**Title:** On the stability of community tolerance for aircraft noise

**Authors:**

Femke B. Gelderblom

SINTEF ICT. Postboks 4760 Sluppen, 7465 Trondheim, Norway

Truls Gjestland

SINTEF ICT. Postboks 4760 Sluppen, 7465 Trondheim, Norway

Sanford Fidell

Fidell Associates Inc. 23139 Erwin St, Woodland Hills, CA 91367, USA

 Bernard Berry

Berry Environmental Ltd. 49 Squires Bridge Road Shepperton, Surrey TW17 OJZ, UK

**Running Title:** Stability of community response to aircraft

# Abstract

 Although aircraft noise-induced annoyance prevalence rates vary greatly for similar noise exposure levels in different times and places, some suggest that communities have recently reacted more strongly to aircraft noise than in the past. Others regard claims of greater annoyance over time at similar exposure levels as inconclusive. The current study examined Community Tolerance Level (CTL) values for aircraft noise annoyance studies for temporal trends in 62 studies conducted between 1961 and 2015. The airports studied were classified as "high-rate-of-change" (HRC) and "low-rate-of-change" (LRC) airports. HRC airports experienced large changes in their operational patterns within three years prior to interviewing, or announcement 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 no major noise-related controversies. No significant temporal trend in CTL values was observed over the past 50 years. However, lower tolerance for noise was observed in communities around HRC airports than in communities around LRC airports. Greater numbers of surveys of annoyance at HRC airports in recent years confound differences in CTL values with recency of assessment.

PACS numbers: 43.50.Qp, 43.50.rq

# Introduction

Annoyance prevalence rates in communities exposed to aircraft noise may increase over time either because exposed populations experience more noise, or because community tolerances for aircraft noise have decreased over time. Ideally, temporal trends in annoyance prevalence rates would be investigated via longitudinal studies of consistent design, in communities with stable noise exposure. Changes in airport communities’ tolerance for noise exposure and changes in exposure levels, however, are more often than not confounded with other factors. Long-term changes in community exposure to aircraft noise may be either incremental or abrupt, and the accuracy and precision of survey and noise assessment methods have generally improved over time.

Guski (2004) interpreted the results of a repeated Swiss study on aircraft noise reported by Oliva (1998) as producing no evidence of significant differences in annoyance reactions over the period 1971-1991. Kastka *et al.* (1995) reported a large increase in annoyance prevalence rates between studies conducted in 1987 to 1995 at Düsseldorf Airport. Results of the 1995 study may have been influenced by fears that a newly built replacement for the main runway would attract additional air traffic.

Gelderblom *et al.* (2014) replicated a 1991 study (Gjestland *et al.* 1994) of aircraft noise-induced annoyance at two airports in Norway. They observed no significant change in annoyance prevalence rates between 1991 and 2014. Although the airports experienced no major operational changes in the period between the studies, study methods differed slightly with respect to wording of questions, annoyance scales and noise metrics used.

Babisch *et al.* (2009) adopted an indirect approach to analyzing temporal trends by comparing the average annoyance prevalence rates at four major European airports to the EU standard curve (European Union, 2002; Miedema and Vos, 1998). In this “HYENA” study, Babisch *et al.* distinguished between aircraft noise annoyance during the day and night, but did not ask for overall annoyance due to aircraft noise. Vincent *et al.* (2000) have shown that general annoyance cannot be determined from annoyance reports for specific periods of the day. Further, the sample of four airports studied by Babisch[[1]](#endnote-1) *et al.* is also less diverse than the set of studies used to construct the EU curve. The HYENA study nevertheless concluded (in part) that annoyance due to aircraft noise had increased over time.

A meta-analysis of trends in annoyance prevalence rates at different times and places is one alternative to the conduct of longitudinal studies. Several researchers (Brooker, 2009; Guski, 2004; Janssen and Guski, 2015; Van Kempen and Van Kamp, 2005, *inter alia*) have attempted to discern consistent trends over time intended to yield a universal exposure-response function. (ISO 1996-1 (ISO, 2016) summarizes many such efforts.) Often, however, such analyses have effectively ignored trends in airport operational patterns over time.

 Guski (2004) found that a quarter of survey respondents were highly annoyed at a noise exposure level of *L*dn = 68 dB in 1965, but the same percentage of respondents were highly annoyed at *L*dn = 61 dB in 1990. Guski fitted a second order polynomial (r2 = 0.40) to 18 data sets provided by Miedema and Vos (1998). A linear regression line (r2 = 0.38) fitted to the same data sets indicates a decrease in tolerance for aircraft noise exposure of 0.31 dB/year. Janssen and Guski (2015) subsequently analyzed the findings of 32 aircraft noise annoyance surveys contained in a TNO database for the period 1961 to 2005. Janssen and Guski focused on the percentage of survey respondents describing themselves as highly annoyed at an exposure level of *L*dn = 55 dB. They found that at *L*dn = 55 dB, the prevalence of high annoyance had increased from about 10 percent in 1960 to about 30 percent in 2000. They also found that the sound level associated with an annoyance prevalence rate of 25 percent had decreased from about *L*dn = 65 dB in 1970 to about *L*dn = 55 dB in 2000.

 Janssen and Guski (2015) defined two classes of airports 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 the operational plans within 3 years before and after the study.* However,Janssen and Guski did not conduct separate analyses of the two types of airports.

Brooker (2009) reported that although some indications may be found of a decrease in tolerance for noise exposure over the last 25 years, the reported trends are weak, and could also be attributed to sampling and/or methodological differences among studies. Van Kempen and Van Kamp (2005) proposed several explanations for reported reductions in tolerance for aircraft noise over time, but found consistent and credible evidence lacking. Janssen *et al.* (2011) observed that the annoyance scale used was an important source of heterogeneity in annoyance response, but dismissed it as a fully satisfactory explanation for the observed trend of a decrease in tolerance.

Noise exposure grows gradually at many airports, but in some cases, new runway construction, fleet changes, extension of operating hours or an increase in numbers of night flights or other events can cause abrupt changes. Such abrupt changes affect annoyance prevalence rates (Brink *et al.*, 2008; Brown and Van Kamp, 2008, 2009a; Fidell *et al.*, 2002). Likewise, public debate and fear of future increases in aircraft noise exposure can also increase annoyance prevalence rates (Van Kempen and Van Kamp, 2005) when residents expect an abrupt change in noise exposure.

