{(Eq. C-4)}$$

Taking 10 log10 of both sides of the equation produces

$$10 \log_{10} \{-\ln[p(HA]\} = 10 \log_{10} A – 0.3 \text{ DNL} \quad \text{(Eq. C-5)}$$

Adding 0.3 DNL to both sides and rearranging terms then yields

$$10 \log_{10} A = 10 \log_{10} \{-\ln[p(HA]\} + 0.3 \text{ DNL} \quad \text{(Eq. C-6)}$$

The empirical distribution of community-specific A values can be determined by means of these equations directly from databases of community-specific social survey findings, such as those published by Fidell *et al.*, 2011 (for aircraft). The distribution of A values is shown in Figure 12, from Fidell *et al.*, 2014.

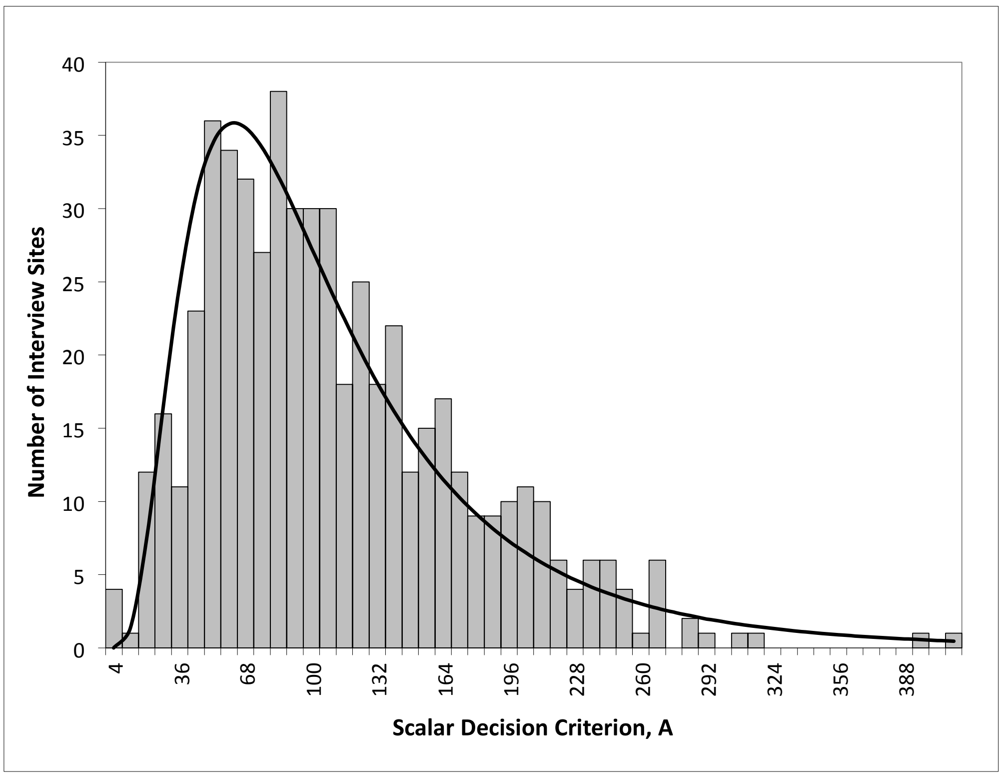

Figure 12: Histogram of scalar quantity, A, in 44 communities exposed to aircraft noise.

Figure 12 shows that the distribution of tolerance for aircraft noise exposure among communities is highly skewed. A few communities are highly tolerant of aircraft noise exposure, but that most are relatively intolerant. Predictions of community response to aircraft noise exposure which fail to take the shape of this distribution into account – *i.e.*, those which apply only to a hypothetical community of average tolerance for aircraft noise – are likely to be appreciably in error in most communities. Conversely, regulatory policy that ignores *bona fide* differences across communities in tolerance for noise exposure cannot have uniform effect nationwide.

Table 3, from Fidell *et al.* (2014), illustrates this point for three communities: one that is one standard deviation *less* tolerant of aircraft noise than average ("-1σ"); one of average tolerance for aircraft noise ("mean"), and one that is one standard deviation *more* tolerant of aircraft noise than average ("+1σ"). According to ISO 1996-1, FAA's current definition of significant noise impact (L_{dn} = 65 dB) protects only 53% of the residents of the first community from exposure to highly annoying aircraft noise, but 86% of the residents of the latter community from exposure to highly annoying aircraft noise.

Table 3. Percentages of residential populations of communities of varying tolerance for noise exposure protected from exposure to highly annoying aircraft noise for various definitions of significant noise impact

	% OF POPULATION PROTECTED FROM HIGH ANNOYANCE		
DNL	CTL = 66.3 (-1σ)	CTL=73.3 (mean)	CTL=80.3 (+1σ)
65	53	71	86
60	66	80	94
55	78	91	98
50	88	97	100
45	95	99	100

12 APPENDIX D: RATIONALE FOR FAA LAND USE COMPATIBILITY RECOMMENDATIONS

All regulation is intended to balance conflicting societal interests. In the case of aircraft noise regulation, the conflicting interests include satisfying demand for air transportation services, maintaining the habitability of residential neighborhoods near airports and the integrity of local government tax bases, and protecting both public investment in airport infrastructure and private residential property values.

