

Aircraft Noise and Annoyance: Recent findings

CAP 1588



Published by the Civil Aviation Authority, 2018

Civil Aviation Authority,
Aviation House,
Gatwick Airport South,
West Sussex,
RH6 0YR.

You can copy and use this text but please ensure you always use the most up to date version and use it in context so as not to be misleading, and credit the CAA.

First published 2018

Enquiries regarding the content of this publication should be addressed to: darren.rhodes@caa.co.uk
Environmental Research and Consultancy Department, CAA House, 45-59 Kingsway, London, WC2B 6TE

The latest version of this document is available in electronic format at www.caa.co.uk,

Contents

Contents	3
Chapter 1	4
Introduction	4
Chapter 2	5
Background	5
Chapter 3	9
Measuring Annoyance	9
Chapter 4	23
Recent findings	23
Changes in annoyance over time	23
Trends in annoyance over time	28
Psychological factors	33
Evening/ night noise and lack of annoyance studies	33
Children's annoyance/vulnerable groups	37
Other annoyance findings	39
Chapter 5	44
Non-acoustic factors	44
Chapter 6	54
Summary and Conclusions	54
Chapter 7	55
References	55

Chapter 1

Introduction

The aim of this report is to provide an overview of the recent research into and state of knowledge on the effects of aircraft noise and annoyance responses. It is a complex area, and this report is split into sections in order to cover each subject.

Chapter 2 addresses the definition of annoyance and how it came to attention as a public issue, the pathways in which annoyance can interact with other health endpoints and external factors, and an explanation of the current thresholds for describing degrees of annoyance.

Chapter 3 describes the methodologies used to measure aircraft noise-induced annoyance, and the most commonly used dose-response relationships to date.

Chapter 4 discusses the recent developments in research findings over the past ten years or so, and suggestions for how methodologies could be improved for future research.

Chapter 5 explains the complexities of how non-acoustic factors can influence the annoyance results and new methods that may be employed to take account of them when designing future annoyance studies.

Chapter 6 offers a summary of the report and conclusions.

Chapter 2

Background

The ever-increasing demand for regular and convenient road, rail and aircraft transportation consequently brings with it an increase in environmental noise and subsequent effects.

The most widespread and well documented subjective response to noise is annoyance; which can be defined as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with thoughts, feelings or activities. The annoyance of populations exposed to environmental noise varies not only with the acoustical characteristics of the noise, but also with a range of non-acoustical factors of social, psychological or economic nature.

Transportation noise, amongst other noise sources such as that from construction, was brought to people's attention in 1963, via a report entitled "Noise", written by the Committee on the Problem of Noise, and commonly referred to as the "Wilson Report" after Sir Alan Wilson, Chairman of the committee. The Wilson Report stated that solving "noise problems must involve people and their feelings, and its assessment is a matter rather of human values and environments than of precise physical measurement". The issues raised in the Wilson Report are still, if not more, relevant today with an increasing demand for travel, 24-hour society and requirements for transport links.

Annoyance is considered to be a detriment to quality of life, well-being and ultimately, health. The World Health Organization's (WHO) definition of health is¹:

"Health is a state of complete physical, mental and social well-being, and not merely an absence of disease and infirmity."

Annoyance from any source represents a diminished state of well-being and noise is often referred to as the stressor that is implicated in a variety of responses (Figure 1). In their 'evidence review of annoyance' paper, (2016) the WHO described the complex annoyance response to noise as comprising three main elements:

1. An often repeated disturbance due to noise (repeated disturbance of intended activities e.g. communicating with other persons, listening to TV or music, reading, working, sleep), and often combined with behavioural responses in order to minimise disturbance.
2. An attitudinal response (anger about the disturbance, and negative evaluation of the noise source) and;

¹ World Health Organization. (2006). [*Constitution of the World Health Organization*](#) – Basic Documents, Forty-fifth edition, Supplement, October 2006.

3. A cognitive response (a distressful insight that one cannot do much about this unwanted situation).

Such responses are consolidated with memory of the stressor, or noise, and thus result in a long-term annoyance response to noise.