A temporal trend analysis should therefore take into account differences in reported aircraft annoyance prevalence rates in communities near low- and high rate of change (“LRC” and “HRC”, respectively) airports, as defined by Janssen and Guski. A set of 62 aircraft noise annoyance survey outcomes was assembled and classified as either HRC or LRC for this purpose. The findings of these studies were then analyzed for temporal trends in community tolerance for aircraft noise exposure.

# Method

 The assembled field studies were classified as HRC or LRC airports as proposed by Janssen and Guski (2015). The criterion for classification as an HRC airport required a change in exposure and/or operational pattern to have occurred within three years of interviewing. An HRC classification also required that experienced or expected step-changes in airport operations last for more than three months. Information needed for this classification was gathered from several sources: that presented in original publications; that presented in Bassarab *et al.* (2009); that contained in the Airports Council International "Annual world airport traffic report" (ACI, 2014); at the relevant airport web sites; and through personal communications with researchers.

 Note that classification of an airport as HRC is not determined solely by a step change in noise exposure. An airport is also classified as HRC if major changes in the operational pattern have been introduced or have been announced. Changes in the operational pattern may imply new flight procedures and/or new flight tracks but not necessarily a change in number of aircraft movements. Residents living near an HRC airport may or may not experience an actual increase or decrease in noise exposure. Noise exposure itself can remain unchanged, noise exposure patterns can change without a corresponding change in DNL, or both exposure levels and cumulative noise metrics can change.

## Measure of change in community response

As described in Annex H of the current revision of ISO 1996-1 (2016), a CTL value is a predicted value of a Day-Night Average Sound Level (DNL) at which half of the survey respondents report high annoyance with aircraft noise exposure. Large values of CTL indicate a high tolerance for noise exposure in a community, while small values of CTL indicate a low tolerance for noise exposure. Differences among survey findings may be characterized in decibel-denominated units via simple comparisons of CTL values across communities.

The shape of the dose-response function is fixed in CTL analysis, rather than derived from a curve fitting analysis[[2]](#endnote-2). Its shape is based on the observation that the rate of change of annoyance with DNL closely resembles the rate of change of loudness with sound level. The CTL approach accounts for half again as much variance in the relationship between aircraft noise exposure and annoyance prevalence rates in communities as conventional analyses (Fidell *et al.*, 2011.)

The position of the CTL dose-response function on the exposure (X) axis for a given community is determined empirically, from social survey data. The location of the dose-response function is fully specified by a single parameter which anchors the function to the X-axis. The slope of the dose-response relationship is steepest at the 50% point, so that uncertainty in the percentage highly annoyed introduces only relatively small inaccuracies in CTL values.

Fidell *et al.* (2011) found a grand mean CTL value of 73.3 dB for the 43 aircraft noise studies that they analyzed. They also showed that for their predicted dose-response function, this average CTL differed only negligibly from the dose-response curve derived by Miedema and Vos (1998) and recommended by the European Union. Higher annoyance prevalence rates with aircraft noise than predicted by the EU curve are associated with CTL values lower than 73.3 dB, and *vice versa*.

## Data

For their initial CFL analysis, Fidell *et al.* (2011) compiled a set of 43 studies conducted during the period 1961 to 2007. The present study combines the 43 studies analyzed by Fidell *et al.* with nine additional studies analyzed by Janssen and Guski, (2015), but not analyzed by Fidell *et al.* The present data set also includes the findings of five post-2007 studies from Vietnam (Gjestland *et al.*, 2015b; Nguyen *et al.*, 2011, 2012, 2015) and five studies from Norway (Gelderblom *et al.*, 2014, 2016). The entire dataset analyzed contains 650 paired observations of aircraft noise exposure and prevalence of high annoyance, measured in 100,631 interviews conducted in the course of 62 field surveys of aircraft noise annoyance conducted between 1961 and 2015.

Table I lists all 62 surveys, including their CTL values and HRC/LRC classification. The average unweighted CTL value for all 62 surveys is equal to 72.3, with a standard deviation of 7.2. Table II presents the rationale for the HRC classification.

## Linear Regression Models

With CTL as the predicted variable and study year as predictor variable, simple linear regression is the simplest form of temporal trend analysis:

(Univariate model)

 $CTL=β\_{intercept}+ β\_{year}x\_{year}$ (1)

This model can be extended by adding a second (HRC) predictor variable:

(Multivariate model)

$CTL=β\_{intercept}+ β\_{year}x\_{year}+β\_{HRC}x\_{HRC}$ (2)

High rate of change ($x\_{HRC}$) is a dichotomous (True/False) variable. Its value depends on the recent occurrence or near-future expectation of abrupt, long-lasting changes in airport operations according to the definition above.

Response variables in a regression model should be weighted if they are of unequal variance. In case of a sufficient study sample size, the uncertainty of CTL values originates from often-unknown factors and uncertainties in noise estimates and survey methods. Weightings based on sample size would produce a questionable bias in favor of larger studies in the present case.

Brooker (2009) notes that improvements in survey and noise estimation methods over time render CTL values of studies from 30-40 years ago more uncertain than those of more recent studies. The change of uncertainty over time is, however, difficult to quantify.

The univariate linear regression was therefore performed twice: once on the entire dataset of 62 studies, and once on a subset containing all surveys conducted within the last three decades. This subset contained 52 studies from 1978 and later.

# Results

Figure 1and Table III show the results of a simple linear regression analysis of the entire data set of 62 surveys, with study year as the sole predictor variable (Univariate model).The trend toward lower CTL values over time indicates a decrease in tolerance for aircraft noise exposure over time. The trend is a weak one that accounts for only 9 % in the variance of the relationship between study year and CTL value, but its slope, -0.15 dB in CTL value per year, is unlikely to have arisen by chance alone.



Figure 1. (Color online) CTL-values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al.*, triangles: Vietnam and Norway. The solid line ($R^{2}=0.09$) shows the linear fit of all data, including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU guideline.

