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Prevalence of Noise Induced Annoyance and Its Dependency on Number of Aircraft Movements

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Summary
The relationship between the prevalence of noise induced annoyance and the noise exposure is traditionally described by a cumulative noise metric such as DNL. Such dose-response functions have no restrictions regarding how the dose has been derived, *e.g.* either a large number of low level noise events or a small series of high level events. Community Tolerance Level values (CTL) for 32 aircraft noise surveys have been examined with respect to the yearly number of aircraft movements. The airports included in this study were divided into two categories: "high-rate-of-change" (HRC) airports and "low-rate-of-change" (LRC) airports. HRC airports experienced large changes in their operational patterns within three years prior to the surveys, or there had been announcements of controversial plans for major changes, and/or extensive public discussions and media focus on operational issues. LRC airports experienced only minor changes in operations and noise-related controversies. At LRC airports there is a clear relationship between annoyance and the number of aircraft movements. At equal DNL the prevalence of annoyance increases with an increasing number of movements. At HRC airports the prevalence of annoyance is higher. However, the same dependency on number of aircraft movements cannot be found.

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1. Introduction

Numerous social surveys of people's response to aircraft noise have been conducted in the past half century [1]. The primary results of these surveys have typically been reported as prevalence of annoyance as a function of the noise exposure expressed by a cumulative measure such as day-night average sound level (DNL), or day-evening-night level (DENL) after this index was introduced in the European Noise Directive [2].

Several recommendations and standards present the prevalence of annoyance with aircraft noise as a simple two-dimensional issue; i.e. the percentage of a population being highly annoyed vs. the cumulative noise exposure ([3, 4, 5, 6] *inter alia*).

However, a simple visual inspection of a compilation of available survey results as shown in Figure 1, illustrates the great variability of measurements of aircraft annoyance prevalence rates across communities[1]. Some of this variability may be attributed to differences in study methods. However, it has long been recognized that the annoyance response may also depend on other non-DNL determinants [9, 10]. Such factors can be either acoustic, *e.g.* maximum levels, or non-acoustic, *e.g.* fear of accidents, situational factors, etc.

Numerous models for prediction of the prevalence of annoyance based on various acoustic parameters have been proposed [11] but none of these, except for the simple "annoyance vs. DNL", has been universally accepted and adopted. Most countries still rely on DNL-based metrics for regulatory purposes regarding annoyance from aircraft noise [12], but there is also some work on supplementary noise metrics [13].

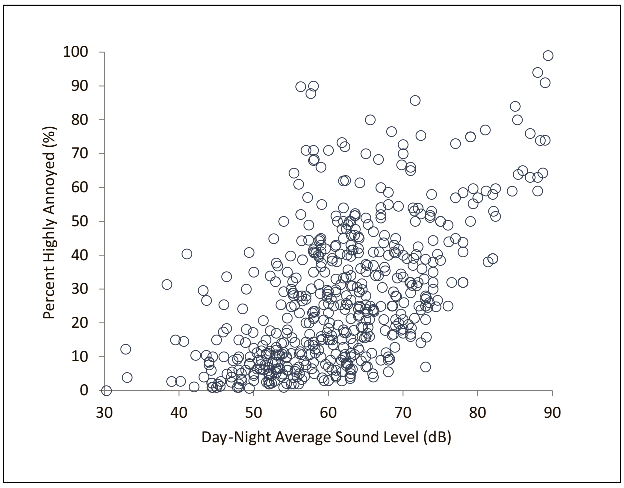

Figure 1. A compilation of primary results from 43 different surveys on aircraft noise conducted between 1961 and 2005. Each data point represents aggregated results from one survey and for one particular exposure level [7].

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[1] The data points in Figure 1 are mainly based on data found in the annexes of the international standard ISO 1996 [6] and Fidell *et al.* [7]. The

Fidell *et al.* [7] have presented the concept of Community Tolerance Level (CTL) as a means to account for the aggregate influences of non-DNL related factors on annoyance prevalence rates. The CTL parameter, expressed in DNL units, quantifies the magnitude of the influence of all non-DNL related factors, but it does not explain how these different factors affect the annoyance response, *i.e.* the percentage highly annoyed.