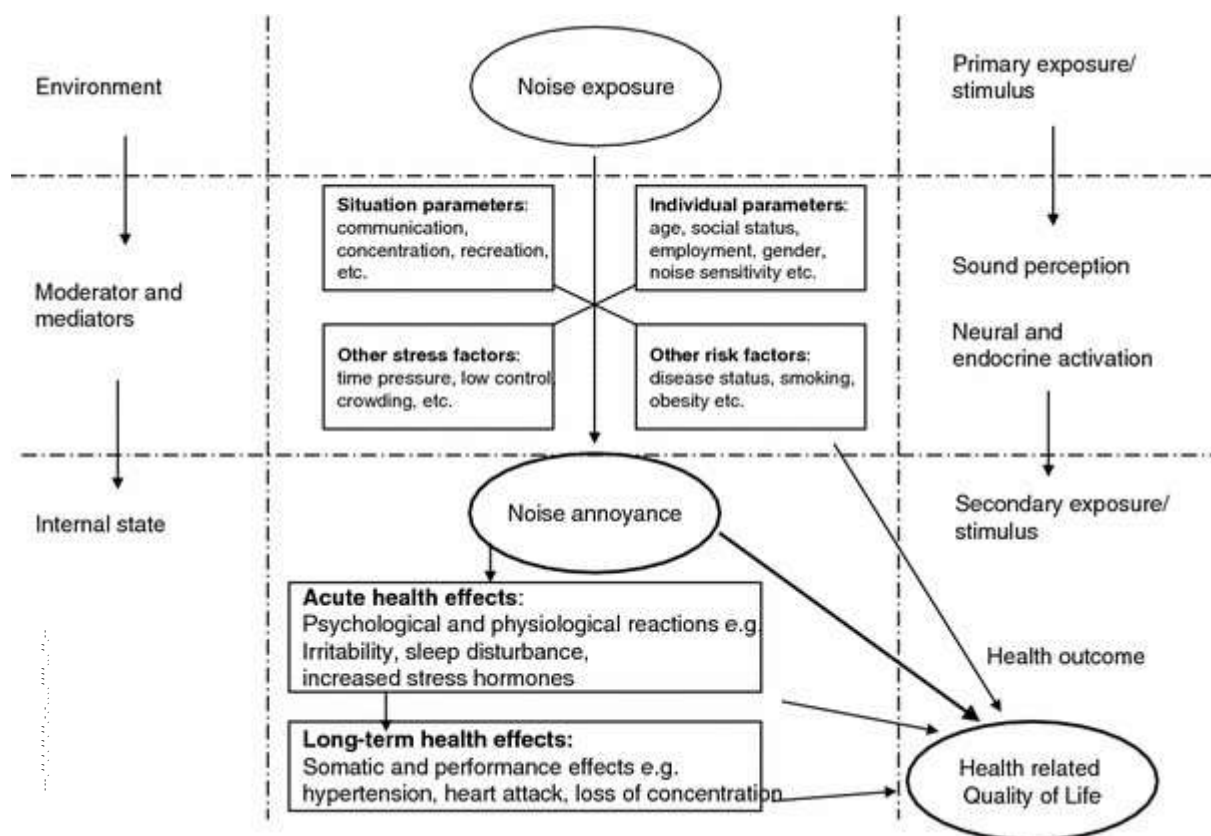


Figure 1: Conceptual model of non-auditory effects of environmental noise and noise annoyance (reproduced from Dratva et al, 2010)

Figure 1 illustrates the pathways that connect the noise exposure to the annoyance response and ultimately, health related quality of life. The diagram includes external factors, or mediators, which may contribute to the risk of annoyance and the internal state of the responder, and their subjective response. Although this diagram was taken from a paper reporting on a road traffic study, the pathways are identical for aircraft noise and the resulting outcomes. Figure 1 is a good illustration of the complexities in trying to separate out the contribution from noise annoyance alone, to health related quality of life outcomes, particularly due to the many potential moderators/mediators that must be controlled for.

In order to provide public protection from aircraft noise, an ‘annoyance threshold’ currently exists within UK policy. The time period for noise exposure used is an average summer day, from June 16th to September 15th and from 7am to 11pm. The Wilson report originally recommended the use of summer days (7am – 7pm) due to the increased likelihood of more people being outdoors and having windows open, and also because aviation levels are at their highest during summer months. The 1982 Aircraft Noise Index Study, the outcomes of which were adopted in policy in 1990, extended the reference day period from

7am to 11pm to reflect that there is a difference in terms of daytime and night-time noise exposure and consequently, annoyance reactions, resulting in the need for distinctive daytime and night-time noise exposure metrics. The noise exposure metric $L_{Aeq,16h}$, was adopted in 1990 on the basis of the ANIS findings. The UK government defined three thresholds for policy consideration: 57, 63 and 69 dB $L_{Aeq,16h}$, representing low, moderate, and high annoyance levels.

The 2003 Air Transport White Paper subsequently defined 57dB $L_{Aeq,16h}$ as marking the approximate onset of significant community annoyance, and this was reaffirmed in the Government's 2013 Aviation Policy Framework. Critics argue that attitudes have changed since the 1982 survey. This could be because of general shifts in attitudes to annoyance, changes in the pattern of aircraft noise experienced, and/or because of changes to lifestyle that are affected by aircraft noise. This ultimately led to the UK government commissioning the Survey of Noise Attitudes 2014: Aircraft study². The methods for measuring annoyance are discussed in Chapter 3.

The government published their Response³ to their Airspace Consultation in 2017 and acknowledged the evidence from the SoNA study, which showed that sensitivity to aircraft noise has increased, with the same percentage of people reporting to be highly annoyed at a level of 54 dB $L_{Aeq,16hr}$ as occurred at 57 dB $L_{Aeq,16hr}$ in the past.

Taking account of this and other evidence on the link between exposure to noise from all sources and chronic health outcomes, the government decided to adopt the risk based approach proposed in their consultation, so that airspace decisions are made in line with the latest evidence and consistent with current guidance from the World Health Organisation.

In 2010 the Department for Environment, Food and Rural Affairs (Defra) released the Noise Policy Statement for England (NPSE), which aimed to provide clarity on noise and set out the government's long-term vision of noise policy for all noise sources. The noise policy vision was to "promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development."

The NPSE aims are:

Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of government policy on sustainable development:

- avoid significant adverse impacts on health and quality of life;
- mitigate and minimise adverse impacts on health and quality of life; and
- where possible, contribute to the improvement of health and quality of life.

² CAP1506. Survey of Noise Attitudes 2014: Aircraft. Civil Aviation Authority on behalf of the DfT.

³ Consultation Response on UK Airspace Policy: A framework for balanced decisions on the design and use of airspace. Department for Transport. 2017

The phrases “Significant adverse” and “adverse” refer to the two established concepts that are applied to noise impacts worldwide, namely:

NOEL – No Observed Effect Level

This is the level below which no effect can be detected. In simple terms, below this level, there is no detectable effect on health and quality of life due to the noise.