Taken at face value, this finding suggests that people's tolerance for aircraft noise is currently about 8 dB lower than in the 1960s. Similarly, the aircraft noise exposure necessary to highly annoy 50% of residential populations in 1970 is about 4.5 dB lower than that necessary to yield the same effect in 2000. This is less than half of the difference found by Janssen and Guski (2015), but the present analysis also suggests a decrease in community tolerance for noise exposure. Additionally, the difference between the dash-dot line and the model fit indicates that communities in 2015 are about 4.5 dB ± 3 dB less tolerant of aircraft noise than predicted by the EU dose-response curves.

Table IV shows the results of the multivariate linear regression. The effect of study year is reduced in the multivariate regression from 0.15 to 0.04 dB per year, and is not significant at *p* ≤ 0.05. In other words, field study evidence does *not* support a claim that tolerance for aircraft noise has decreased over time in this analysis.

Figure 2 shows the results of the linear regression on the multivariate model with two predictive variables. The square symbols represent HRC studies, while triangular symbols represent the rest of the studies. The dichotomous nature of $x\_{HRC}$ results in two possible outcomes of the model. Tolerance for aircraft noise is 9 dB ± 3 dB lower in studies at HRC airports; an effect unlikely to have occurred by chance alone. A CTL value of 73.7 dB ± 3 dB in 2015 for steady-state conditions remains in good agreement with the earlier average of 73.3 dB reported by Fidell *et al.* (2011).



Figure 2. (Color online) CTL-values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 categorized by HRC (squares) or LRC (triangles) (see text). The solid upper and lower lines show their respective linear fits ($R^{2}=0.33$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.

After categorization by rate of change, the extended model accounts for 33 % of the variance in the data. The data no longer exhibit a meaningful trend over time. Further, the year in which a study was conducted has a smaller effect on CTL than the univariate model suggests, and the fit does not predict the prevalence of aircraft noise-induced annoyance in 2015 to be significantly greater than the European guideline levels.

The above analysis weights all studies equally, even though the uncertainty of CTL estimates from earlier studies may be greater than of later studies. The analysis was therefore repeated for all airport surveys undertaken later than 1978. (The rationale for selecting 1978 as cut-off year is described above.)

Table V and Figure 3 show the result of a linear regression with only study year as a predictive parameter based on the 52 studies completed since 1978. Again, this univariate model explains only 9 % of the variance in CTL scores, but for this subset, the effect of year is no longer significant at a significance level of *p* ≤ 0.05. If a trend in tolerance for noise exposure exists, its magnitude over 40 years is no more than 2.1 dB. However, the CTL estimates for all years lie below the Fidell *et al.* (2011) average (suggesting lower tolerance for noise), even though the confidence intervals for the fit are almost everywhere wide enough to include it. In short, CTL values appear to have been stable in the past forty years, even if categorization is not taken into account.



Figure 3. (Color online) CTL-values for 52 aircraft noise annoyance studies conducted between 1978 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al*., triangles: Vietnam and Norway). The circles indicate excluded studies. The solid line shows the linear fit of all data ($R^{2}=0.005$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.

Table VI and Figure 4 show the results of the multivariate model (considering HRC/LRC classification) from 1978 onward. Study year once again has no significant predictive value, and its effect size is negligible. Extending the model again improved the fit considerably, however, with the variance accounted for increasing to 30 %.



Figure 4. (Color online) CTL-values for 52 aircraft noise annoyance studies conducted between 1978 and 2015 categorized by HRC (squares) or LRC (triangles)(see text). The circles indicate excluded studies. The solid upper and lower lines show their respective linear fits ($R^{2}=0.3$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.

CTL values in LRC communities are 75 dB ± 7 dB, in good agreement with the European guideline. Tolerances for aircraft noise exposure noise at HRC airports were 9 dB ± 4 dB lower than at the LRC airports.

The distribution of the two types of studies (LRC *vs*. HRC) explains these findings. The great majority of the HRC studies were conducted relatively recently (later than 1996). This group is therefore (overly) well represented in the past two decades.

As a result, the results from HRC studies depress the average CTL of studies from the past two decades. HRC studies do not affect the average CTL of studies earlier than 1978, as there is no evidence of HRC studies from this period.

**DISCUSSION**

##  Classification of airports by rate of change

 All 62 airports in this study were initially classified as LRC-airports. A re-classification to HRC was only done when information that matched the classification criteria defined by Janssen and Guski (2015) could be found. As previously explained such information comprised findings in the original study publication *e.g.* journal articles, scientific reports etc., individual annual reports from the relevant time period by the airports themselves, and annual reports published by national and international bodies. Whenever feasible the scientists that conducted the different studies were contacted, and the HRC/LRC issue was discussed with them. About half of the studies had previously been classified by Janssen and Guski, and their classification was re-assessed, and in a few cases reversed. After this process, about a quarter of the airports were classified as HRC-airports, see Table I. The rationale for the HRC classification has been listed in Table II.

## **Sensitivity of findings to misclassification of airports by rate of change**

Since many of the field studies that were analyzed were conducted decades ago, information about rates of operational changes and other relevant classification information at some airports may be imperfect. The classification task has also a certain subjective element. In principle, an airport could thus have been misclassified as HRC instead of LRC, or *vice versa*. A simple Monte Carlo simulation was conducted to quantify the influence of potential misclassification errors.

Each of the 62 studies in Table I was assigned a random number, *U*, between 0 and 1. To determine the effect of, say, an incorrect misclassification rate of 5%, each survey assigned a *U* value less than 0.05 was re-classified from HRC to LRC or *vice versa*. The rate of change classifications for surveys with *U* values greater than 0.05 were unchanged, and a new linear fit was performed for the complete data set as shown in Figure 4. Each new linear fit predicted two new CTL values (one for each category) for the year 2015. This procedure was repeated 100,000 times, yielding 100,000 estimates for today's CTL value for each category. Finally, means and standard deviations for these estimates were calculated. Similar calculations were performed for all other *U* values in the range 0 to 0.5 (in steps of 0.05), corresponding to 0 % to 50 % misclassification rates. The results are plotted in Figure 5.



Figure 5. (Color online) The influence of incorrect study classification. The two curves show the predicted CTL (± 2σ) in 2015 for an HRC airport (red) and an LRC airport (green) as a function of erroneous classification of rate of change.