2. Background

For their work on the CTL concept, Fidell *et al.* [7] compiled at list of 43 surveys on aircraft noise annoyance conducted over the past 60 years. The CTL value for these studies varied across a range of about 25 dB, from 62 dB to 86 dB. The grand average for all 43 surveys was 73.3 dB. The CTL-function associated with this value closely resembles the dose-response function proposed by Miedema and Vos [5], and which has later been adopted as the EU-recommended curve for assessment of aircraft noise. The definition and use of CTL is described in the 2016 revision of the standard ISO 1996 [6].

The CTL value for a particular survey gives a simple, single number description of the annoyance response. CTL values below 73.3 dB indicate that the community is less tolerant to noise than the average, and values above 73.3 dB indicate that the community is more tolerant. Differences in CTL values can therefore be used to compare the annoyance response in different communities with different noise exposure situations, provided the definition of *highly annoyed* is based on the same cut-off point (usually responses above 72% on the annoyance scale).

Janssen and Guski [14] have presented a study on temporal trends in the aircraft noise annoyance response. They analyzed a set of 32 aircraft noise studies contained in the TNO database. They recognized that abrupt changes in the airport operations will affect the annoyance response, and therefore introduced a classification procedure as follows:

> *For the purposes of this review, we call airports "low-rate change airports", as long as there is no indication of a sustained abrupt change of aircraft movements, or the published intention of the airport to change the number of movements within 3 years before and after the study. An abrupt change is defined here as a significant deviation in the trend of aircraft movements from the trend typical for the airport. Each trend is calculated by means of total movement data during a five year period. If the typical trend is disrupted significantly and permanent, we call this a "high-rate change airport". We also classify this airport in the latter category if there has been public discussion about operational plans within 3 years before and after the study.*

cut-off point above which respondents are counted as highly annoyed in a specific survey varies between 67% and 75%, with the bulk of the surveys using 72% [5]. For post 2001 surveys the response on the standardized numerical scale (three upper categories) has been used wherever available [8].

This classification procedure was adopted by Gjestland *et al.* [15], and they showed that there is a significant difference between the two classes of airport communities. People living near a "low-rate-of-change" (LRC) airport are in general more tolerant to noise than people living near a "high-rate-of-change" (HRC) airport. The average difference in CTL values between the two types was found to be 8 dB ±5 dB. They did not observe any temporal change in the prevalence of noise annoyance when differentiating the studies in LRC/HRC types; the response in 2015 was similar to the response 30-40 years ago. With these important observations it should be possible to study differences between aircraft noise surveys conducted at different times without having study year or classification LRC/HRC as confounding factors.

3. Method

A database of social survey findings about the prevalence of aircraft noise-induced annoyance was constructed on the basis of the lists provided by Fidell *et al.* [7], Janssen and Vos []11), Janssen and Guski [14], and Gjestland *et al.* [15]. The objective of the analysis was to find a possible link between the annoyance response characterized by the CTL value and the amount of traffic at the airport, characterized by the average number of movements per year. The number of aircraft movements is defined as the total number of arrivals and departures. The number includes commercial jets and turbo pro aircraft (both passenger and freight), but excluding GA traffic.

Therefore only studies where the number of aircraft movements could be confirmed were included. This information was either found in the original survey reports or from historical data provided by the airports or national aviation authorities.

The classification LRC/HRC was based on the classification definition introduced by Jansen and Guski, by using information provided in the original survey reports, and/or through communication with the researchers that conducted the survey.

The surveys that were included in the following analysis are shown in Table I. The rationale for the HRC classification is shown in Table II. All remaining airports were classified as LRC. The CTL values in Table I have been calculated using a "least square error" method using aggregated results for percentage highly annoyed. The cut-off point for %HA is similar for all studies (about 72%). For details on the CTL calculations, see Fidell *et al.* [7], ISO [6] and Taraldsen *et al.* [16].

