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Fifty years of aircraft noise annoyance – time to introduce new ideas

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ABSTRACT

Researchers have tried for half a century to establish predictively useful relationships between transportation noise exposure and annoyance. Several curves have been developed since Schultz' initial general dose-response curve in 1978. Although most researchers agree that the annoyance of aircraft noise is only partially determined by noise exposure levels, many still believe that a single "correct" dosage-response relationship can be used to predict annoyance in all airport communities. Researchers continue to feed the ever-growing database of social survey results into correlational software which yields regression functions that only statisticians appreciate, and which lack causal interpretability. This conventional search for a holy grail of annoyance prediction is futile. Noise-induced annoyance depends on a variety of survey-specific, non-acoustic factors that move dose-response curves back and forth or up or down. A modern, causal approach to creating dose-response relationships for aircraft noise annoyance, which systematically treats non-acoustic factors and quantifies their influence, is described.

1 INTRODUCTION

Transportation noise was first recognized as a major environmental pollutant in the 1960s. Many formal attempts have subsequently been made in laboratory and field settings to quantify and predict adverse consequences of noise exposure. Many such attempts have involved social surveys conducted with residents of neighborhoods near noise sources of interest to estimate the prevalence of a consequential degree of annoyance (or other adverse effects of noise exposure) within groups of respondents with more or less uniform noise exposure. Adverse effects of noise that have been investigated have included sleep disturbance, interference with conversation, listening to radio or television, and annoyance (McKennell, 1973) (Alexandre, 1973). Most field studies of annoyance have assumed that a measure of noise exposure can, by itself, account for useful amounts of variance in social survey data on the prevalence of noise-induced annoyance in communities.

Even in the earliest field studies, observed associations between noise exposure and <u>individual</u> subjective responses have been weak. When self-reports of adverse reactions to noise have been pooled across respondents with similar noise exposure, however, the correlation between the noise and the mean responses are typically greater.

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Early indices of the annoyance of noise exposure were often constructed from a combination of responses to multiple questions on activity interference. It was soon realized, however, that simply posing a direct question of the form “How annoyed are you by (some form of noise)?” is a more straightforward and reliable way of assessing community response to transportation noise. Respondents were usually constrained to respond to such a direct question about annoyance with a closed response category scale with category labels such as "not at all annoyed", "a little annoyed", and so forth, or required to describe the intensity of their annoyance on a numerical scale. The International Commission on Biological Effects of Noise, ICBEN, (Fields *et al.* 1997), (Fields *et al.* 2001) eventually attempted to standardize response measurement.

2 NON-ACOUSTIC FACTORS

Non-acoustic factors were soon recognized as playing an important role in determining individual annoyance reactions (Job, 1988). Some researchers even suggested that noise exposure itself was among the less important determinants of the prevalence of noise-induced annoyance (McKennell, 1969). Others argued that weak associations of noise exposure with annoyance prevalence rates were due to mis-measurement of *acoustical* influences on annoyance (Schultz, 1978). A wide variety of acoustic factors other than cumulative, long-term exposure have been suggested as predictors of annoyance.

Further analyses (Basner *et al.* 2017) of surveys on noise annoyance have shown that cumulative measures of noise exposure *per se*, expressed in units similar to Day-Night Average Sound Level (DNL), rarely account for as much as half of the variance in community-level data. The prevalence of noise-induced annoyance in communities is clearly moderated by factors other than noise exposure. Acoustic factors that have been identified as moderating community response to transportation noise include maximum sound levels, numbers of flights, fleet composition, and their respective distributions over time. All of these factors are highly correlated with cumulative noise exposure. Non-acoustic factors include individual noise sensitivity, community economic dependence on airport operation, fear of crashes, attitudes of malfeasance and misfeasance toward the noise source, and so forth. In the aviation industry, all "non-DNL factors" are commonly referred to as "non-acoustic."

Individual- (rather than community-) level factors may also account for minor additional amounts of variance, but are primarily of academic interest, and are of little or no value as practical predictors of annoyance prevalence rates for regulatory and policy analyses.

3 THE SCHULTZ CURVE

In 1978, Schultz (Schultz, 1978) published what proved to be a highly influential article on community reactions to transportation noise. Schultz demonstrated that the results of social surveys on aircraft and surface transportation noise conducted in different cities by different researchers and using different languages and study designs could be interpreted in common terms, and usefully summarized in the form of an exposure-effect relationship.

Although highly controversial at the time it was published, Schultz's paper eventually came to be regarded as conventional wisdom. In his first attempt to synthesize a relationship from the results from social surveys on noise-induced annoyance, Schultz proposed a common exposure-effect function for all types of transportation noise. He developed exposure-effect functions, also known as dose-response curves, that showed the percentage of people "highly annoyed by noise" as a function of the noise exposure described by the day-night weighted equivalent level, DNL. Schultz adopted as a basic rule that people who responded to the upper 27%-29% of a numeric annoyance scale, could be considered *highly annoyed.* For surveys that used a verbal annoyance scale those people who described themselves as being *highly annoyed* were also counted as highly annoyed.

Figure 1 shows what Schultz called *the best currently available estimate of public annoyance due to transportation noise of all kinds.*

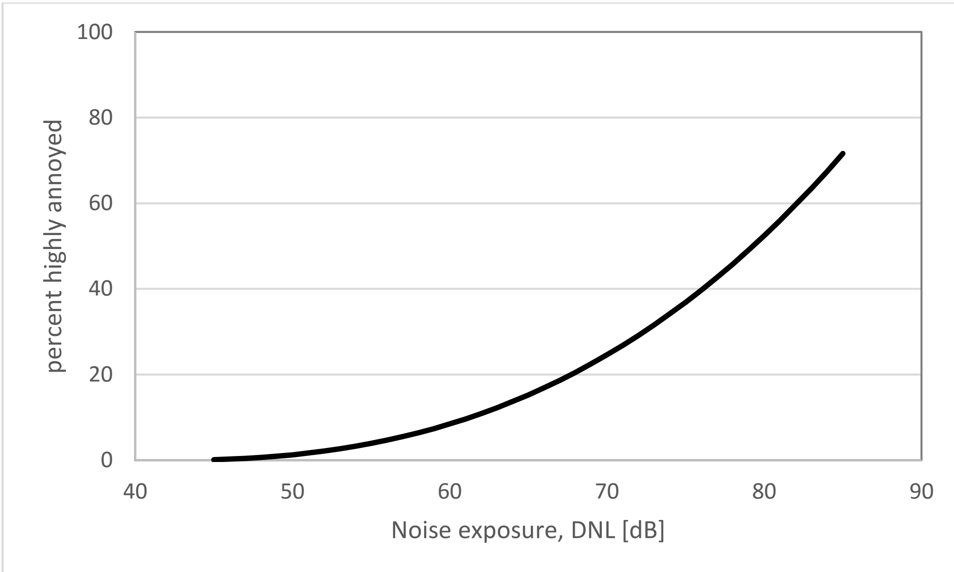

Figure 1. Dose-response curve for transportation noise.
Synthesis of eleven clustering survey results according to Schultz (1978).