The figure shows that the difference in CTL value for the two types of airports decreases as the percentage of classification errors increases. At a 50 % misclassification rate (random classification), the difference between the two types disappears. A significant difference in CTL values between the two types of airports persists as long as at least 76.5 % of the studies are correctly categorized. Given the care taken in making classification decisions about airports, it seems quite unlikely that mis-classification errors could have been made in 14 (23.5 %) of the 62 cases considered.

## Potential effects of population mobility

The temporal dynamics of noise-induced annoyance provide the broader context for understanding the results described above. The literature offers only a few systematic analyses or quantitative answers to questions about how promptly and closely annoyance prevalence rates track changes in transportation noise exposure (*cf.* Brown and Van Kamp, 2009b; Fidell *et al.*, 1985; Gjestland *et al.*, 1995; Horonjeff and Robert, 1997; Schuemer and Schreckenberg, 2000). Questions about the time constants of aircraft noise annoyance include “How long does it take for community annoyance to become fully aroused by a novel noise exposure situation?”, “How much time must pass with stable operations before annoyance prevalence rates diminish?”, “How much do short-term changes in annoyance prevalence rates overshoot or undershoot changes in exposure?”, and in general, “How much and for how long do annoyance prevalence rates vary from asymptotic values as aircraft operations vary?”

Not all changes in annoyance prevalence rates are necessarily due to changes in noise exposure. As formally recognized by CTL analysis, attitudinal changes can affect annoyance prevalence rates as well. For example, feelings of helplessness and lack of control have been found to increase individual annoyance. A belief that people are not being treated fairly can also increase annoyance prevalence rates (Bauer *et al.*, 2014; Hatfield *et al.*, 2002; Schreckenberg *et al.*, 2010 *inter alia*).

The community (rather than the individual) was selected as the unit of analysis for calculating CTL values in the belief that many factors affecting annoyance are similar for all residents of a community, but may differ widely between different communities. When a sudden change in airport operations occurs, it affects all residents, so the community’s tolerance for aircraft noise change. A modicum of evidence (Brown and Van Kamp, 2009a; Horonjeff and Robert, 1997) suggests that an individual’s elevated annoyance due to a sudden change does not subside over time: once highly annoyed, always highly annoyed.

However, community populations are not static over time. Some residents leave neighborhoods, while others arrive. Community size and composition may vary for noise exposure-related reasons, but also due to changes in land use, economic, and other social conditions. National census bureaus provide information on local migration. In 2010, ten percent of US households expressed a desire to move, and about half of these cited 'neighborhood conditions' as the main reason for their desire to change residence. In 2014, 12 % of the US population actually did move to a new location (US Department of Commerce, 2015). Similar data from Norway show that in 2014, 15 % of the population relocated to a new residence. The percentage of households which change residence annually ranges between 2 % and 15 % for all OECD countries (Caldera *et al.*, 2011).

The quantitative effects of population mobility on the stability of CTL values in airport neighborhoods can be assessed with the aid of a simple modeling exercise. Population mobility creates two categories of residents within communities: those who were present prior to a large operational change at an airport (pre-change residents), and those who moved in afterward (post-change residents). The first group decreases as a percentage of a community’s population over time, while the second group grows at a similar but opposite rate2.

For a fixed total community size over time, the percentage of pre-change residents ($P\_{pre}$) can be calculated recursively from the yearly mobility percentage rate ($r\_{m}$) and the time (*t*) passed since the change.

$P\_{pre}\left(t\right)=\frac{100\%-r\_{m}}{100\%} P\_{pre}\left(t-1\right)$ (3)

The percentage of post change residents at time *t* ($P\_{post}\left(t\right)$) is then equal to:

$P\_{post}\left(t\right)=100\%- P\_{pre}\left(t\right)$ (4)

Figure 6 shows the change of resident type in the time following a change, at an assumed mobility rate of 10 % per year.



Figure 6. (Color online) Example of change of resident type over time, when mobility rate is equal to 10 % per year.

Assuming that an operational change has permanently decreased the tolerance for aircraft noise of pre-change residents, while post-change residents have average tolerance for aircraft noise (or possibly even self-select for greater than average tolerance), the community’s average CTL over time ($CTL\_{Community}(t)$) becomes a weighted average of CTL scores for each respective group of residents ($CTL\_{pre}$ and $CTL\_{post}$).

$CTL\_{Community}\left(t\right)=\frac{P\_{pre}\left(t\right)CTL\_{pre}+ P\_{post}\left(t\right)CTL\_{post}}{100\%}$ (5)

Figure 7 shows the change of a community’s CTL over time for different mobility rates and for different change in tolerance (TC), assuming that new residents are of average tolerance for noise exposure. Higher rates of mobility and smaller differences in tolerance of pre- and post-change residents lead to shorter recovery times, but the effects of a change in aircraft noise annoyance will generally take decades to disappear if only normal mobility of residents is considered. This is consistent with findings that recovery from excess reaction (overshoot) to noise changes is very slow (Horonjeff and Robert, 1997).



Figure 7. (Color online) Examples of recovery in CTL values for a range of mobility rates and changes in tolerance for aircraft noise.

Straightforward modeling of the effects of self-selection of neighborhood residents on the basis of tolerance for aircraft noise exposure provides some insights into potential effects of population changes on the temporal stability of annoyance prevalence rates and CTL values.

The model can be altered to take into account additional effects. The current modeling exercise suggests that following hypotheses merit testing in potential longitudinal studies:

* If residents who are highly annoyed by aircraft noise exposure are more likely to leave a neighborhood following an increase in aircraft noise exposure, $CTL\_{pre}$ will increase over time, accelerating the increase of $CTL\_{community}$. The rate at which people move in and out of the community ($r\_{m}$) may not be directly affected by a step change in the airport operations, but the selection of people who actually move may change.
* Similarly, if a step change in operations motivates residents to leave a community, which directly affects $r\_{m}$, $P\_{pre}$ will decrease at a greater rate. Again, the increase of $CTL\_{community}$ over time will be quicker. This enhanced "recovery" of $CTL\_{community}$ may well depend on the size of the step increase in noise. It seems plausible that community residents who are highly annoyed by aircraft noise are more likely to leave a neighborhood in the aftermath of an increase in noise exposure, but data to support this assumption is inconclusive (Nijland *et al*., 2007). In one aircraft noise study in Norway (NOR-311, 1989), respondents were asked about plans or desire to move. Among those (only about 1 %) who had plans to move out of the community in the near future, none listed aircraft noise as the main reason. Gelderbrom *et al.* (2016) found that about 25 % of the residents expressed plans or desires to move, but only 25 % of these (about 6 % of the total community) were highly annoyed by aircraft noise. About 40 % of those wanting to move cited "noise" as their primary reason for moving, even though only half of them considered themselves highly annoyed.
* If residents who choose to move into a noise-exposed neighborhood are more tolerant of aircraft noise, the $CTL\_{post}$ will be above average. If so, the community as a whole will eventually become above average tolerant of noise.