LOAEL – Lowest Observed Adverse Effect Level

This is the level above which adverse effects on health and quality of life can be detected.

Extending these concepts for the purpose of the NPSE leads to the concept of a significant observed adverse effect level.

SOAEL – Significant Observed Adverse Effect Level

This is the level above which significant adverse effects on health and quality of life occur.

It is not possible to have a single objective noise-based measure that defines SOAEL that is applicable to all sources of noise in all situations. Consequently, the SOAEL is likely to be different for different noise sources, for different receptors and at different times. SOAEL is therefore not specifically defined in the NPSE, for flexibility purposes in the future, with the addition of more research findings.

Annoyance from aircraft noise is a global issue, not just confined to the UK. In 2011, the WHO Europe and the Joint Research Centre published the report: Burden of Disease from Environmental Noise. The aim of this report was to provide technical support to policy-makers in the form of quantitative risk assessment of environmental noise, using the evidence available in Europe.

For each noise-induced outcome, the report estimated the number of life years that are affected by noise, defined as Disability Adjusted Life Years (DALYs). DALYs are the sum of the potential years of life lost due to premature death and the equivalent years of “healthy” life lost by virtue of being in states of poor health or disability. The outcomes included were ischemic heart disease, cognitive impairment of children, sleep disturbance, tinnitus and annoyance. It was estimated that 654,000 years were lost annually due to annoyance in the EU Member States, and other western European countries (from combined noise sources, but predominantly road traffic noise). This was only exceeded by those lost due to sleep disturbance annually, which were calculated as 903,000 years.

All transportation noise sources result in a degree of annoyance, and this remains a growing concern, particularly with the possible links to other health endpoints. This report will focus on aircraft noise-induced annoyance. Annoyance from aircraft noise and other transportation sources is often studied as part of complex pathways which may exist between acute and chronic health effects such as cardiovascular disease, disturbed sleep patterns with subsequent next-day effects, and even the cognitive performance and learning aspects in children, as detailed in the Burden of Disease Report.

The much anticipated update to the 1999 WHO Community Noise Guidelines is currently being developed, and it is expected that this document will now be published in 2018.

Chapter 3

Measuring Annoyance

Annoyance is a subjective response and therefore cannot be measured objectively, but rather through self-rated responses to survey questions as part of social survey studies that are linked to the aircraft (or other transportation source) noise exposure level of each respondent.

In this field, a widely quoted seminal dose-response relationship is the Schultz curve (Schultz, 1978). The Schultz curve (Figure 2) is a graph of percentage highly annoyed against noise exposure level; it was based on data from numerous social survey studies of public reactions to transport noise available at that time. Since 1978 there have been a number of subsequent extensions and updates of the original Schultz work.

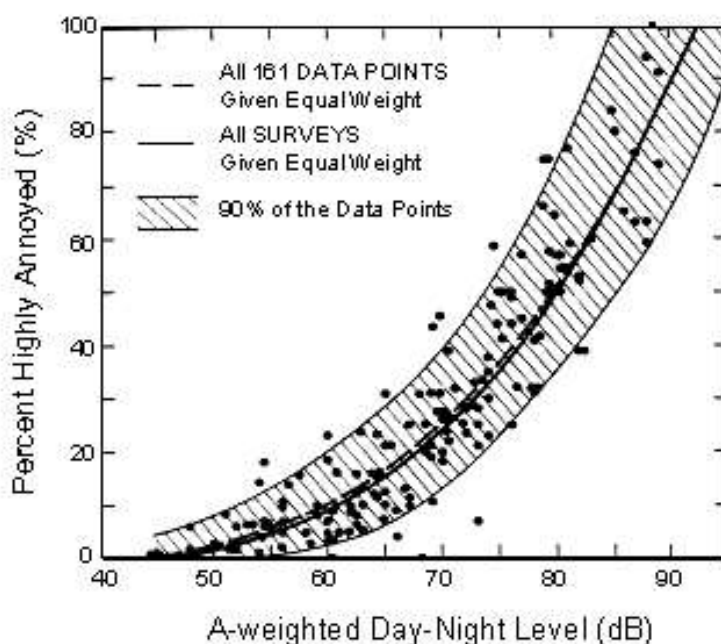


Figure 2: The original Schultz curve (1978)

Schultz used "highly annoyed" (HA) as the measure of community response and day-night average sound level (DNL)⁴ as the measure of the noise environment. There is significant scatter to the data points and the 90 percent prediction intervals are quite sizeable.

Schultz identified different reactions to different noise sources, but did not make it a feature of his work. However later researchers found considerable differences in

⁴ The day-night average sound level (Ldn or DNL) is the average noise level over a 24-hour period. The noise between the hours of 10pm and 7am is weighted by an increase of 10 dB. This is to take into account the decrease in background noise during this period.

annoyance for the same noise level from different sources. For example, a synthesis by Miedema and Vos (1998) (building further on the Schultz curve approach), of data for three types of transport noise (road, air, and railway) suggests that aircraft noise produced a stronger annoyance response than road traffic and that the annoyance response to rail noise was less than for road traffic.