Schultz not only developed a curve that showed how people reacted to transportation noise, but also speculated about the reason for its shape. Figure 2 shows a logarithmic plot of the dose-response curve in Figure 1. Schultz offered the following explanation: "If the noise source in question is altogether masked, there is no response at all. As the noise exposure increases, an increasing number of people notice it and become aroused. Finally, when people actually attend to the noise, their annoyance increases at the same rate as the well-known loudness function." Although Schultz was aware that this view was merely speculation, he believed that it was one that deserved further study.

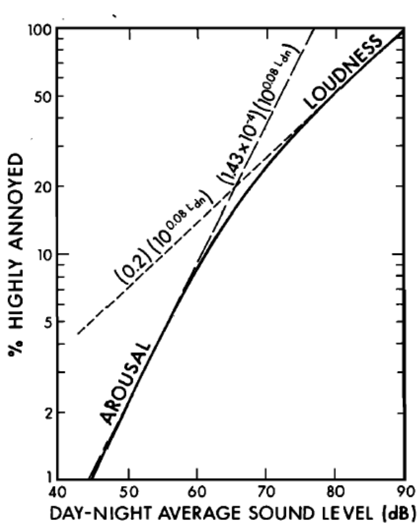

Figure 2. Power function approximation to the cubic equation for relating annoyance to day-night average sound level.

3.1 Subsequent studies

Schultz’s original “synthesis curve” was greeted with considerable controversy. Schultz was criticized for his conversion of diverse noise metrics into Day-Night Average Sound Level (DNL), and for his use of self-reported annoyance rather than indirect annoyance indicators like sleep interference or number of complaints. Others objected to the use of a single dose-response relationship for both aircraft and surface transportation sources, and still others suggested alternate fitting functions. One researcher even feared that Schultz's synthesis would put an end to all future annoyance studies: the matter of community response to environmental noise was now settled, and no further comparative research was needed! This fear has proved to be mis-placed: an abundance of additional studies have been conducted, and a variety of alternate dose-response relationships have been developed.

The US Federal Interagency Committee on Noise, FICON, declared in its 1992 report that annoyance was its preferred *summary measure of the general adverse reaction of people to noise*, and that *the percentage of the area population characterized as "highly annoyed" by long-term exposure to noise* was its preferred measure of annoyance. This view became more or less a *de facto* standard for reporting adverse reaction to noise. FICON also institutionalized an ogival fitting function originally developed for the US Air Force.

The dose-response curve originally presented by Schultz was based on 161 data points (pairs of exposure and % HA) from 11 different surveys. Fidell *et al.* (1991) developed an update of Schultz’s curve from 292 additional data points from 15 newer surveys. This curve is shown in Figure 3, together with the original Schultz 1978 curve and the FICON 1992 curve. The three curves are described by the following equations:

Schultz 1978: $\%HA = 0.8533\ L_{dn} - 0.0401\ L_{dn}^2 + 0.00047\ L_{dn}^3$ [1]

FICON 1992: $\%HA = 100/(1 + e^{(11.13 - 0.141\ Ldn)})$ [2]

Fidell 1991: $\%HA = 0.0360\ L_{dn}^2 - 3.2645\ L_{dn} + 78.9181$ [3]

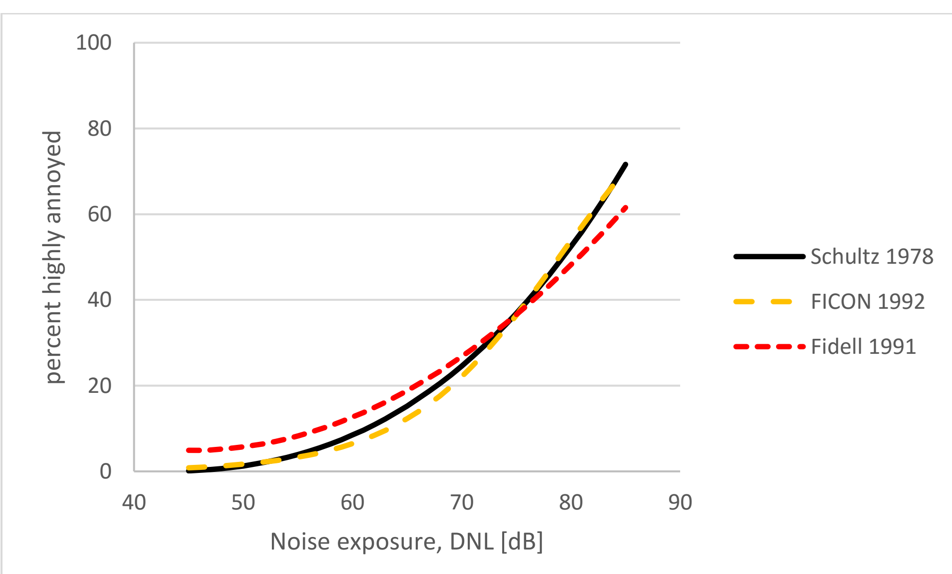

Figure 3. Dose-response curves for transportation noise

3.2 Dose-response curves for separate sources

As ever more surveys with differing results were published, some researchers suggested that the annoyance reactions were source dependent, and that dose-response functions should be developed separately for noise from aircraft, road traffic and rail traffic. In 1998, Miedema and Vos presented separate dose-response curves for the prevalence of annoyance due to aircraft, road and rail noise. The Miedema and Vos curves combined information about individual annoyance reactions from individuals with similar noise exposure across multiple airports. In so doing, it intentionally ignored any airport-specific influences on annoyance. These curves were later adopted by the European Union as a standard reference for annoyance reactions to transportation noise.