# Conclusions

No evidence was found for a large enough temporal trend in aircraft noise-induced annoyance prevalence rates to justify updating existing exposure-response curves. The airports included in the current analysis were classified as low or high rate of change. Residents living near LRC airports experience relatively stable noise conditions and only incremental changes in the airport operations. Residents at HRC airports experience major changes in operational patterns, and/or controversial plans for anticipated changes, often accompanied by airport/community conflicts. Without this distinction between LRC and HRC airports, annoyance prevalence rates appear to have increased since the 1960s for the same noise exposure values. This observation is misleading, however, due to the temporal distribution of 'high rate of change' surveys. All but two surveys conducted before 1995 were conducted in communities with relative stable aircraft noise exposure and stable airport operations. In contrast, about half of the studies conducted after 1995 were conducted in communities at high rates of change airports. No significant increase or decrease over time in annoyance due to aircraft noise was observed when the rate of change of airport operations was taken into account.

The average annoyance response from HRC surveys indicated 9 dB ± 6 dB less tolerance for aircraft noise compared with communities near LRC airports. The average annoyance response in airport communities with relatively stable operating conditions (LRC airport communities) was very similar to the mean CTL-value for 43 aircraft noise surveys initially analyzed by Fidell *et al*. (2011). The exposure-response curve associated with this CTL-value is almost identical to the exposure-response curve recommended by the European Union (European Union, 2002).

Incompleteness of available data, especially for studies completed decades ago, complicates classifying airport communities into LRC and HRC categories. The analysis of data is based on (and therefore sensitive to) the likely imperfectness of the chosen categorization. However, the existence of a difference between CTL values for the two types of airports is robust. Even if nearly a quarter of the studies are misclassified, that tolerance for aircraft noise exposure is significantly lower at HRC airports than at LRC airports.

Although over-reaction caused by a major change in airport operations may be permanent and stable on an individual level, CTL values can eventually revert to pre-change levels due to migration of residential populations. Depending on the rate by which people move into and out of the community and the initial change in CTL, the effect of the change may persist for a decade or more.

# References

ACI (**2014**). "Annual world airport traffic report", Airports Council International, [www.aci.aero/publications/ACI-Economics-and-Statistics](http://www.aci.aero/publications/ACI-Economics-and-Statistics)

Babisch, W., Houthuijs, D., Pershagen, G., Cadum, E., Katsouyanni, K., Velonakis, M., Dudley, M.-L., Marohn, H., Swart, W., Breugelmans, O.R.P., Bluhm, G., Selander, J., Vigna-taglianti, F., Pisani, S., and Haralabidis, A. (**2009**). "Annoyance due to aircraft noise has increased over the years — Results of the HYENA study," Environ. Int. **35**, 1169–1176.

Bassarab, R., Sharp, B., and Robinette, B. (**2009**). An updated catalog of 628 social surveys of residents’ reaction to environmental noise (1943-2008). Wyle Laboratories, WR 09-18.

Bauer, M., Collin, D., Iemma, U., Janssens, K., Márki, F., and Müller, U. (**2014**). "COSMA - A European Approach on Aircraft Noise Annoyance Research," Proc INTER-NOISE 14, 1–13, Melbourne, Australia.

Brink, M., Wirth, K.E., Schierz, C., Thomann, G., and Bauer, G. (**2008**). "Annoyance responses to stable and changing aircraft noise exposure.," J. Acoust. Soc. Am. **124**, 2930–2941.

Brooker, P. (**2009**). "Do people react more strongly to aircraft noise today than in the past?," Appl. Acoust. **70**, 747–752.

Brown, A.L., and Van Kamp, I. (**2008**). "Estimating the magnitude of the change effect," Proc ICBEN 08, Foxwoods.

Brown, A.L., and Van Kamp, I. (**2009a**). "Response to a change in transport noise exposure: a review of evidence of a change effect," J. Acoust. Soc. Am. **125**, 3018–3029.

Brown, A.L., and Van Kamp, I. (**2009b**). "Response to a change in transport noise exposure: competing explanations of change effects," J. Acoust. Soc. Am. **125**, 905–914.

Caldera Sanchez, A., and Andrews, D. (**2011**). "Residential mobility and public policy in OECD countries," OECD J. **2011/1**, 185–206.

European Union (**2002**). Directive relating to the assessment and management of environmental noise. Directive 2002/49/EC.

FAA (**2006**) "APO Terminal Area Forecast", Federal Aviation Administration, http://tafpub.itworks-software.com/taf2006/default.asp

Fidell, S., Horonjeff, R.D., Mills, J., Baldwin, E., Teffeteller, S., and Pearsons, K. (**1985**). "Aircraft noise annoyance at three joint air carrier and general aviation airports," J. Acoust. Soc. Am. **77**, 1054–1068.

Fidell, S., Silvati, L., and Haboly, E. (**2002**). "Social survey of community response to a step change in aircraft noise exposure," J. Acoust. Soc. Am. **111**, 200–209.

Fidell, S., Mestre, V., Schomer, P.D., Berry, B., Gjestland, T., Vallet, M., and Reid, T. (**2011**). "A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure.," J. Acoust. Soc. Am. **130**, 791–806.

Gelderblom, F.B., Gjestland, T., Granøien, I.L.N., and Taraldsen, G. (**2014**). "The impact of civil versus military aircraft noise on noise annoyance," Proc INTER-NOISE 14, 1–10, Melbourne, Australia.