Figure 13 depicts FAA's view of the proper balance between these interests. FAA places the fulcrum – the level of noise exposure which it believes strikes the appropriate balance between aviation-related and community interests – at L_{dn} = 65 dB. At this level of noise exposure, FAA (erroneously, as explained in Chapter 4) believes that 12.3% of the residential population is highly annoyed by *all* transportation noise exposure.

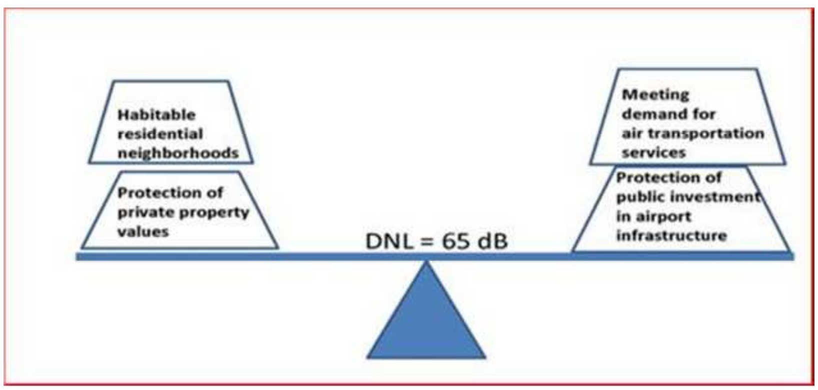

Figure 13: FAA view of the correct balance between community and airport interests.

FAA routinely expresses the significance of noise impacts indirectly, as a magnitude of noise exposure, rather than as a magnitude of noise effect (for example, as a prevalence of high annoyance). Fidell *et al.* (2014) note that this practice is a form of shorthand that focuses attention on noise exposure *per se*, rather than on its effects – even though the plain object of regulation of aircraft noise is to identify and control noise impacts. Indirect expression of noise impacts is also an impediment to public understanding of FAA definitions of their significance. While few members of the public fully understand decibel notation and decibel arithmetic, a great many appreciate what it means to be annoyed by aircraft noise.

The primary goal of FAA land use compatibility recommendations is to protect public investment in airport infrastructure. FAA's "compatibility" guidelines suggest land uses that do not threaten the continued operation and expansion of airports, not land uses that preserve neighborhood amenities and residential quality of life. FAA has never had a legislative charter to protect the habitability of residential neighborhoods, nor to balance aviation industry interests against community interests.

As used by FAA, the concept of land use compatibility is not a reciprocal one. The one-way nature of FAA's land use compatibility guidance is readily apparent from official statements such as the following:

> *"Many [local officials] are not clearly aware of their responsibility to protect the local airport from adjacent non-compatible development that can slow or even halt airport growth. All too often, in jurisdictions around the nation, we see residential development around airports that is not compatible with current or projected noise impacts." (Dykeman, 1997)*

> *"State and local governments and planning agencies must [emphasis added] provide for land use planning and development, zoning, and housing regulation that will limit the uses of land near airports to purposes compatible with airport operations." (Dykeman, 1997)*

In other words, even though FAA has no authority over local land use decisions, the agency subordinates community interests to those of airports. FAA policy even asserts that it is the responsibility of local governments to actively restrict community development in order to facilitate unfettered airport operations and potential airport growth. This is a remarkably broad reading of the original 1958 Federal Aviation Act, let alone the post-Public Law 104-264 amendment which relieved the agency of responsibility for promoting civil aeronautics.

FAA's land use compatibility recommendations are set forth, among other places, in the 1985 publication of FAR Part 150 – the implementing regulation for ASNA. Table 1 in Appendix A of FAR Part 150 lists FAA's recommendations for land uses that do not threaten or impede airport operations or future growth of airports. The most relevant part of the table for the current discussion is that no residential land uses are considered to threaten continued operation and expansion of airports at noise exposure levels less than L_{dn} = 65 dB. (The table also recommends noise exposure levels considered suitable for non-residential land uses, such as commercial, industrial and recreational uses).

FAR Part 150 provides no systematic rationale, nor any objective analysis, nor documented evidentiary basis, nor technical justification, nor any other explanation of its recommendations. Instead, FAA typically characterizes its land use compatibility recommendations as "widely recognized" and "generally accepted," without documenting why or by whom the agency believes that they are recognized and accepted.

The lack of a systematic rationale in FAR Part 150 for land use compatibility recommendations is traceable to their wholesale adoption from prior practice and publications. Identification of DNL at 65 dB as the level of cumulative aircraft noise considered significant can be traced to the FAA's Aviation Noise Abatement Policy of 1976 and to the FICUN (1980) report. The Part 150 land use compatibility recommendations differ only in minor detail from those of FICUN's 1980 report, for example.