Since the WHO Guidelines (1999) were published there have been many further studies of annoyance from transport noise, these studies provide new data on specific local circumstances and contribute to the database that can be used for developing dose-response curves. Miedema (2001) reanalysed the available international data on transport noise and annoyance (a total of 45 studies including 19 studies on aircraft noise) and produced revised curves for the relationships for the association between noise from road, rail and aircraft and annoyance using DNL (day-night level) and DENL (day-evening-night level). Figure 3 illustrates the Miedema curves for road, rail and aircraft plotted against DENL. The distribution of the annoyance scores at a given noise exposure level can be summarised in various ways. Often a cut-off point is chosen on the scale, and the percentage of the responses exceeding the cut-off is reported. If the cut-off is 72 on a 0–100 scale, then the result is called the percentage of “highly annoyed” people (%HA); with a cut-off at 50 it is the percentage “annoyed” (%A), and with a cut-off at 28 it is the percentage “(at least) a little annoyed” (%LA). An alternative to these types of measures is the average annoyance score.

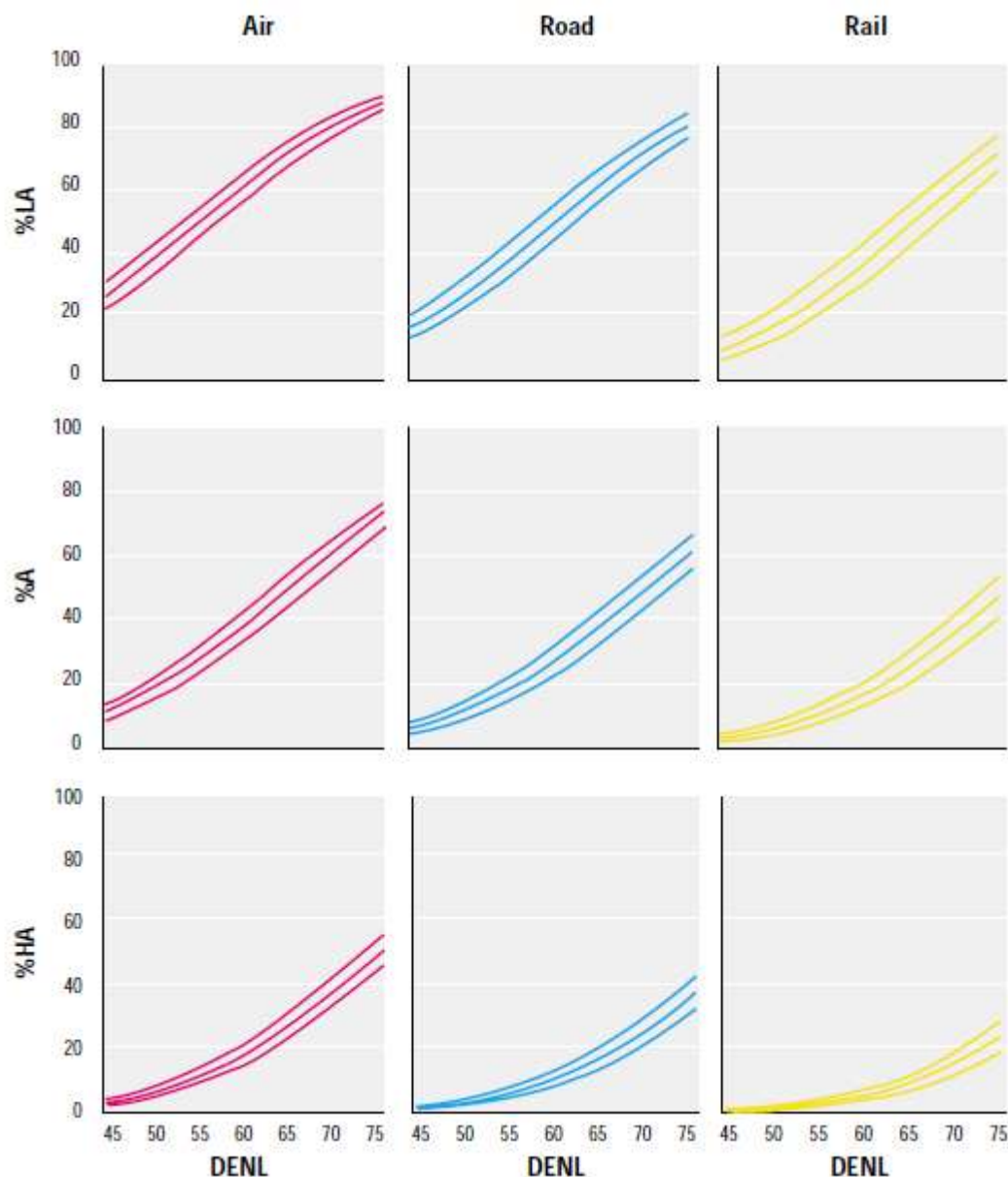


Figure 3: Miedema and Oudshoorn (2001) annoyance curves for aircraft, road and rail noise against DENL, including 95% confidence levels. LA = at least “a little annoyed”, A = “annoyed”, HA = “highly annoyed”

The above charts and DENL indicator were adopted as the European Common indicators for noise exposure for road, rail and air.

Miedema published a discussion paper on annoyance (2007), in which he proposed a model of environmental noise disturbance as a stressor, impacting on behaviour (communication, concentration) and desired state (sleep and relaxation), with the ability to cope with such disturbance being important for health and well-being. The effects of noise depend on acoustical characteristics of the noise, such as loudness, time, pattern, and on aspects of the noise situation that may involve cognitive processing, such as expectations regarding the future development of the noise exposure, lack of short-term predictability, and a feeling of a lack of control over the source of the noise. Miedema suggests that the model (Figure 4) involves four routes through which noise exerts its primary influence.