4. Results

The data from Table I is plotted in Figure 2. The figure shows CTL as a function of the number of movements per year using a logarithmic scale. A linear regression line with corresponding 95% confidence intervals has been fitted to the complete data set, with CTL as the predicted variable and log(movements) as a predictor variable:

$$\mathrm{CTL} = \beta_{\mathrm{intercept}} + \beta_{\log(m)} x_{\log(m)}.$$

Table I. Summary of surveys included in the analysis.

Study	year	Primary author	Res.	Study code	CTL	Move	H/L
LAX	1973	Fidell and Jones	940	USA-082	72.6	450000	L
Burbank airport	1979	Fidell *et al.*	5041	USA-203	63.0	270000	H
Orange County	1981	Fidell *et al.*	3103	USA-204	63.6	522000	H
Westchester A/C	1982	Fidell *et al.*	1465	USA-301	70.3	222000	L
Decatur airport	1982	Schomer	231	USA-250	78.6	83000	L
Brussels	1980	Jonckheere	677	BEL-288	82.3	100000	L
Glasgow	1984	Atkinson *et al.*	608	UKD-238	70.0	93000	L
Amsterdam	1984	Miedema	581	NET-240	71.6	141000	L
Long Beach	1989	Fidell and Silvati	2505	LGB	65.0	462000	L
Oslo A/C	1989	Gjestland *et al.*	3337	NOR-311	74.3	100000	L
Trondheim	1990	Gjestland *et al.*	1195	NOR-366	77.3	65000	L
Atlanta	1991	Fidell and Silvati	922	USA-349	72.3	640000	L
Bodø Lufthavn	1992	Gjestland *et al.*	3267	NOR-328	83.0	70000	L
Seattle A/C	1995	Fidell *et al.*	1444	USA-431	81.3	382000	L
Amsterdam	1996	Breugelmans *et al.*	11812	NET-371	62.3	322000	H
Birmingham	1996	Witfield	1072		66.0	96000	H
Minneapolis	1996	Fidell *et al.*	2880	USA-428	74.3	484000	L
El Segundo, CA	1997	Fidell *et al.*	644	USA-432	77.6	771000	L
Frankfurt	1998	Kastka	1147	FRA1	62.3	416000	H
San Fransisco	1999	Fidell and Silvati	1250	SFO	71.0	437000	L
Munich	2000	Kastka	775	MUC	58.6	334000	L
Zurich	2001	Brink *et al.*	1520	SWI-525	68.0	257000	H
Amsterdam	2002	Breugelmans *et al.*	640	GES-2	63.3	401000	H
Richfield, MN	2002	Fidell *et al.*	495	MSP	72.6	498000	L
Zurich	2003	Brink *et al.*	1444	SWI-534	69.0	269000	H
Amsterdam	2005	Breugelmans *et al.*	478	GES-3	63.3	405000	H
Cincinnati	2005	Fidell and Sneddon	1606	CVG	71.0	519000	H
Frankfurt	2005	Schreckenberg	2309	FRA	63.3	490000	H
Ho Chi Minh	2008	Nguyen *et al.*	880		75.5	80000	L
Hanoi	2009	Nguyen *et al.*	824		68.2	57000	L
Cologne/Bonn	2010	Bartels	1239		67.6	121000	L
Da Nang	2011	Nguyen *et al.*	528		75.0	29000	L
Bodø	2014	Gelderblom *et al.*	302		81.3	38000	L
Trondheim	2014	Gelderblom *et al.*	300		82.3	56000	L
Oslo	2015	Gelderblom *et al.*	300		68.0	247000	H
Stavanger	2015	Gelderblom *et al.*	300		80.0	61000	L
Tromsø	2015	Gelderblom *et al.*	300		83.0	36000	L
Hanoi	2014	Nguyen *et al.*	890		65.6	88000	H
Hanoi	2015	Nguyen *et al.*	1121		63.0	170000	H

Figure 3 shows the same data set, but in this case the two different classes of airports have been taken into account by adding a second predictor variable.

$$\mathrm{CTL} = \beta_{\text{intercept}} + \beta_{\log(m)} x_{\log(m)} + \beta_{\text{HRC}} x_{\text{HRC}}.$$

The new variable is dichotomous (True/False) variable.