Gelderblom, F.B., Gjestland, T., and Granøien, I.L.N. (**2016**) "Noise surveys at five Norwegian airports", INTER-NOISE 2016

Gjestland, T., Liasjø, K.H., and Granøien, I.L.N. (**1994**). Response to noise around Værnes and Bodø Airports. SINTEF, STF40 A94095.

Gjestland, T., Liasjø, K.H., and Granøien, I.L.N. (**1995**). "Community response to noise from short-term military aircraft exercise," J. Sound Vib. **182**, 221–228.

Gjestland, T., Gelderblom, F.B., Fidell, S., and Berry, B. (**2015a**). "Temporal trends in aircraft noise annoyance," Proc INTER-NOISE 15, 1–8, San Francisco, USA.

Gjestland, T., Nguyen, T.L., and Yano, T. (**2015b**). "Community response to noise in Vietnam: Exposure-response relationships based on the community tolerance level," J. Acoust. Soc. Am. **137**, 2596–2601.

Guski, R. (**2004**). "How to forecast community annoyance in planning noisy facilities," Noise Health **6**, 59–64.

Hatfield, J., Job, R.F.S., Hede, A.J., Carter, N.L., Peploe, P., Taylor, R., and Morrell, S. (**2002**). "Human response to environmental noise: the role of perceived control," Int. J. Behav. Med. **9**, 341–359.

Horonjeff, R.D., and Robert, W.E. (**1997**). Attitudinal Responses to Changes in Noise Exposure in Residential Communities. NASA, CR-97-205813.

International Standards Organisation (**2016**). *Description, Measurement and Assesment of Environmental Noise - Part 1: Basic Quantities and Assessment Procedures*, Annex H [*in press*].

Janssen, S.A., and Guski, R. (**2015**). *Aircraft Noise and Health: Review of Evidence*, (Directorate General Joint Research Center and Directorate General for Environment, European Union) Chap.7 [*in press*].

Janssen, S.A., Vos, H., Van Kempen, E.E.M.M., Breugelmans, O.R.P., and Miedema, H.M.E. (**2011**). "Trends in aircraft noise annoyance: the role of study and sample characteristics.," J. Acoust. Soc. Am. **129**, 1953–1962.

Kastka, J., Borsch-Galetke, E., Guski, R., Krauth, J., Paulsen, R., Schümer, R., and Oliva, C. (**1995**). "Longitudinal study on aircraft noise effects at Düsseldorf airport 1981-1993," Proc ICA 95, 447–451, Trondheim, Norway.

Van Kempen, E.E.M.M., and Van Kamp, I. (**2005**). Annoyance from air traffic noise: Possible trends in exposure-response relationships. RIVM National Insititute for Public Health and the Environment, 01/2005 MGO EvK.

Miedema, H.M.E., and Vos, H. (**1998**). "Exposure-response relationships for transportation noise.," J. Acoust. Soc. Am. **104**, 3432–3445.

Nguyen, T.L., Yano, T., Nguyen, H.Q., Nishimura, T., Fukushima, H., Sato, T., Morihara, T., and Hashimoto, Y. (**2011**). "Community response to aircraft noise in Ho Chi Minh City and Hanoi," Appl. Acoust. **72**, 814–822.

Nguyen, T.L., Yano, T., Nguyen, H.Q., Nguyen, K.T.T., Fukushima, H., Kawai, K., Nishimura, T., and Sato, T. (**2012**). "Aircraft and road traffic noise annoyance in Da Nang City, Vietnam," Proc INTER-NOISE 12, 1661–1670, New York, USA.

Nguyen TL, Nguyen T, Yano T, Morinaga M, Yamada I, Sato T and Nishimura T (**2015**), "Social surveys around Noi Bai Airport before and after the opening of the new terminal building", Proc.INTERNOISE15, San Francisco, USA. Nijland, H. A, Hartemink, S., van Kamp, I., and van Wee, B. (**2007**). "The influence of sensitivity for road traffic noise on residential location: does it trigger a process of spatial selection?," J. Acoust. Soc. Am. **122**, 1595.

Oliva, C. (**1998**). “Belastungen der Bevölkerung durch Flug- und Strassenlärm” (“People’s exposure to aircraft and road traffic noise”). Duncker & Humbolt, Berlin.

Schreckenberg, D., Meis, M., Kahl, C., Peschel, C., and Eikmann, T. (**2010**). "Aircraft noise and quality of life around Frankfurt Airport.," Int. J. Environ. Res. Public Health **7**, 3382–3405.

Schuemer, R., and Schreckenberg, D. (**2000**). "Änderung der Larmbelastung bei Massnahme bedingter stufenweise veränderter Geräuschbelastung“ (”The effect of stepwise change of noise exposure on annoyance)," ZfLärmbek **47**, 134–143.

Statistics Norway (**2015**). "Migration in Norway," http://www.ssb.no/en/befolkning/statistikker/flytting.

US Department of Commerce (**2015**). "US Census Bureau," www.census.gov.

Vincent, B., Vallet, M., Olivier, D., and Paque, G. (**2000**). "Evaluation of variations of the annoyance due to aircraft noise," Proc INTER-NOISE 00, 1–4, Nice, France.

# Tables

Table I. CTL scores and rate of change classification of 62 aircraft noise annoyance studies conducted between 1961 and 2015

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Study  | Study year(s)  | Primary authors  | Report year  | No. of interviews  | Study Code | CTL | Change rate class (0 =LRC, 1= HRC)  |
| First Heathrow  | 1961 | McKennell “Wilson report”  | 1963 | 1731 | UKD-008  | 77.6 | 0 |
| French A/C  | 1965–66  | Alexandre  | 1970 | 2000 | FRA-016  | 79.6 | 0 |
| Second Heathrow  | 1967 | MIL research, HMSO SS394 | 1971 | 4699 | UKD-024  | 84 | 0 |
| Tracor, large cities, phase II  | 1967–69  | Connor and Patterson  | 1976 | 2912 | USA-032  | 72.6 | 0 |
| Tracor, large cities, phase I  | 1967–69  | Connor and Patterson  | 1976 | 3590 | USA-022  | 74.3 | 0 |
| Munich A/C  | 1969 | Rohrman *et al*.  | 1973 | 660 | GER-034  | 78 | 0 |
| Tracor, small cities  | 1970–71  | Connor and Patterson  | 1972 | 1960 | USA-044  | 86.3 | 0 |
| Swiss A/C  | 1971–72  | Grandjean *et al*.  | 1973 | 2995 | SWI-053  | 76.6 | 0 |
| Scandinavian A/C  | 1972 | Rylander *et al*.  | 1972 | 2900 | SWE-035  | 79.6 | 0 |
| LAX  | 1973 | Fidell and Jones  | 1975 | 940 | USA-082  | 72.6 | 0 |
| Canadian A/C-street  | 1978 | Hall *et al*. (1979, 80, 81, 82)  | 1983 | 673 | CAN-168  | 68.6 | 0 |
| Burbank airport  | 1979–80  | Fidell *et al*.  | 1985 | 5041 | USA-203  | 63 | 1 |
| Australian A/C  | 1980 | Hede and Bullen  | 1982 | 3575 | AUL-210  | 79 | 0 |
| Orange County A/C  | 1981 | Fidell *et al*.  | 1985 | 3103 | USA-204  | 63.6 | 1 |
| U.S. airbase  | 1981 | Borsky  | 1983 | 874 | USA-338  | 75.6 | 0 |
| Westchester A/C  | 1982 | Fidell *et al*.  | 1985 | 1465 | USA-301  | 70.3 | 0 |
| Decatur airport  | 1982 | Schomer  | 1983 | 231 | USA-250  | 78.6 | 0 |
| Brussels airport  | 1980–85  | Jonckheere  | 1988,89  | 677 | BEL-288  | 82.3 | 0 |
| Pittsburgh airport  | 1983 | Fidell  | 1983 | 140 | PIT  | 83 | 0 |
| Glasgow | 1984 | Atkinson *et al* | 1985 | 608 | UKD-238 | 70 | 0 |
| Amsterdam | 1984 | Miedema | 1987 | 581 | NET-240 | 71.6 | 0 |
| French A/C-road  | 1984–86  | Vallet *et al*.  | 1988 | 1032 | FRA-239  | 74.6 | 0 |
| British ANIS  | 1982 | Brooker *et al*.  | 1985 | 2173 | UK-242 | 72.6 | 0 |
| German A/C-road  | 1987 | Kastka *et al*.  | 1996 | 516 | GER-373  | 62.6 | 0 |
| Small airports  | 1988–93  | Rylander and Björkman  | 1997 | 513 | SWE-419  | 70 | 0 |
| Long Beach  | 1989 | Fidell and Silvati  | 1989 | 2505 | LGB  | 65 | 0 |
| Oslo A/C  | 1989 | Gjestland *et al*.  | 1990 | 3337 | NOR-311  | 74.3 | 0 |
| Trondheim Værnes  | 1990–91  | Gjestland *et al*.  | 1994 | 1195 | NOR-366  | 77.3 | 0 |
| Atlanta  | 1991 | Fidell and Silvati  | 1991 | 922 | USA-349  | 72.3 | 0 |
| Zurich + Geneva | 1991 | Oliva | 1998 | 2052 | SNS1990 | 72.6 | 0 |
| Bodø Lufthavn  | 1992 | Gjestland *et al*.  | 1994 | 3267 | NOR-328  | 83 | 0 |
| Seattle A/C  | 1995 | Fidell *et al*.  | 1998 | 1444 | USA-431  | 81.3 | 0 |
| Vancouver round 1  | 1995 | Fidell *et al*.  | 2002 | 1000 | CAN-385  | 84 | 0 |
| Amsterdam | 1996 | Breugelmans *et al*. | 2007 | 11812 |  | 62.3 | 1 |
| Birmingham | 1996 | Witfield | 2003 | 1072 |  | 66 | 1 |
| Osaka international airport  | 1996 | Yamada and Kakua  | 1996 | 215 | JPN-491  | 68.3 | 1 |
| Minneapolis (MSP)  | 1996 | Fidell *et al*.  | 1996 | 2880 | USA-428  | 74.3 | 0 |
| El Segundo, CA (LAX)  | 1997 | Fidell *et al*.  | 1999 | 644 | USA-432  | 77.6 | 0 |
| Vancouver round 2  | 1998 | Fidell *et al*.  | 2002 | 1067 | YVR  | 70.6 | 0 |
| Frankfurt | 1998 | Kastka | 1999 | 1147 | FRA1 | 62.3 | 1 |
| Orly/Roissy  | 1998 | Vallet *et al*.  | 2000 | 1334 | FRA-395  | 67.6 | 1 |
| South San Fransisco  | 1999 | Fidell and Silvati  | 1999 | 1250 | SFO  | 71 | 0 |
| Munich | 2000 | Kastka | 2001 | 775 | MUC | 58.6 | 0 |
| Swiss Zurich-Kloten  | 2001 | Brink *et al*.  | 2008 | 1520 | SWI-525  | 68 | 1 |
| Amsterdam | 2002 | Breugelmans *et al*. | 2007 | 640 | GES-2 | 63.3 | 1 |
| Richfield, MN (MSP)  | 2002 | Fidell *et al*.  | 2002 | 495 | MSP  | 72.6 | 0 |
| Swiss Zurich-Kloten  | 2003 | Brink *et al*.  | 2008 | 1444 | SWI-534  | 69 | 1 |
| Korean airports  | 2004 | Lim *et al*.  | 2006 | 753 | KOR-554  | 54.6 | 0 |
| Amsterdam | 2005 | Breugelmans *et al*. | 2007 | 478 | GES-3 | 63.3 | 1 |
| Cincinnati  | 2005 | Fidell and Sneddon  | 2005 | 1606 | CVG  | 71 | 1 |
| ANASE  | 2005 | Le Masurier *et al*.  | 2007 | 2132 | UKD-604  | 63 | 0 |
| Frankfurt  | 2005 | Schreckenberg and Meis  | 2007 | 2309 | FRA  | 63.3 | 1 |
| Ho Chi Minh | 2008 | Nguyen *et al*. | 2011 | 880 |  | 75.5 | 0 |
| Hanoi-Noi Bai | 2009 | Nguyen *et al*. | 2011 | 824 |  | 68.2 | 1 |
| Da Nang | 2011 | Nguyen *et al*. | 2012 | 528 |  | 75 | 0 |
| Bodø | 2014 | Gelderblom *et al*. | 2014 | 302 |  | 81.3 | 0 |
| Trondheim-Værnes | 2014 | Gelderblom *et al*. | 2014 | 300 |  | 82.3 | 0 |
| Oslo-Gardermoen | 2015 | Gelderblom *et al.* | 2016 | 300 |  | 68 | 1 |
| Stavanger-Sola | 2015 | Gelderblom *et al.* | 2016 | 302 |  | 80 | 0 |
| Tromsø-Langnes | 2015 | Gelderblom *et al.* | 2016 | 300 |  | 83 | 0 |
| Hanoi-Noi Bai | 2014 | Thu Lan Nguyen | 2015 | 890 |  | 65,6 | 1 |
| Hanoi-Noi Bai | 2015 | Thu Lan Nguyen | 2015 | 1121 |  | 63 | 1 |