The recommendations in the FICUN report, in turn, are based on little more than custom and common practice, professional judgment, anecdotal military experience in the 1950s, and the opinions and intuitions of the World War II generation of acoustical consultants, first expressed in the 1950s and 1960s. These traditional value judgments lack meaningful scientific content.

Eagen and Gardner (2009) further note that:

"Review of the actions leading to adoption of DNL 65 land use compatibility guideline demonstrates that it was intended to be adjusted as industry needs changed (in particular, as technology improvements resulted in quieter aircraft). In addition, adoption of the DNL 65 guideline in the 1970s and 1980s reflected a compromise between what was environmentally desirable and what was economically and technologically feasible at the time."

As noted above, even though regulation of aircraft noise exposure is intended to manage and control aircraft noise effects, cell entries in Table 1 of FAR Part 150 quantify "compatibility" indirectly; that is, in units of noise exposure, rather than in units of noise effects. (As discussed in Section 2.5.3, conversion from noise exposure units to the prevalence of noise exposure in communities is accomplished by means of a dosage-response relationship that transforms noise exposure into the prevalence of a consequential degree of annoyance in communities.)

The table entries indicate that FAA considers residential land uses as "compatible" with airports at noise exposure levels as high as L_{dn} = 65 dB. Having been released by the U.S. Supreme Court of liability for aircraft noise damages in the 1962 Griggs *v.* Allegheny County[31] litigation, the Federal government has since been at pains to avoid incurring further liability. A footnote accompanying Table 1 in Appendix A of FAR Part 150 therefore states that:

"The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses."

The language of this footnote indicates that FAA recognizes that local land use decisions are the exclusive domain of local governments.

[31] Griggs *v.* Allegheny County established that the U.S. Government (which controls the movements of aircraft in flight) and airlines (which own airplanes) have *no* liability for aircraft noise damages. The Supreme Court ruling established that this liability belongs exclusively to airport proprietors.

13 APPENDIX E: DERIVATION OF NOISE EXPOSURE FORECAST EQUATIONS

This appendix provides the assumptions and constants used in the equation relating Noise Exposure Forecast (NEF) to Effective Perceived Noise Level (EPNL) and the number of daytime and nighttime operations producing identical EPNLs. This process is documented in Bishop & Horonjeff (1969). The basic equation relating these variables

$$NEF = EPNL + 10\ Log10\ \left[\frac{N(day)}{K(day)} + \frac{N(night)}{K(night)}\right] - C$$

Eqn. E-1

where: *NEF* = Noise Exposure Forecast, in dB
EPNL = Effective Perceived Noise Level, in EPNdB

K (day) was chosen so that for 20 movements of a given aircraft per daytime period (0700 to 2200), the adjustment for number of operations would be zero. Hence,

$$10\ Log\ \left[\frac{20}{K(day)}\right] = 0$$

Eqn. E-2

Therefore,

$$K(day) = 20$$

K (night) was chosen such that for the same average number of <u>operations per hour</u> during daytime or nighttime (2200-0700) periods the NEF value for nighttime operations would be 10 units higher than for daytime operation. Hence,

$$10 = 10\ Log\ \left[\frac{K(day)}{K(night)} \cdot \frac{9}{15}\right]$$

Eqn. E-3

Where: 9 and 15 are the number of hours in the nighttime and daytime periods respectively.

Therefore,

$$K(night) = 1.2$$

The value assigned to C was 75. Choice of this value was based upon two considerations.
First, it was desirable that the number assigned to the NEF values be distinctly different in magnitude from the effective perceived noise level so that there would be little likelihood of confusing effective perceived noise levels with NEF values. Second was the desirability of selecting a normalization factor that would roughly indicate the size of the NEF value above

some threshold value, indicating the emergence of the noise exposure levels which would have little or no influence on most types of land usage.

Substituting these three constants into Equation E-1 yields the following:

$$NEF = EPNL + 10\ Log\ \left[\frac{N(day)}{20} + \frac{N(night)}{1.2}\right] - 75$$

Eqn. E-4

Multiplying the terms inside the brackets by 20 and compensating for the multiplication outside the brackets produces:

$$NEF = EPNL + 10\ Log\ [\ N(day) + 16.67 \cdot N(night)\ ] - 10\ Log\ [20] - 75$$

Eqn. E-5

And:

$$NEF = EPNL + 10\ Log\ [\ N(day) + 16.67 \cdot N(night)\ ] - 13 - 75$$

Eqn. E-6

Resulting in:

$$NEF = EPNL + 10\ Log\ [\ N(day) + 16.67 \cdot N(night)\ ] - 88$$

Eqn. E-7

By comparison:

$$DNL = SEL + 10\ Log\ [N(day) + 10\ N(night)] - 49.4$$

Eqn. E-8