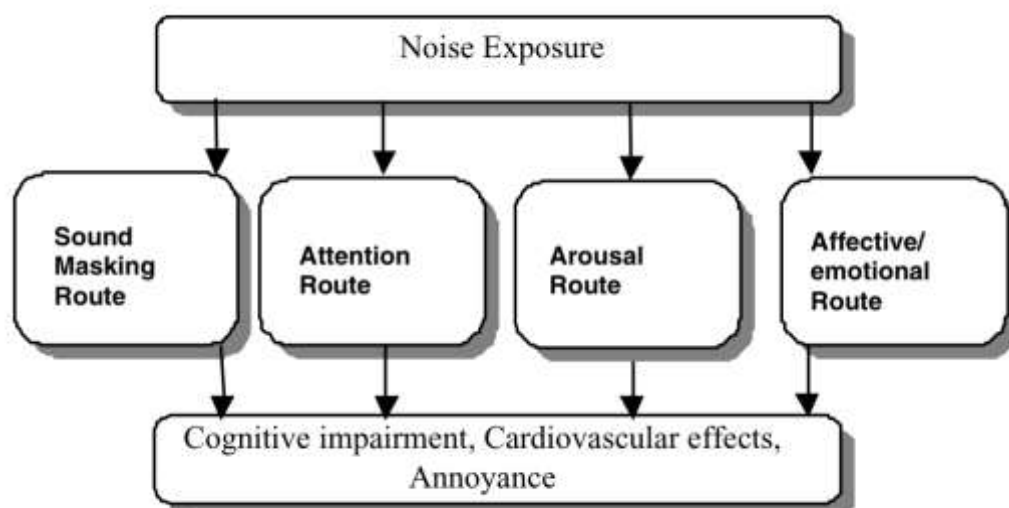


Figure 4: Miedema's (2007) model illustrating the four pathways through which the effects of noise are mediated.

Of the four pathways in Figure 4, three relate to daytime annoyance and the Arousal Route refers to night-time sleep disturbance, which will not be discussed here as this report relates to annoyance only.

Sound Masking Route

This route reduces the comprehension of speech and masks speech, signals, music or natural sounds. International standards for the assessment of speech communication say that one-to-one conversation 1 metre apart requires that the noise level does not exceed 41dBA. These are very rarely achieved in urban areas and imply that the effects of environmental noise on communication are ubiquitous, especially in cities.

Attention Route

Noise can negatively affect processes requiring attention. The effect of noise is probably most harmful when impacting on working memory, and has been found to depend on the priority and difficulty of the memory task, and type of sound. Millar (1979) indicated that it is the rehearsal of the items in working memory that is negatively affected by noise. If noise detracts from rehearsal it can have negative effects on the ability to derive implications and restructure information into more meaningful clusters.

Affective/Emotional route

As a result of noise affecting sleep, concentration, communication etc this frustration may lead to irritation or anger reactions. Fear can also be elicited with noise if it is associated with danger that threatens the individual. In this context it may be the worry of being in close proximity to an airport and therefore the concern over accidents that may induce fear, along with self-reported sensitivity to noise. People high in trait anger may be more likely to show stronger emotional reactions when noise disturbs them.

Miedema suggests that through masking, noise reduces comprehension, and through its effect on attention, noise affects the mental processing of information e.g. in reading. Also,

it may elicit emotional reactions when it interferes with behaviour or a desired state and may act as a stressor, or when it is associated with fear (aircraft noise). Such primary effects may in the long-term lead to annoyance, cognitive impairment, and/or cardiovascular effects. Chronic stress is also likely to be important in some long-term effects, in particular cardiovascular effects.

Dose-Response Function for different transport sources

Annoyance is an insightful gauge of adverse noise effects and by itself means that noise affects people's quality of life as shown in Figure 1. Therefore it is often taken as an indicator of the acoustical climate. For noise annoyance, extensive research has provided relationships that give the expected noise annoyance at a given level of noise exposure. Miedema conducted a further meta-analysis of several studies examining the effects of aircraft, road and railway noise on annoyance, including the original Shultz data and that from other meta-analyses by Fidell (2001), to produce a set of dose-response relationships for each transport mode, (Figure 5). L_{den} is the yearly "average" of the daytime level (0700–1900), evening level (1900–2300) plus 5 dBA, and night-time level (2300–0700) plus 10 dBA at the most exposed facade of a dwelling. The "A" indicates that contributions to noise from different frequencies are weighted according to the sensitivity of the ear for those frequencies.

The relationships indicate again that aircraft noise elicits a higher degree of annoyance than road or rail, though the reasons for this cannot be concluded. It is possible that due to the quiet periods between trains, annoyance is less than the constant stream of road traffic. It could be that the regularity of flights and inability to get away from the noise at a different facade of the building may be contributing factors for the response to aircraft noise being higher than the other two noise sources, along with a myriad of other hypotheses. There are also complex relationships between the annoyance response and non-acoustical factors, for example fear and individual noise sensitivity. Non-acoustical factors will be discussed in Chapter 5.