Figure 4 shows the results of yet another analysis. In this case the two sets of data for HRC- and LRC- airports have been analyzed separately.

Dashed lines show 95% confidence intervals. The horizontal dash-dot line indicates the CTL value corresponding to the dose-response function recommended by the EU.

5. Discussion

The CTL value, calculated as described above is a single number description of a certain community with respect to the prevalence of noise-induced annoyance. CTL denotes the noise level at which 50% of the exposed population in that particular community is highly annoyed. A low CTL value indicates a low tolerance for noise and vice versa. Figure 2 shows a plot of the CTL value for 39 aircraft noise surveys and the corresponding traffic volume at these airports. The traffic volume, *i.e.* the total number of take-offs and landings per year, is presented on a logarithmic scale. A univariate linear regression line seems to indicate that there is a correlation between CTL and number of aircraft movements. The regression line has a downward slope of −8.6, indicating a decrease in noise tolerance at a given exposure level corresponding to 2.6 dB per doubling of the traffic.

The different survey sites have been classified as LRC airports and HRC airports according to the definition proposed by Jansen and Guski [14]. A simple visual inspec-

Table II. Rationale for the HRC classification.

Study	Year	Rationale
Burbank	1979	Closure and re-opening of runways due to major repairs. Main runway was closed from September 1979 to October 1980
Orange County	1981	Evaluation of three different departure procedures for jet carriers fall 1981
Amsterdam	1996	Comprehensive public discussion about airport expansion
Birmingham	1996	Announced changes. In 1997 a major restructuring program that would double the airport capacity, would be started
Frankfurt	1998	More or less continuous protests against the airport since 1973. A new terminal that opened in 1994 allowed a large expansion over the following years
Zurich	2001	Public discussions about changes of flight paths. (Personal communication, M Brink)
Amsterdam	2002	Discussions about expansion. 6th runway completed in 2003
Zurich	2003	New flight procedures were implemented. (Personal communication M. Brink)
Amsterdam	2005	Changes in operations after 6th runway was completed
Cincinnati	2005	Large expansion of jet aircraft operations prior to study
Frankfurt	2005	US Air Force Base was closed and the location of maintenance facility for Airbus 380 was decided
Oslo	2015	High Court decision on economic compensation for only some residents. Discussions about the location of a third runway
Hanoi	2014	Expansion of airport capacity nearly completed
Hanoi	2015	Opening of new terminal. 20% increase in movements

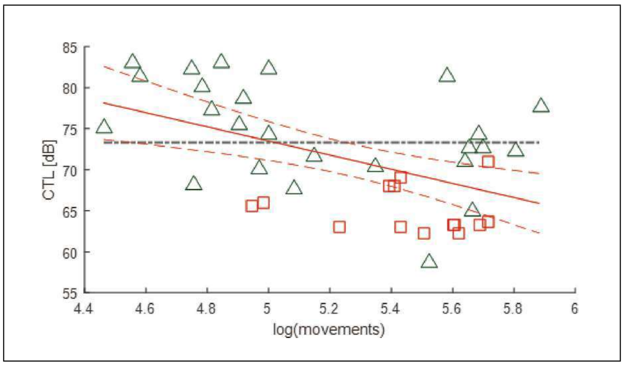

Figure 2. CTL values for 39 aircraft noise studies as a function of number of movements, triangles: LRC airports, squares: HRC airports. Univariate linear regression to the complete data set (slope: -8.6, adjusted r2: 0.23). Dashed lines show 95% confidence intervals. The horizontal dash-dot line indicates the CTL value corresponding to the dose-response function recommended by the EU.