Table II. Basis for the HRC classification

|  |  |  |
| --- | --- | --- |
| Study  | Study year(s)  | Rationale |
| Burbank airport  | 1979–80  | Closure and reopening of runways due to major repairs. Main runway was closed from September 1979 to October 1980. |
| Orange County A/C  | 1981 | Evaluation of three different departure procedures for jet carriers fall 1981 |
| Amsterdam | 1996 | Extensive public discussion about airport expansion |
| Birmingham | 1996 | Announced changes. In 1997 a major restructuring program that would double the airport capacity would be started. |
| Osaka international airport  | 1996 | Original plans to close the airport after opening of Kansai Airport in 1994, but in 1996 the airport was partly closed and rebuilt to serve domestic travel |
| 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. |
| Orly/Roissy  | 1998 | Evaluation of large increase in noise levels at Roissy Airport (CDG), personal communication, M. Vallet |
| Swiss Zurich-Kloten  | 2001 | Public discussion about change of flight paths. Personal communication, M. Brink |
| Amsterdam | 2002 | Discussions about expansion. 6th runway completed in 2003. |
| Swiss Zurich-Kloten  | 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 A380 was decided |
| Hanoi-Noi Bai | 2009 | Decision to expand airport |
| Oslo-Gardermoen | 2015 | High Court decision on economic compensation to some residents. Discussions about a third runway |
| Hanoi-Noi Bai | 2014 | Expansion nearly completed |
| Hanoi-Noi Bai | 2015 | Opening of new terminal. 20 % increase in aircraft movements |

Table III. Linear regression results for the univariate model for the 62 aircraft noise annoyance studies conducted between 1961 and 2014

|  |  |  |
| --- | --- | --- |
| Coefficient | Estimate | *p* |
| $$β\_{intercept}$$ | 367 | 0.004 |
| $$β\_{year}$$ | -0.15 | 0.02 |

Table IV. Linear regression results using the multivariate model for the 62 aircraft noise annoyance studies conducted between 1961 and 2014

|  |  |  |
| --- | --- | --- |
| Coefficient | Estimate | *p* |
| $$β\_{intercept}$$ | 161 | 0.17 |
| $$β\_{year}$$ | -0.04 | 0.5 |
| $$β\_{HRC}$$ | -8.7 | 0.00002 |

Table V. Linear regression results using the univariate model for the 52 aircraft noise annoyance studies conducted between 1978 and 2015

|  |  |  |
| --- | --- | --- |
| Coefficient | Estimate | *p* |
| $$β\_{intercept}$$ | 166 | 0.4 |
| $$β\_{year}$$ | -0.05 | 0.6 |

Table VI. Linear regression results using the multivariate model for the 52 aircraft noise annoyance studies conducted between 1978 and 2015

|  |  |  |
| --- | --- | --- |
| Coefficient | Estimate | *p* |
| $$β\_{intercept}$$ | -49 | 0.8 |
| $$β\_{year}$$ | 0.06 | 0.4 |
| $$β\_{HRC}$$ | -8.7 | 0.00003 |

# Figure Captions

[Figure 1. (Color online) CTL-values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al.*, triangles: Vietnam and Norway. The solid line ($R2=0.09$) shows the linear fit of all data, including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU guideline.](#_Toc443473035)

[Figure 2. (Color online) CTL-values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 categorized by HRC (squares) or LRC (triangles) (see text). The solid upper and lower lines show their respective linear fits ($R2=0.33$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.](#_Toc443473036)

[Figure 3. (Color online) CTL-values for 52 aircraft noise annoyance studies conducted between 1978 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al*., triangles: Vietnam and Norway). The circles indicate excluded studies. The solid line shows the linear fit of all data ($R2=0.005$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.](#_Toc443473037)

[Figure 4. (Color online) CTL-values for 52 aircraft noise annoyance studies conducted between 1978 and 2015 categorized by HRC (squares) or LRC (triangles)(see text). The circles indicate excluded studies. The solid upper and lower lines show their respective linear fits ($R2=0.3$), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 for comparison with the EU standard curve.](#_Toc443473038)

[Figure 5. (Color online) The influence of incorrect study categorization. The two curves show the predicted CTL (± 2σ) in 2015 for an HRC airport (red) and an LRC airport (green) as a function of erroneous classification of rate of change.](#_Toc443473039)

[Figure 6. (Color online) Example of change of resident type over time, when mobility rate is equal to 10 % per year.](#_Toc443473040)

[Figure 7. (Color online) Examples of recovery in CTL values for a range of mobility rates and changes in tolerance for aircraft noise.](#_Toc443473041)

1. **END NOTES**

 The HYENA study was conducted at six airports. The results at two of these (MXP and ATH) were excluded by the authors themselves. [↑](#endnote-ref-1)
2. In conventional regression analysis, the shape of the dose-response relationship is an artifact of the analysis technique. Logistic regression, for example, yields a dose-response relationship of sigmoidal shape whose slope and position on the abscissa are determined by a best fit criterion to a set of data points. CTL analysis yields a dose-response relationship with a pre-defined shape. The only free parameter of CTL analysis is the position of the assumed relationship on the exposure axis. [↑](#endnote-ref-2)