The Miedema and Vos curves for aircraft and road traffic noise are shown in Figure 4, together with the general annoyance curve proposed by Fidell *et al.* (1991). The figure shows that the curve for aircraft noise is located above the road traffic curve. In other words, for equal noise exposure, the annoyance caused by aircraft noise is greater than the annoyance caused by road traffic noise. The Miedema and Vos curves were based on 20 aircraft noise surveys and 26 road traffic noise surveys. These dose-response relationships are currently considered *best practice* by many authorities.

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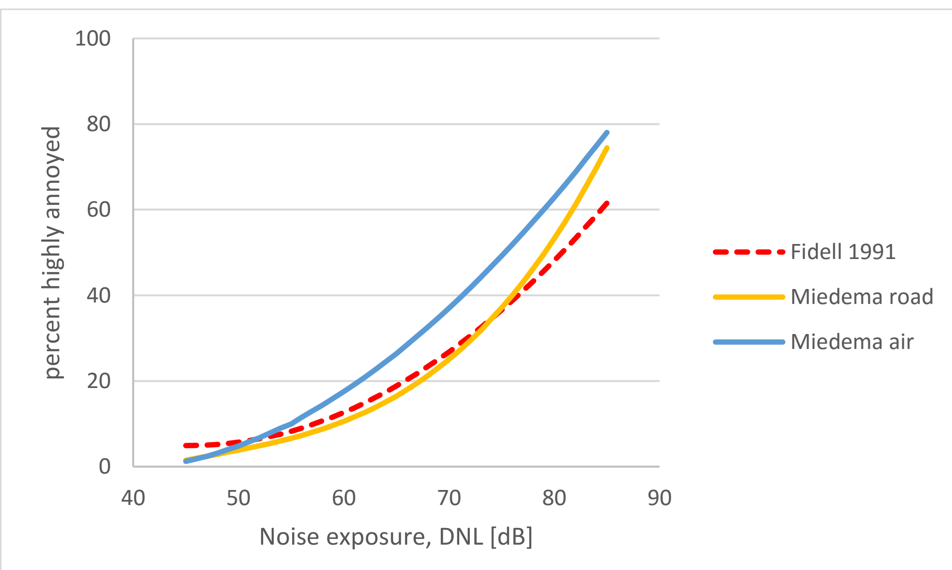

Figure 4. Dose-response curves for transportation noise

3.3 More surveys on aircraft noise

New surveys on the annoyance of transportation noise continue to be conducted. The author has identified 63 surveys on aircraft noise that in combination solicited annoyance reactions from more than 100 000 respondents. These studies have yielded a total of 653 paired observations of aircraft noise exposure and prevalence of high annoyance. These data pairs are plotted in Figure 5. Most of the data pairs have been reported in Fidell *et al.* (2011) and Gelderblom *et al.* (2017).

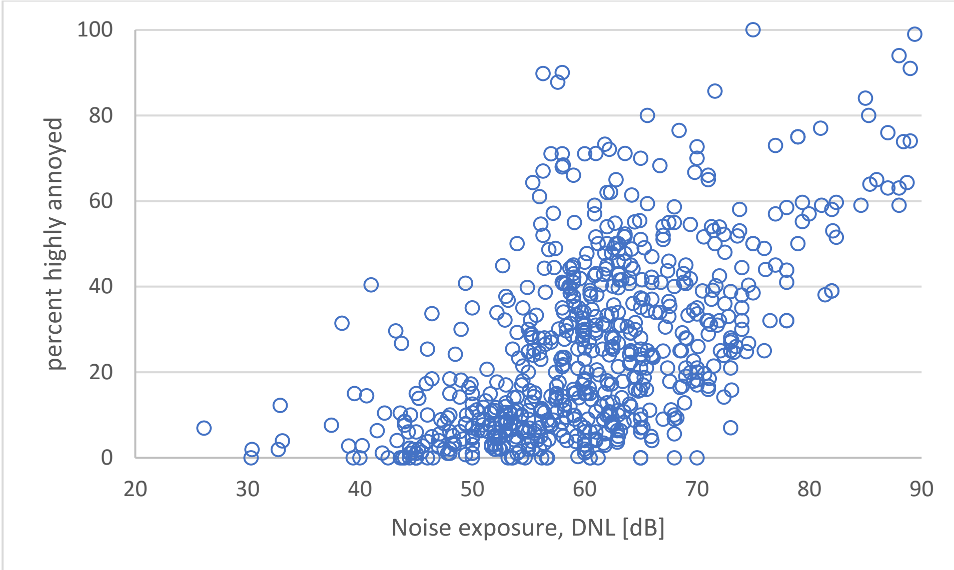

Figure 5. Results from 63 different surveys on aircraft noise annoyance, 653 paired responses from more than 100 000 individual respondents

Univariate logistic regression analysis, the common statistical approach to interpreting scatter plots such as that of Figure 5, is purely descriptive, and relies solely upon correlational (rather than causal) association of dose with response. Regression yields only an average dose-response function for the entire data set. Simple visual inspection of the data plotted in Figure 5 reveals that an average dose-response function derived by regression analysis cannot be very representative for most of the survey data. At a noise level of L_{dn} = 55 dB, the prevalence of highly annoyed varies between 0 % and 90 %. Conversely, a 10 % prevalence rate of highly annoyed has been observed at exposure levels between 35 dB $\leq L_{dn} \leq$ 70 dB.

The relatively small numbers of data points at the upper and lower parts of the exposure range exercise a disproportionate influence on the shape and position of the dose-response function. A closer look at the exposure range 50 dB<DNL<70 dB – the range of greatest practical interest – reveals no obvious tendencies or exposure-related trends. As new data sets are added the average dose-response function, will deviate slightly from the old one.