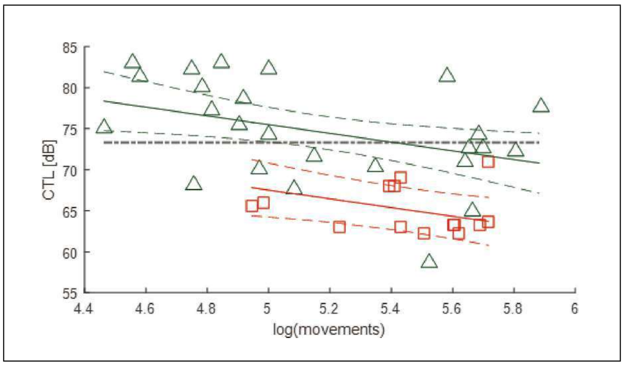

Figure 3. CTL values for 39 aircraft noise studies as a function of number of movements, triangles: LRC airports, squares: HRC airports. A multivariate linear regression function has been applied to the two data sets (slope: −5.3, adjusted r2: 0.5, shift: 8 dB). Dashed lines show 95% confidence intervals. The horizontal dash-dot line indicates the CTL value corresponding to the dose-response function recommended by the EU.

tion of the data reveals that all but one of the HRC data points fall below the trend line, indicating that most people living near an HRC airport are more annoyed than the average.

In Figure 3 a multivariate linear regression function is fitted to the same data set. For a given noise level and a fixed number of movements the response at an HRC airport is shifted equivalent to 8 dB compared with an LRC airport. This shift is in agreement with that reported by Gjestland *et al.* [15]. The downward slope of the trend lines using this analysis method is −5.3. Thus the dependency on the number of movements seems to be less pronounced. A doubling of the traffic at a given exposure level corresponds to a shift in CTL of 1.6 dB.

Figure 4 shows the results if the two data sets are analyzed independently. The trend line fitted to the data for the LRC airports, has a downward slope of −6.0 indicating a decrease in noise tolerance at a given exposure level corresponding to 1.8 dB per doubling of the traffic. The trend line fitted to the HRC data points, however, is almost horizontal with a slope of only −0.75. This indicates that the annoyance response at these airports is virtually independent of the traffic volume. At 100,000 movements per year ($\log m = 5.0$) the difference in the annoyance response between the two classes of airports, is equivalent to a shift of 7.9 dB in the noise exposure, but at 1,000,000 movements per year ($\log m = 6.0$) the difference has decreased to 5.2 dB.

According to these results the EU recommended dose-response function corresponding to a CTL value of 73.3 dB gives a "correct" estimate of the prevalence of annoyance at an LRC airport having about 250,000 aircraft movements per year. The EU-curve over-estimates the annoyance at smaller airports, as higher CTL-values

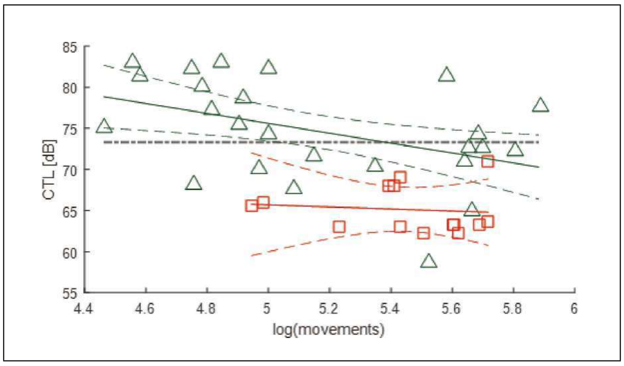

Figure 4. CTL values for 39 aircraft noise studies as a function of number of movements, triangles: LRC airports, squares: HRC airports. Independent univariate regression lines have been fitted to the two data sets (slope LRC: −6.0, slope HRC: −0.75, adjusted r2: 0.5). Dashed lines show 95% confidence intervals. The horizontal dash-dot line indicates the CTL value corresponding to the dose-response function recommended by the EU.