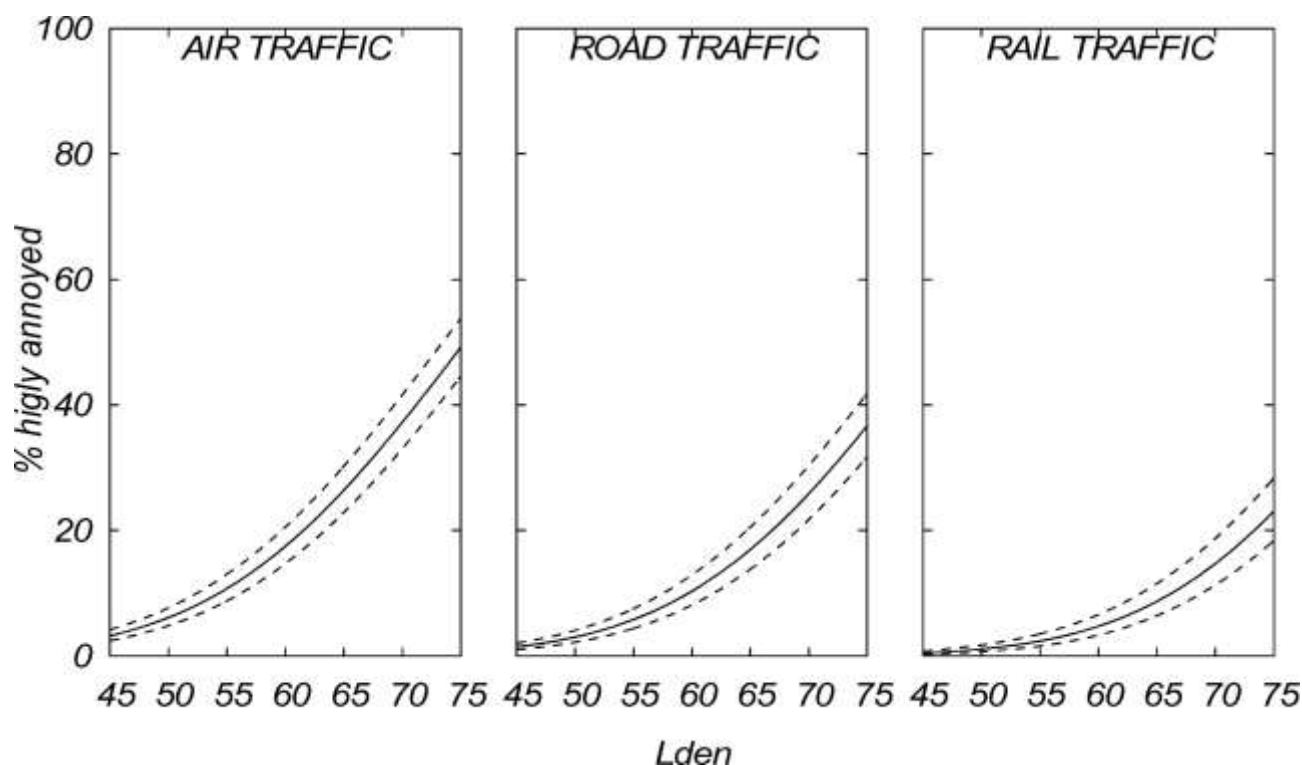


Figure 5: The percentage highly annoyed (%HA; solid lines) as a function of L_{den} , for air, road, and rail traffic noise, and the confidence interval (broken lines). Miedema (2007)

Community Tolerance Level

In 2011 Fidell et al published a paper on their model for estimating the prevalence of annoyance with aircraft noise exposure. There are issues surrounding single metric predictors of annoyance, such as DNL, in light of previous evidence suggesting that annoyance comprises both non-DNL and acoustic components in addition to the DNL metric. Debate continues about optimal metrics for predicting transportation noise impacts; and about the relative importance of acoustic and non-DNL related influences on annoyance. There are also discussions about effects of transportation modality and annoyance responses, national and regional differences, and about temporal trends in sensitivity to transportation noise. The issue of variability was discussed by Fidell, with Figure 6 illustrating how wide the variation of annoyance responses can be.

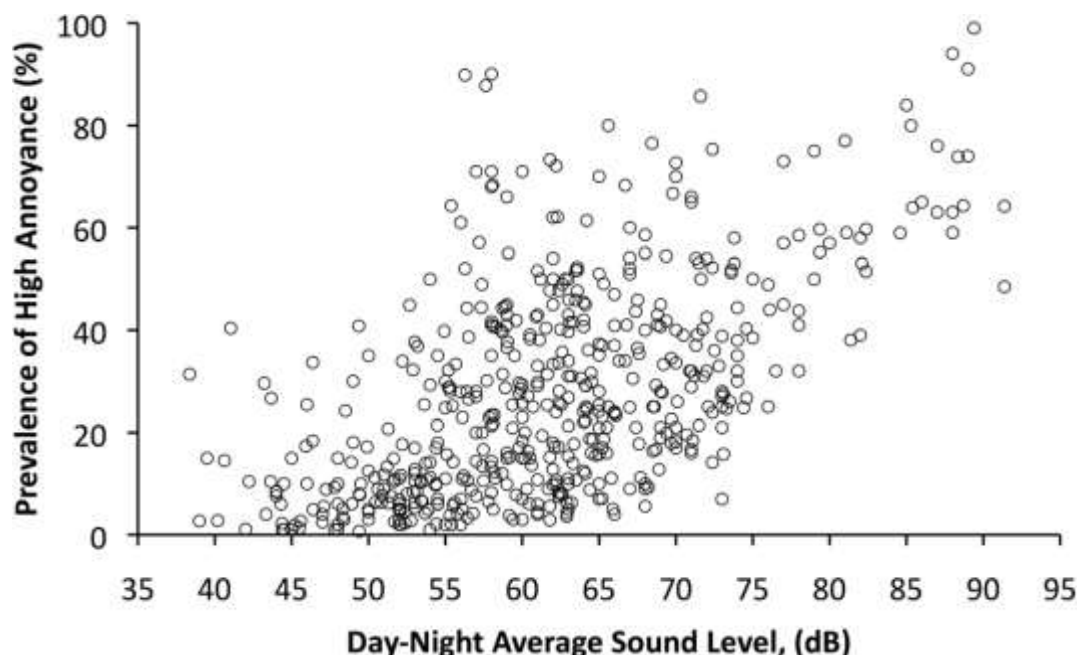


Figure 6: Illustration of variability in annoyance prevalence rates as a function of cumulative noise exposure. Each point represents an estimate of the prevalence of high annoyance at a single interviewing site.