4 TIME TO LOOK FOR ANOTHER STRATEGY

After half a century of meager success in predicting community reaction to transportation noise, it is time for a new approach. The first step in developing a more sophisticated understanding of community response to transportation noise is to formally acknowledge that responses to questions of the form "How annoyed are you by aircraft noise?" are controlled not only by noise exposure, but also by a variety of non-acoustic (or more specifically, "non-DNL") factors. As Basner *et al.* have noted (2017), noise exposure alone accounts for only about a third of the variance of individual responses. Since the aggregate influence of these non-acoustic factors varies from one airport community to the next, it may be futile to seek a single function that accurately describes the relationship between noise exposure and prevalence of annoyance in all airport communities.

Schultz observed in his original synthesis that when people actually attend to an intruding noise, their annoyance seemed to increase at the same rate as the well-known loudness function (see Figure 2.) This notion has been systematically treated by Fidell *et al.* (2011) in the Community Tolerance Level ("CTL") analysis. The CTL approach is implemented via a simple set of equations. The basic predictive relationship is given by:

$$p(\mathrm{HA}) = e^{(-A/m)} \qquad [4]$$

where p(HA) is the portion of the population highly annoyed by noise, A is a scalar quantity characterizing a community's annoyance decision criterion, and m is the noise dose, defined as:

$$m = \{ 10^{(Ldn / 10)} \}^{0.3} \qquad [5]$$

The functional relationship specified by the basic predictive relationship defined by Eq. [4] is a sigmoid. The exponential form of the relationship was chosen as the most plausible single parameter transition function to model the growth, from zero to one, of the proportion of a community highly annoyed by increasing levels of noise exposure.

CTL analysis treats the proportion of a community that describes itself as highly annoyed as equally influenced 1) by noise exposure, and 2) by a non-acoustic criterion for self-reporting of annoyance. As noted earlier, univariate regression analyses ignore the influence of the second of these determinants of annoyance prevalence rates. In CTL analysis, the slope (shape) of the dose-response relationship is fixed at that of the exponential growth rate of loudness with sound level, while the parameter *A* in Eq.[4] translates the sigmoidal function along the abscissa. Because the slope of the transition function is fixed, CTL analysis is more parsimonious than regression analysis, which separately estimates the slope and intercept of regression functions.

The growth of annoyance with noise exposure follows the effective loudness function, but the "starting point" on the abscissa of the response curve is determined by non-acoustic factors. The effect of these factors is a real change in noise-induced annoyance, not just an "additional annoyance" caused by other factors.

The community-specific constant, *A*, can be found by minimizing the least square difference between the annoyance prevalence rates predicted by an exponential function with a slope equal to the rate of growth of loudness with level ("the effective loudness function") and those observed at the interviewing sites in each community. This process slides the effective loudness function along the DNL axis to the point at which a best fit between the predicted and observed points occurs.

Any arbitrary point on the effective loudness function could be selected to anchor a function with a fixed slope to the DNL axis. For example, DNL values corresponding to the 10% or 90% highly annoyed points could serve to describe the position of the effective loudness function along the DNL axis. Since the choice is arbitrary, the midpoint of the effective loudness function—the point corresponding to a 50% annoyance prevalence rate, and the point with the steepest growth —was selected as a convenient anchor point. This choice of anchor point has mistakenly led some to believe that the CTL method only considers annoyance at very high levels (50 %HA). On the contrary, however, a single CTL value is associated with a complete dose-response curve from 0% to 100% HA, and the corresponding noise levels at which these responses can be observed.

In practice, the value of the parameter *A* for a particular community is determined empirically from social survey findings. The Community Tolerance Level is defined as the value of the noise exposure, DNL, at which 50 percent of the population describes itself as highly annoyed. CTL values so defined may be calculated from the equation:

$$L_{ct} = 33.3 \log_{10} (A) + 5.32 \qquad [6]$$

Taraldsen *et al.* (2016) have shown that instead of a minimal least squares goodness of fit estimate of the value of the parameter *A,* a maximum likelihood ratio criterion may be a better choice, especially when the number of observations at each exposure level differs greatly. In practice, the least squares and maximum likelihood estimates of A yield CTL values that differ slightly, by one to two dB.

So, instead of finding an arbitrary mathematical function to fit a set of empirical field measurements that lacks any physiological, psychological or other interpretability (as in standard regression analysis), the CTL method seeks to fit an *a priori* function *(i.e.*, a duration-adjusted loudness function) to the survey data. The method is further explained in International standard ISO 1996-1 (ISO, 2016).

Each community is treated separately in CTL analysis, and characterized by a single value of A. Values of A may be transformed into decibel-denominated units as shown in Eq. 6. The results from different surveys can be combined simply by calculating means and standard deviations of individual CTL values. Each CTL value is associated with a unique dose-response function. The panels in Figure 6 show examples of CTL calculations for six airports. These curves are *not* derived by any correlation-based curve fitting method. They instead reflect only lateral shifts of an effective loudness function along the abscissa.

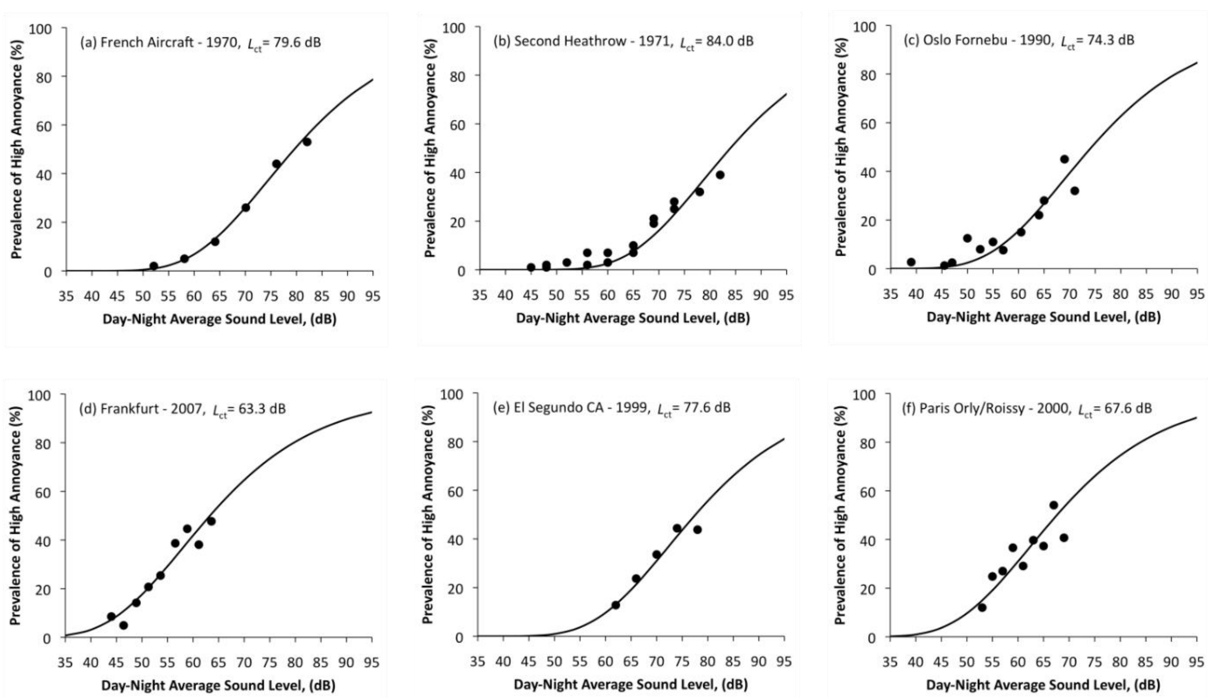

Figure 6. Examples of fit of field measurements of prevalence of high annoyance to the effective loudness curve for six studies of community reaction to aircraft noise, from data compiled in Fidell et al. (2011)

4.1 Common pitfalls in statistical regression analyses

Analysts often rely on statistical software to develop regression-based dose-response relationships without detailed concerns for the assumptions made by various regression techniques, and for their implications. One common pitfall is weighting in proportion to the number of respondents. This weighting is appropriate when studying a one-dimensional problem, but not when analyzing aircraft noise annoyance. A simple example clarifies the issue.

Consider representative samples of opinions derived from two airport communities, A and B, in which the influences of non-acoustic factors on annoyance prevalence rates differ considerably. A survey yields the empirical findings shown in Figure 7. If the analytic task were simply to derive an average dose-response curve for these two airports, one would expect a curve somewhere mid-way between the two datasets. However, the statistician notes that five times as many respondents were interviewed at airport A than at airport B and applies a weighting accordingly. The average dose-response function is strongly affected by this adjustment. Had the number of respondents been reversed, such an adjustment would have yielded yet a very different average dose-response curve.

The average, regression-based dose-response curve thus depends strongly on the number of respondents per survey. A large number of respondents will shrink the confidence interval about the regression curve, but the introduction of a weighting according to the number of respondents will also introduce a bias in the final results. A weighting according to the size of the survey is therefore not recommended.

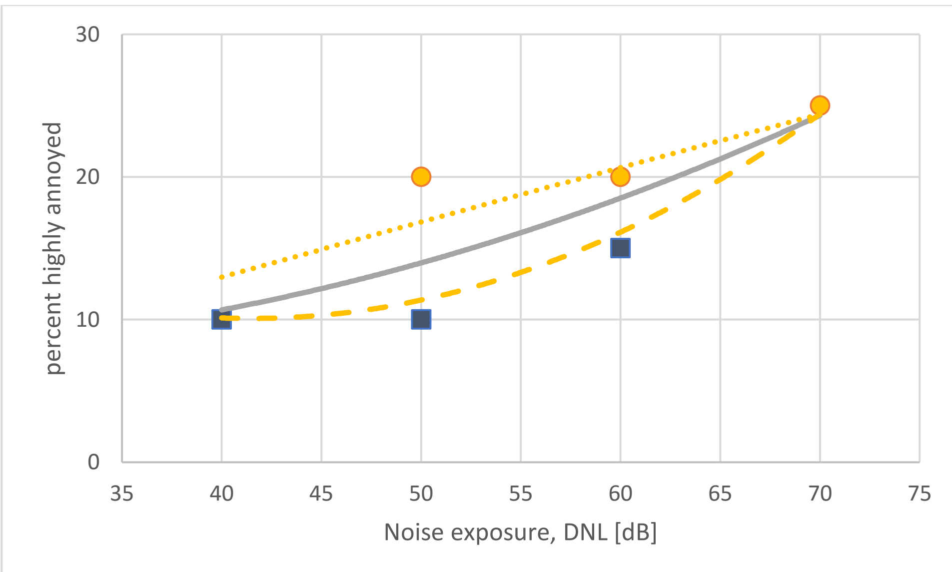

Figure 7. Examples of response weighting for dose-response curves. Two surveys A (circles) and B (squares). Grey solid line: equal weight to both surveys. Yellow dotted line: A = 5xB, yellow dashed line: B = 5xA

5 A REANALYSIS OF EXISTING SURVEY DATA

The data from 63 surveys shown in Figure 5 have been re-analyzed by the CTL method. The mean CTL value for all surveys combined was 72.7 dB. The dose-response curve associated with this CTL value is shown in Figure 8. CTL ± 1σ curves have also been plotted together with the Miedema curve. Agreement between the curve based on the CTL method and the Miedema curve (based on a much smaller sample of surveys) is excellent.

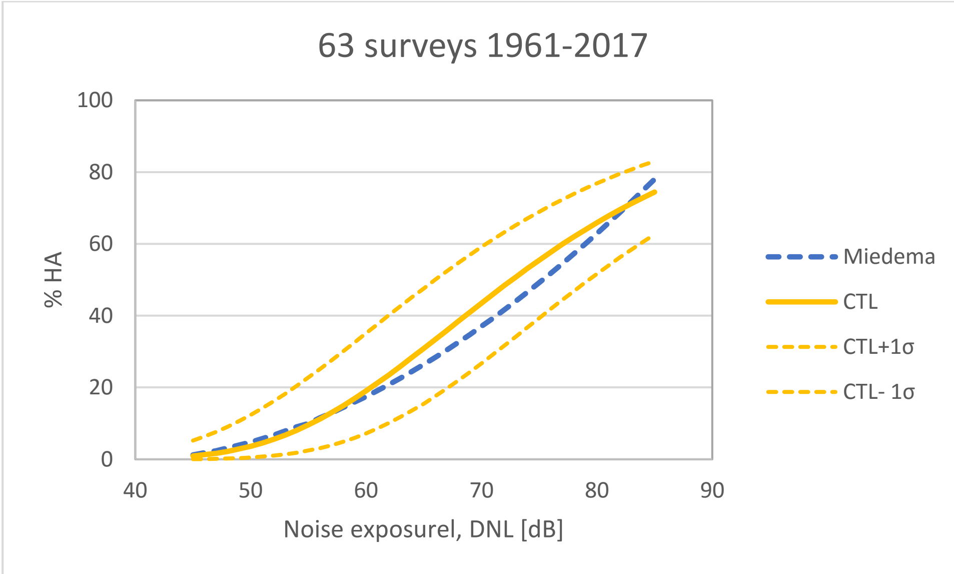

Figure 8. Dose-response curve for aircraft noise annoyance based on the mean CTL value for 63 different surveys conducted 1961 – 2017.

Not only absolute noise exposure levels, but also the circumstances of exposure continually change over time at many airports. At some airports, this change is gradual and reflects slow increases in the numbers of aircraft operations by the same fleet. Other airport communities experience large and abrupt changes such as the opening of a new runway; when an airline company decides to move its main operations to a different airport; when a new aircraft type is added to the fleet serving the airport; or when the operational procedures regarding approach and departure procedures are changed.

Janssen and Guski have proposed a classification of the airports according to the rate of change. High-rate-change airports (HRC) have experienced large operational changes (but not necessarily changes in the noise exposure) within 3 years prior to the survey. An airport is also characterized as HRC if plans have been launched to alter the present operations within 3 years after the survey, and/or if the airport has received controversial public attention. Low-rate-change (LRC) is the default characterization. A more detailed definition of HRS/LRC is given in (Janssen & Guski, 2017) .

The 63 surveys analyzed above have been characterized as HRC or LRC according to the definition presented by Janssen & Guski. The mean CTL value for the two types were 66 ± 4 dB (CTL-HRC) and 75 ± 7 dB (CTL-LRC). The dose-response curves associated with the CTL values and their standard deviation for HRC airports and LRC airports respectively together with the curve for the overall CTL value are plotted in Figure 9.

The average dose-response curve for any group of surveys is likely to fall within the boundaries of the curves defined by CTL_{HRC} - 1σ = 62 dB and CTL_{LRC} + 1σ = 82 dB. As can be seen from Figure 9, the actual *average response curve* is highly dependent on the distribution of HRC or LRC airports within the sample of surveys. The results in Figure 9 indicate that a majority (about 73 %) of the 63 airports have been characterized as LRC airports (LRC: 46 airports, HRC: 17 airports).

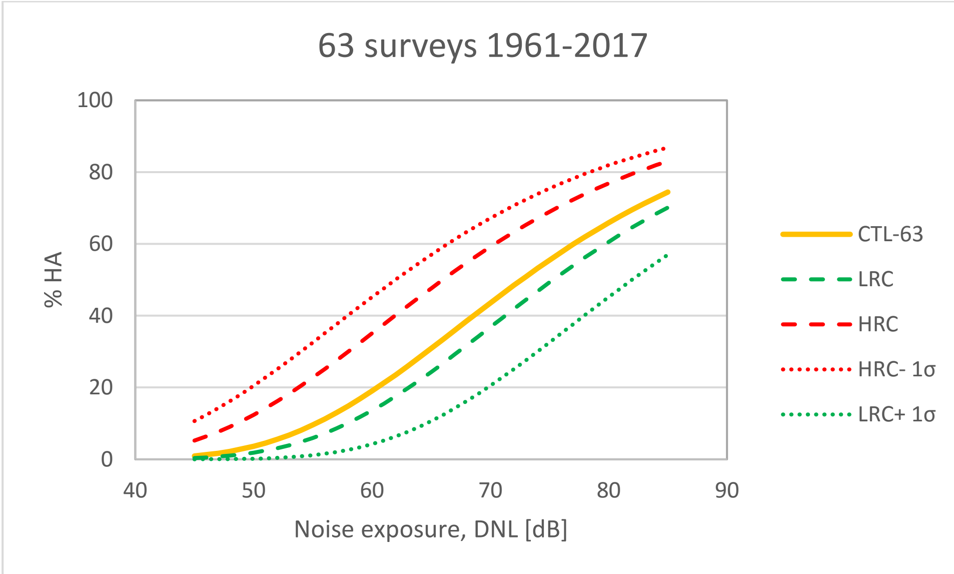

Figure 9. Average dose-response curves for 63 aircraft noise annoyance surveys, and similar curves for HRC and LRC airports respectively

The average CTL value for the airports reported by Fidell *et al.* in their original CTL paper was 73.3 dB . Eighty per cent of these airports were characterized as LRC airports. The average CTL value decreases (airport communities are less tolerant of aircraft noise) as the percentage of HRC airports in the data set increases.

Researchers have continually attempted to update dose-response functions by adding their own survey results to the existing pool of survey data. Figure 9 clearly shows that such updates will be highly dependent on the type of airport that has been studied. Data from an HRC airport is likely to decrease the average CTL value, thereby shifting the dose-response curve to the left (higher % HA at a given exposure level). Adding field measurements made at LRCs airport typically increases average CTL values, and thus shifts the dose-response curve to the right.

5.1 Changes in the annoyance response

Researchers continue to debate whether sensitivity to noise exposure itself has actually changed over the years: are people today more annoyed by noise from transportation sources than they were, say, 25 or 50 years ago? If in fact urban areas are generally noisier today than formerly, or if more people are exposed to noise, more people may be annoyed, and the prevalence of highly annoyed people may have increased over the years. But under equivalent exposure circumstances, and under the influence of equivalent non-acoustic factors, have people's reaction to noise fundamentally changed?

This question can be addressed by comparing the results of recent noise annoyance surveys with those conducted in the past. Schultz's original synthesis of social survey findings was complicated due to a lack of standardization. Existing surveys had been carried out using different questionnaires, different response scales and different noise metrics. Fields *et al.* (2001) proposed a standardized way of conducting community noise surveys. They recommended that two standardized questions be included in future surveys to facilitate inter-survey comparisons. Their recommendation has also been adopted as an international technical specification, ISO/TS 15666.