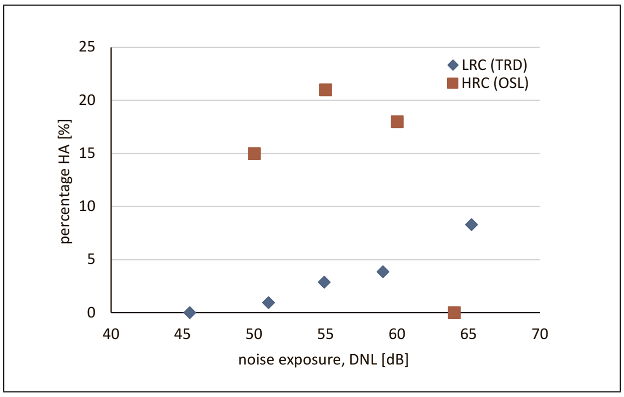

Figure 5. Annoyance reaction results from a noise survey at two Norwegian airports classified as either LRC or HRC [22, 23].

means a greater tolerance to noise, *i.e.* for a given prevalence of annoyance, people tolerate a higher noise level than predicted by the EU-curve. At airports having more than about 250,000 aircraft movements per year, however, the EU-curve under-estimates the prevalence of annoyance. For HRC airports the prevalence of annoyance seems to be independent on the number of aircraft movements.

The negative slope in Figure 2 indicates that for equal noise exposure, the percentage of highly annoyed respondents increases with an increasing number of aircraft movements. An increasing number of movements means that the intervals between each noise event become shorter. Experiments with traffic management to increase the length of respite periods have been tried at various airports for instance in the UK and in Australia [17, 18]. These experiments have shown that noise-induced annoyance at a given exposure level may be reduced by increasing the length of quiet periods between separate noise events. At larger airports this can be achieved by using alternative runways, and thereby spreading the traffic across a larger area. This is a type of air traffic management that should be further explored.

Jansen and Guski's [14] definition of an HRC airport includes among other things ongoing discussions about operations between the airport authorities and the surrounding community and large uncertainties about the future noise impact situation. The prevalence of annoyance at an HRC airport is generally higher than the average [15]. One may assume that the high prevalence of annoyance is only indirectly linked to the noise exposure itself, and that other non-acoustical factors such as mistrust and discontent may be more prominent [19]. The results shown in Figure 4 support this assumption. The prevalence of annoyance at an HRC airport is more or less independent of the number of movements as opposed to the situation at an LRC airport.

A similar conclusion can be drawn from the results shown in Figure 5. This figure shows the results from a recent survey at two Norwegian airports; Trondheim Airport (TRD) which is a typical LRC airport and Oslo Airport (OSL) which is a typical HRC airport. The prevalence of annoyance at Trondheim Airport, described as the percentage of the population that is highly annoyed, is clearly correlated with the exposure level. One may therefore assume that in this case the annoyance is primarily noise-induced. The results from Oslo Airport (OSL), however, are very different. Not only is the annoyance response generally much higher, but there is no clear correlation between the annoyance response and the exposure level. An obvious conclusion would be that in this particular case the annoyance is primarily caused by factors other than the noise level itself.

A plausible explanation would be that the annoyance response is driven by a combination of acoustical and non-acoustical factors, and airport specific situational issues will decide which factors that will dominate.

It should be noted that this analysis is performed on a global level. The CTL calculations are based on aggregated responses and the total number of movements is valid for the whole airport as such, and may not be representative for the number of aircraft that is observed by the individual residents. Never the less a global approach will yield results that can be used for regulatory purposes on a "community level", but the findings are not suitable for application to individual responses. This reservation, however, also applies to other methods used to predict community response to noise.

6. Conclusions

It has long been recognized that prevalence of noise induced annoyance is not unambiguously described by a cumulative measure of the noise exposure alone. Other factors, both acoustical and non-acoustical, have also been found to be of importance [20, 21]. The CTL method provides a robust means to compare the results from different studies. The CTL value for a particular community survey gives a single number quantification of the influence of all acoustical and non-acoustical factors that affects the annoyance assessment.

The present analysis of survey results from 32 different aircraft noise studies shows that the number of aircraft movements may play a significant role. At so-called LRC airports, *i.e.* airports with stable operating conditions, the prevalence of highly annoyed residents increases with an increasing amount of traffic. For a given exposure level the percentage of highly annoyed residents increases equivalent to a DNL increase of 1.8 dB per doubling of the traffic. The same tendency cannot be found for HRC airports. At this type of airports the annoyance assessment is therefore most likely dominated by other non-acoustical factors, and the effect of number of movements seems to be absent or masked.

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