The variability of annoyance prevalence rates can affect the usefulness of predictions developed from dose-response curves; therefore Fidell et al developed an alternate approach to prediction, based on an explanatory model which uses the findings of Stevens (1972), Fidell, Schultz (1978), and Green (1988), and Green and Fidell (1991). The model adds one predictor variable to DNL—a standardised “community tolerance level” (CTL). A “community tolerance level,” is normalised to the DNL value at the middle of the best-fitting effective loudness function for each community. Figure 7 shows the calculated CTLs from the findings of six communities exposed to aircraft noise. This additional parameter enables analyses of the characteristic variability of findings in social surveys on transportations noise and annoyance. The model also accounts for more variance in annoyance prevalence rates than predictions based on DNL alone. The rate of change of annoyance with day-night average sound level (DNL) due to aircraft noise exposure was found to closely resemble the rate of change of loudness with sound level.

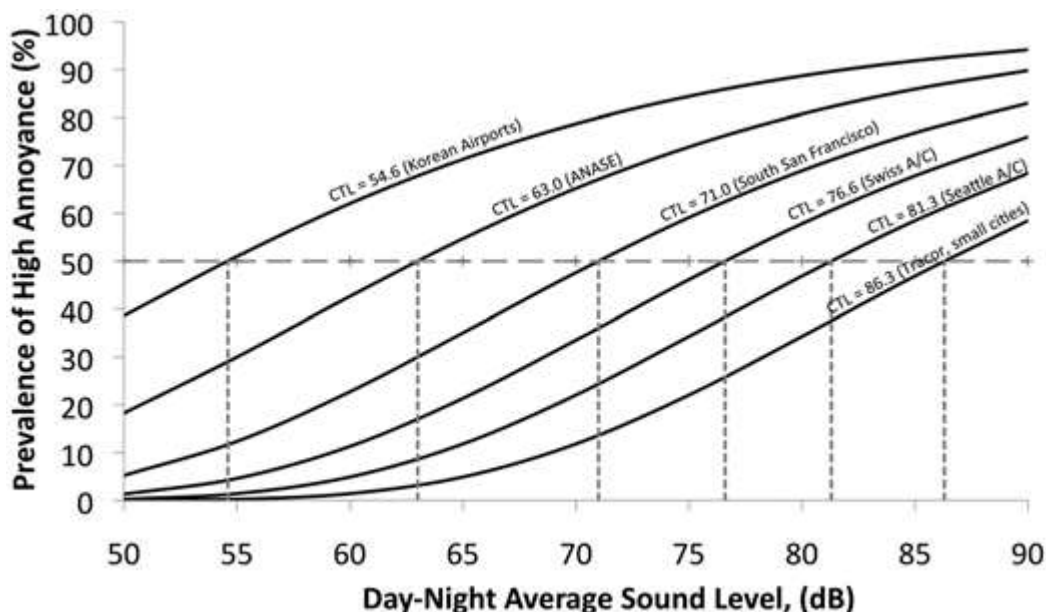


Figure 7: CTL values computed from the findings of six surveys of communities exposed to aircraft noise. Note that CTL values for the different communities shown vary over a range of 30 dB.

The authors found that there was agreement of model predictions with the findings of previous curve-fitting studies such as Miedema and Vos (1998). Even though annoyance prevalence rates within individual communities consistently grow in proportion to duration-adjusted loudness, variability in annoyance prevalence rates across communities remains great.

Fidell's analyses demonstrate that (1) community-specific differences in annoyance prevalence rates can be plausibly attributed to the joint effect of acoustic and non-DNL related factors and (2) a simple model can account for the combined influences of non-DNL related factors on annoyance prevalence rates in different communities in terms of a single parameter expressed in DNL units—a "community tolerance level." It is worth noting, however, that the CTL cannot accurately account for a wide range of outlying responses.

There are some limitations and uncertainties that arise from using this model, but Fidell concluded that using the duration-corrected loudness of noise exposure appears in most cases to link well with aircraft-noise induced annoyance responses on social surveys. This finding was derived from analyses of interviews conducted with nearly 76,000 respondents at hundreds of sites over the last 50 years, and is unlikely to change greatly as additional social survey data become available. The CTL values do not appear to be very influenced by airport size, but may be related to airport type. They also appear to be unrelated to climate variables, but may be related to economic factors such as median housing values and annual household incomes. Figure 8 shows a best-fit curve for all aircraft annoyance data to effective loudness function for a CTL of 73 dB.