The author has identified 18 aircraft noise annoyance surveys conducted after 2000 that have been conducted in accordance with this specification. Reports from other surveys have also been published, but their designs deviate too much to be readily included. The list of specificationcompliant surveys includes 12 studies in Europe, 5 studies in Asia, and 1 in the US. Their results include those of 16047 respondents, as shown in Table 1.

Table 1. Aircraft noise annoyance surveys conducted after 2000

Year	Airport	Reference	respond	CTL	H/L
2001	ZHR	SWI-525 (Brink, Wirth, Schierz, Thomann, & Bauer, 2011)	1520	68.0	H
2002	AMS	GES-2 (Breugelmans, Wiechen, Kamp, Heisterkamp, & Houthuijs, 2005)	640	63.2	H
2002	MSP	(Fidell, Pearsons, Silvati, & Sneddon, 2002)	495	72.6	L
2003	ZHR	(SWI-534) (Brink, Wirth, Schierz, Thomann, & Bauer, 2011)	1444	69.0	H
2003	ANASE	(Le Masurier, 2007)	2132	63.0	L
2005	AMS	(GES-3) (Breugelmans, Wiechen, Kamp, Heisterkamp, & Houthuijs, 2005)	478	63.3	H
2005	FRA	(Schreckenberg & Meis, 2007)	2309	63.3	H
2008	SGN	(Nguyen T. L., 2012)	880	75.5	L
2009	HAN	(Nguyen T. L., 2012)	824	68.2	H
2010	CGN	(Bartels, 2014)	1262	67.6	L
2011	DAD	(Nguyen T. L., 2012)	528	75.0	L
2014	BOO	(Gelderblom F. B., Gjestland, Granøien, & Taraldsen, 2014)	302	81.3	L
2014	TRD	(Gelderblom F. B., Gjestland, Granøien, & Taraldsen, 2014)	300	82.3	L
2014	HAN	(Nguyen T. L., 2015)	910	65.6	H
2015	OSL	(Gjestland, Gelderblom, & Granøien, 2016)	300	68.0	H
2015	SVG	(Gjestland, Gelderblom, & Granøien, 2016)	302	80.0	L
2015	TOS	(Gjestland, Gelderblom, & Granøien, 2016)	300	83.0	L
2015	HAN	(Nguyen T. L., 2015)	1121	63.0	H

The results have been analyzed according to the CTL method. The mean CTL value for these 18 surveys is 70.7 ± 7 dB. The dose-response curve associated with this CTL value is shown in Figure 10.

The average dose-response curve for these post-2000 studies lies above the current EU reference ("The Miedema-curve"), indicating a higher prevalence of high annoyance for comparable exposure, but the difference is less than 1σ. The two dose-response functions cannot be considered significantly different [2].

The list of studies in Table 1 comprises an equal number of HRC and LRC airports. This is not the distribution commonly found when considering all airports within a certain area. In general, there will usually be more LRC airports than HRC airports (*cf.* Figure 9).

[2] There is an ongoing development of the CTL method. Ways of calculating the confidence interval of the predicted CTL value for a given survey data set which includes the number of respondents for each pooled data point, will soon be available.

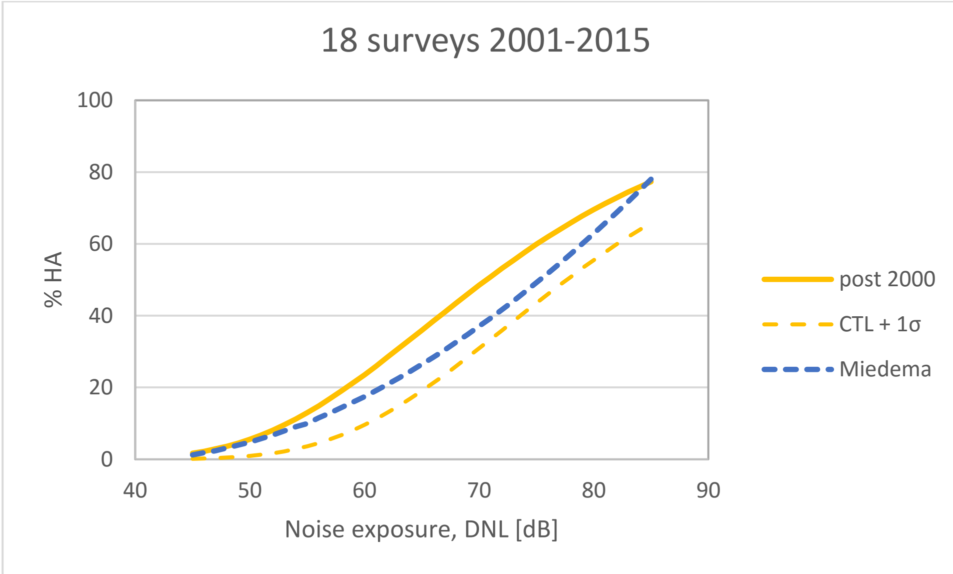

Figure 10. Average dose-response curve for 18 aircraft noise annoyance surveys conducted after 2000 compared with the current EU reference curve (Miedema).

The two categories of airports have been analyzed separately, and the results are shown in Figure 11. The average dose-response curves for the two categories, HRC and LRC, fit well within the range ± 1σ of the curve for all 18 surveys combined. It is, however, self-evident that the actual average dose-response function for a set of surveys is highly dependent on the selection of airports, and especially the distribution of HRC and LRC types.

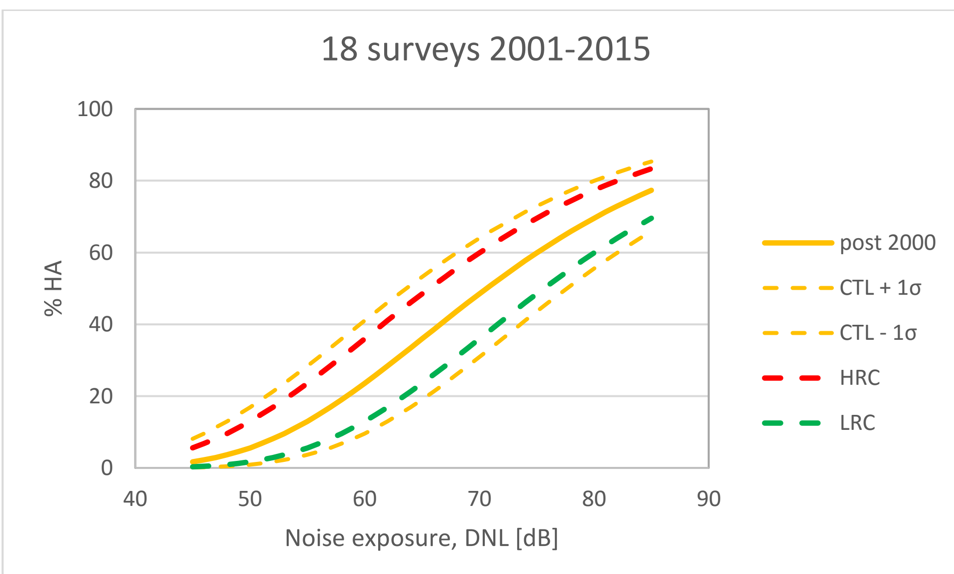

Figure 11. Average dose-response curve for 18 post-2000 surveys and separate curves for HRC and LRC airports respectively.

Several authors have concluded that the annoyance from aircraft noise has increased over the years (Babisch *et al.* 2009), (Guski *et al.* 2017). By comparing the results from a selection of recent studies with well-established references like the Miedema curve, they claim that people today are more annoyed at a given noise exposure than they were 25-50 years ago. The analyses of others do not support this conclusion (Gelderblom *et al.* 2017). A likely explanation is that some analyses have been confounded by different distributions of non-acoustic factors such as HRC and LRC airports. More studies are conducted at HRC airports in recent years, thus shifting the average prevalence of highly annoyed people to higher levels. Under equivalent conditions, however, people today seem to express the same degree of annoyance from aircraft noise as they did 50 years ago.

Figure 12 shows the average dose-response curve for 63 aircraft noise surveys conducted between 1961 and 2015 and a similar curve for 18 post-2000 studies. The total data set comprises about 27 % HRC studies and the post-2000 data set comprises 50 % HRC studies. For comparison the result presented by Guski *et al.* (2017) is also shown.

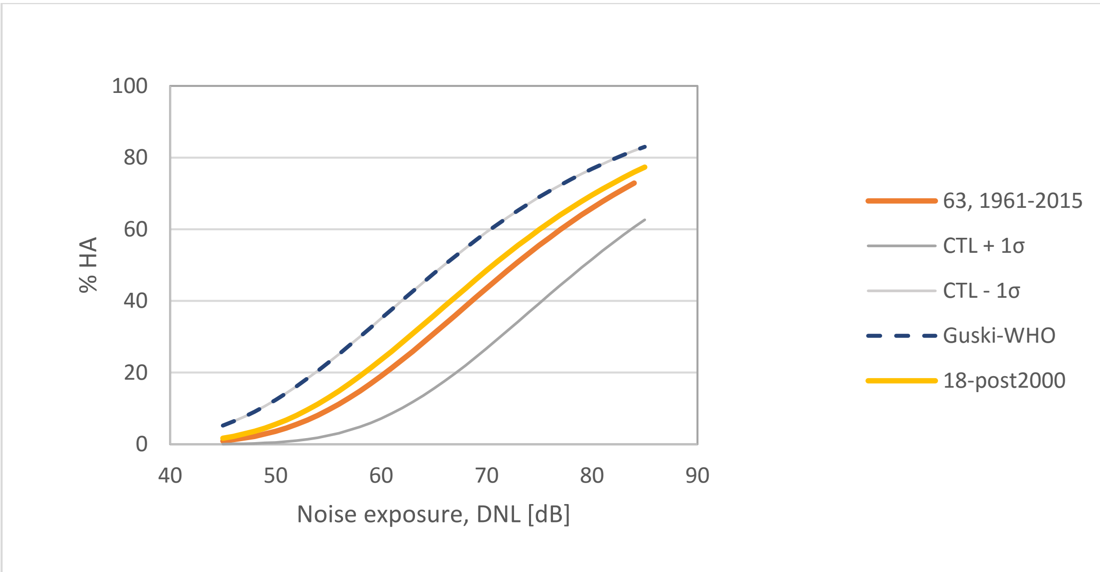

Figure 12. Average dose-response curves for 63 surveys, 1961-2015, for a selection of 18 post-2000 surveys, and for a selection of 12 post-2000 surveys made by Guski et al.(2017).

The data set analyzed by Guski *et al.* comprises 63 – 80 % HRC studies (depending on definition). As the percentage of HRC studies increases, the dose-response curve is shifted towards higher annoyance. However, even the results from the selection done by Guski *et al.* is within the - 1σ interval for the complete data set.

6 CONCLUSIONS

Efforts have been made for more than half a century to establish a single, general dose-response curve that usefully describes the relationship between the average noise level, DNL, and the prevalence of people highly annoyed by aircraft noise. Planners and decision makers rely on such curves to describe the impact of noise on people and communities.

The examples shown in this paper indicate that this search is futile. Community response to aircraft noise exposure is determined not only by the noise level itself, but also a variety of non-acoustic factors. These factors can vary considerably from one community to the next. Similar responses, *i.e.* percentage highly annoyed, can be found in communities with a noise exposure difference of 20 dB or more.

Several dose-response curves have been proposed, and some of them are being used by official authorities. However, their fit to the existing pool of annoyance survey results is rather poor. Fidell *et al.* (2011) have proposed an alternative approach. Instead of looking for a *one curve fits all* solution, they point to the fact that the annoyance caused by aircraft noise is, to a large extent, determined by a number of non-acoustical factors. The noise level itself explains only about one third of the variance of the individual responses. Fidell *et al.* have shown that the annoyance response in a community can be successfully modeled by a Community Tolerance Level, which is a quantification of the influence of all non-acoustical factors. This is a single value parameter given by the community's annoyance decision criterion. So far, this criterion can only be found through direct surveys methods.

However, further analyses of existing survey data may prove a way of dividing airports in different categories that may be characterized by separate "average CTL values" and corresponding dose-response curves. As shown in this paper the rate of change of airport operations is an important parameter. Likewise, the number of aircraft movements regardless of noise level seems to be of importance. The effect of other main characteristics should be further explored.

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