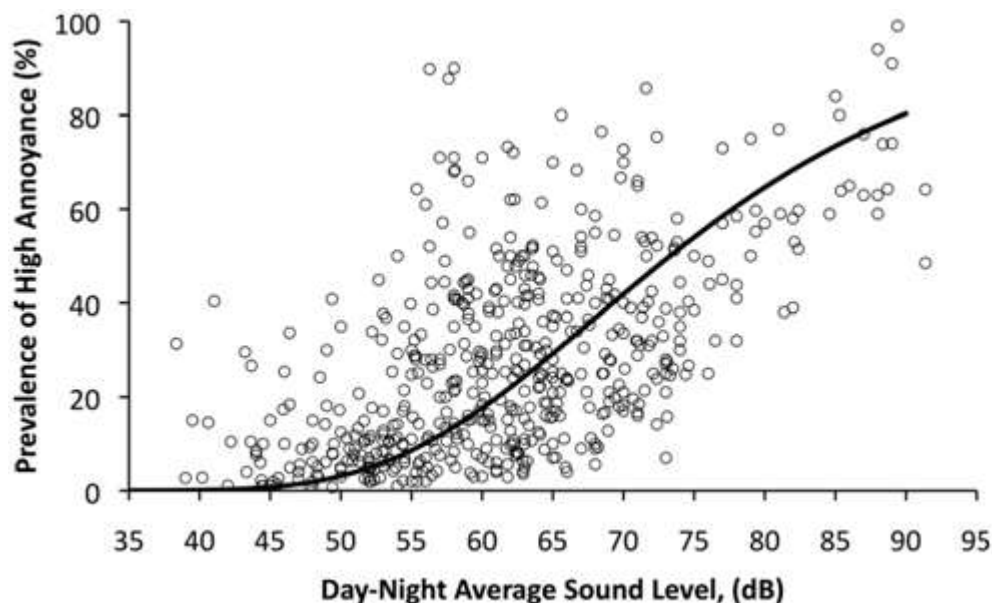


Figure 8: Fit of all aircraft annoyance data to effective loudness function for a CTL value of approximately 73 dB.

UK Aircraft Noise Annoyance Studies

ANIS

In the UK, there have been several aircraft annoyance studies that have produced dose-response relationships. The first was the UK Aircraft Noise Index Study- ANIS (1982). At that time the noise exposure metric that had been used since the 1960s was the Noise Number Index (NNI), which was criticised for being out of date. This aim of the ANIS study was to both substantiate the NNI and disentangle the effects of noise level versus number of aircraft events, or to devise a more appropriate metric that would better reflect the level of disturbance experienced. The findings suggested that NNI gave too much influence to the number of aircraft noise events, and a more appropriate metric to correlate disturbance responses to was the 24 hour L_{Aeq} – a measure of average sound energy received over the 24 hours.

The annoyance questionnaire used in ANIS was a modified version of a questionnaire used in an earlier study in 1967, using the Gutman annoyance scale, and comprised three sections of questions. An introductory section asked questions about general attitudes to the area without being aircraft specific; the second section included questions focussed on disturbance, and then finally came questions about potential confounding factors.

The ANIS study concluded that an appropriate threshold to reflect disturbance would be 55 dB L_{Aeq} , which could be used to mark the onset of community annoyance, and 70 dB L_{Aeq} would mark the onset of high disturbance. 70 dB L_{Aeq} would correspond to 55 NNI, and represents aircraft noise exposure which was:

- “Very much” annoying to two-thirds of the exposed population
- “Not acceptable” to three quarters of the population, and

- The “most bothersome” noise to nine out of ten people.

The noise exposure metric $L_{Aeq,16h}$ was adopted in 1990 following the results of the ANIS study. $L_{Aeq,16h}$ refers to the equivalent continuous sound level between 0700-2300.

ANASE

The Attitudes to Noise from Aviation Sources in England (ANASE) study was commissioned by the Department for Transport in 2001 and was published in 2007. The aims of the study were to re-assess attitudes to aircraft noise in England, re-assess their correlation with the $L_{Aeq,16h}$ noise index and examine willingness to pay in respect of annoyance from such noise, in relation to other elements, on the basis of stated preference survey evidence.

In addition to interview questions, respondents at some of the study sites were played audio recordings of aircraft noise and were also asked to rate their “willingness to pay” to avoid aircraft noise. The study concluded that “levels of annoyance were higher than expected from previous surveys and that the relationship between L_{Aeq} and annoyance was not stable over time:

- the proportion of respondents who are at least very annoyed is less than 10% for areas with L_{Aeq} less than 43dB;
- the proportion of respondents at least very annoyed generally increases with L_{Aeq} for values of L_{Aeq} over 43dB, although there is a relatively large spread in percentages for most L_{Aeq} values; and
- at least 40% of respondents were at least very annoyed for all except one of the areas with L_{Aeq} greater than 57dB.”

Although the researchers concluded there was no clear threshold between 43 and 57dB $L_{Aeq,16h}$, the study suggested that for the same proportion of highly annoyed people as found in ANIS at 57dB $L_{Aeq,16h}$ (10%), the corresponding $L_{Aeq,16h}$ level would be approximately 10-13 dB lower.

The independent peer review by Havelock (CAA) and Turner (Bureau Veritas) raised concerns over the use of and calibration of noise playback equipment prior to the social survey being undertaken. Restricted sites, where no noise playback equipment was used appeared to show differences in attitudes to those from the main study, where noise playback equipment was used. There were also concerns over the estimation of aircraft noise at survey sites. Consequently the peer review concluded that “there were sufficient technical and methodological uncertainties still remaining with the study... [that] the reviewers would counsel against using the results and conclusions in the development of government policy”.

SoNA 2014

In 2014 the Department for Transport commissioned the Survey of Noise Attitudes (SoNA) – Aviation study², which built on previous noise attitudes surveys by Defra with the addition of an aircraft noise section.

The overall aims of SoNA 2014 were to: