Environmental Research and Consultancy Department

Aircraft Noise and Annoyance: Recent findings

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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 Word Health Organization's (WHO) definition of health is[1]:

"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.

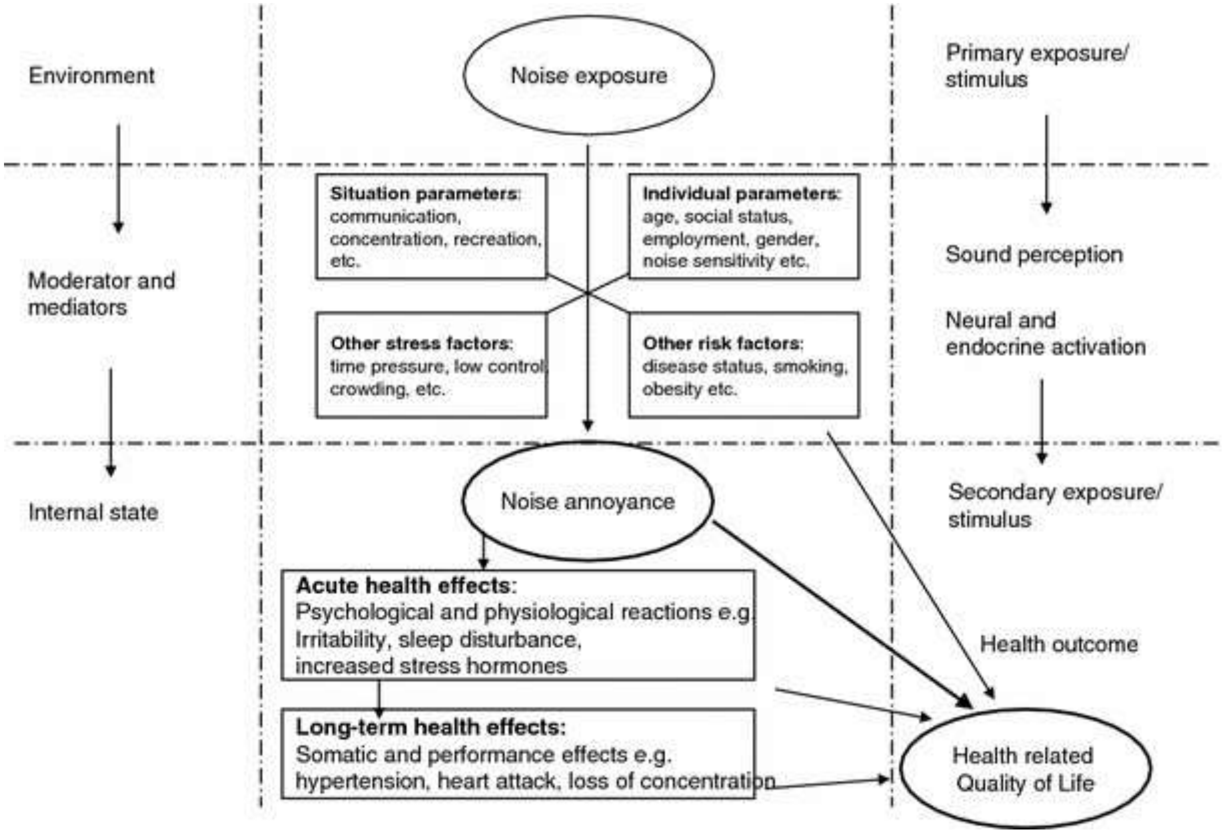

Figure 1: Conceptual model of non-auditory effects of environmental noise and noise annoyance (reproduced from Dratva et al, 2010)

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_{Aeq16h}, 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 study[2]. The methods for measuring annoyance are discussed in Chapter 3.

The government published their Response[3] 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.

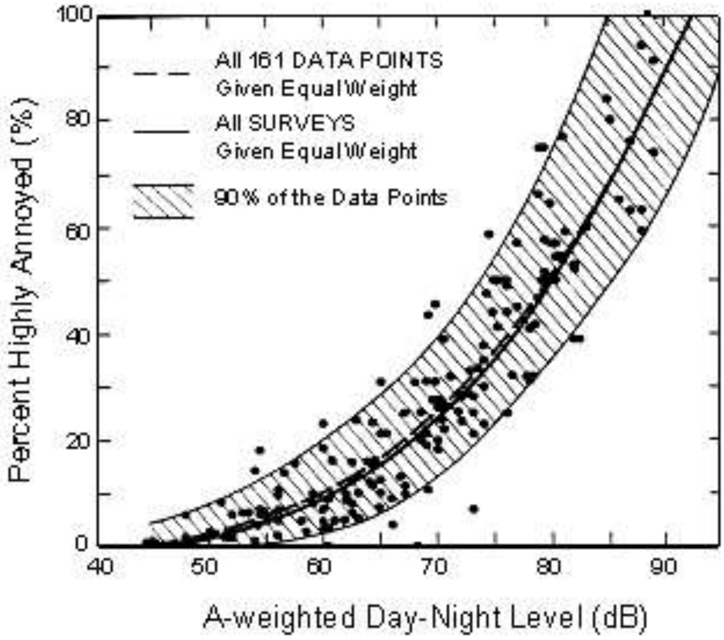

Figure 2: The original Schultz curve (1978)

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.

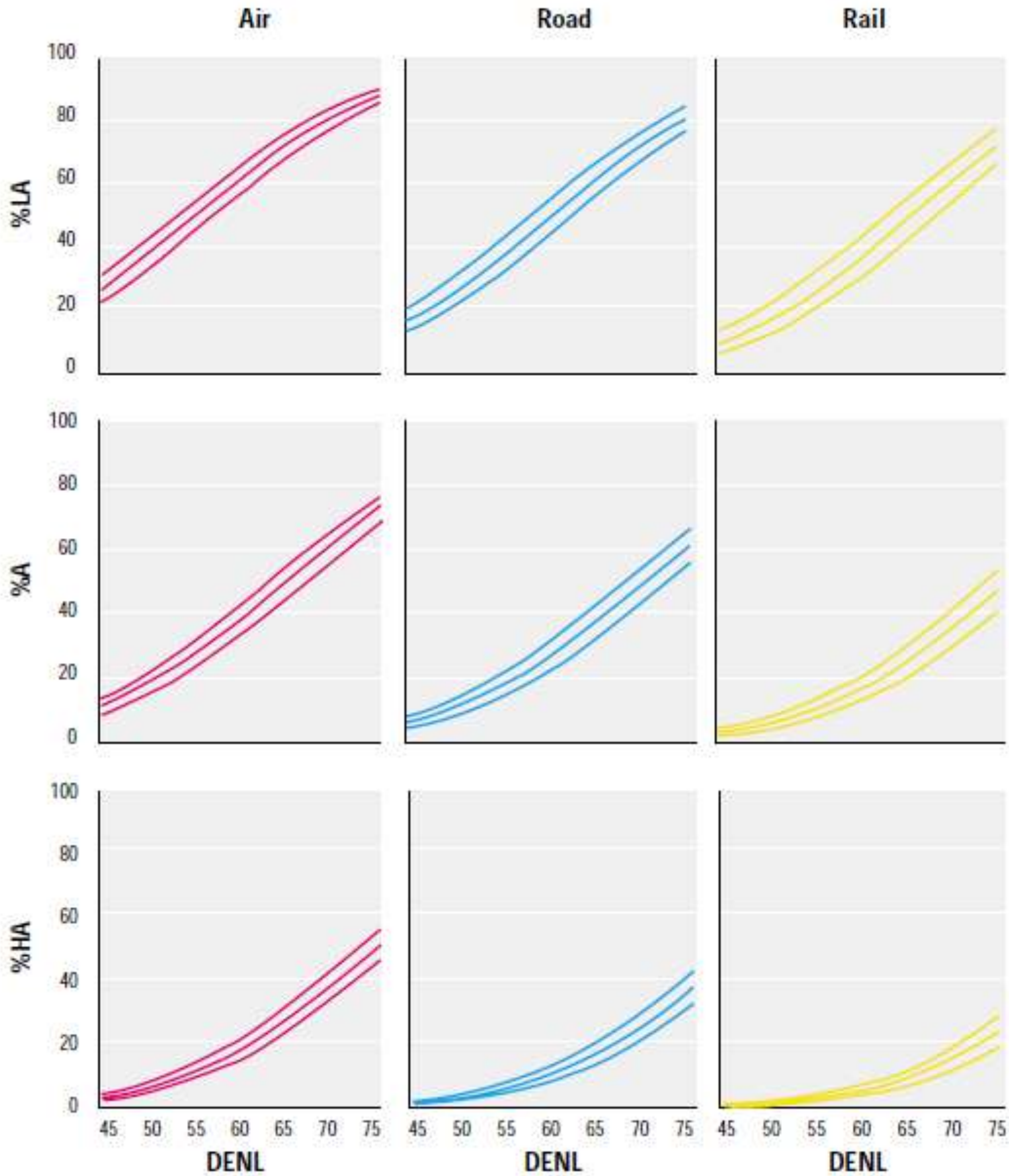

Figure 3: Miedema and Oudshoorn (2001) annoyance curves for aircraft, road and rail noise against DENL, including 95% confidence levels. LA = at least "a little annoyed", A = "annoyed", HA = "highly annoyed"

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.

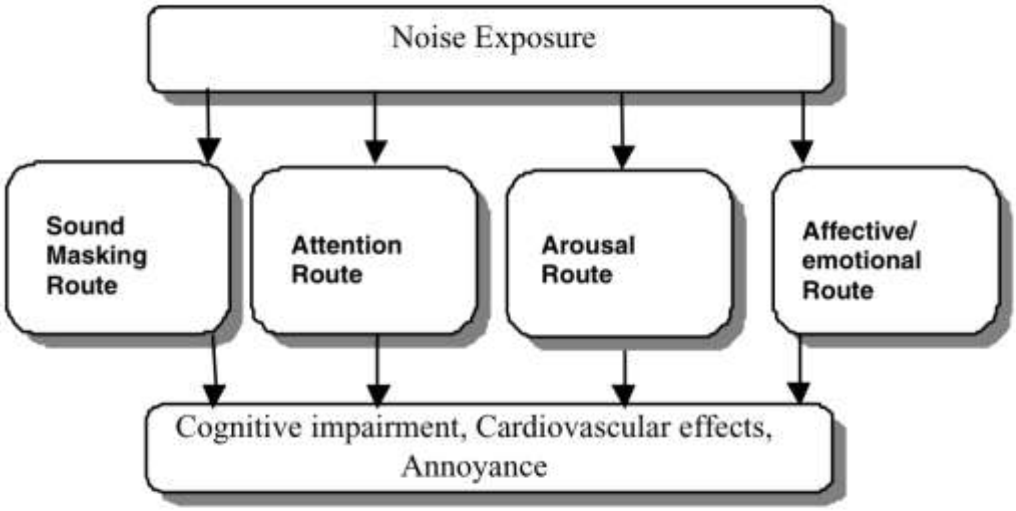

Figure 4: Miedema's (2007) model illustrating the four pathways through which the effects of noise are mediated.

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 façade 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.

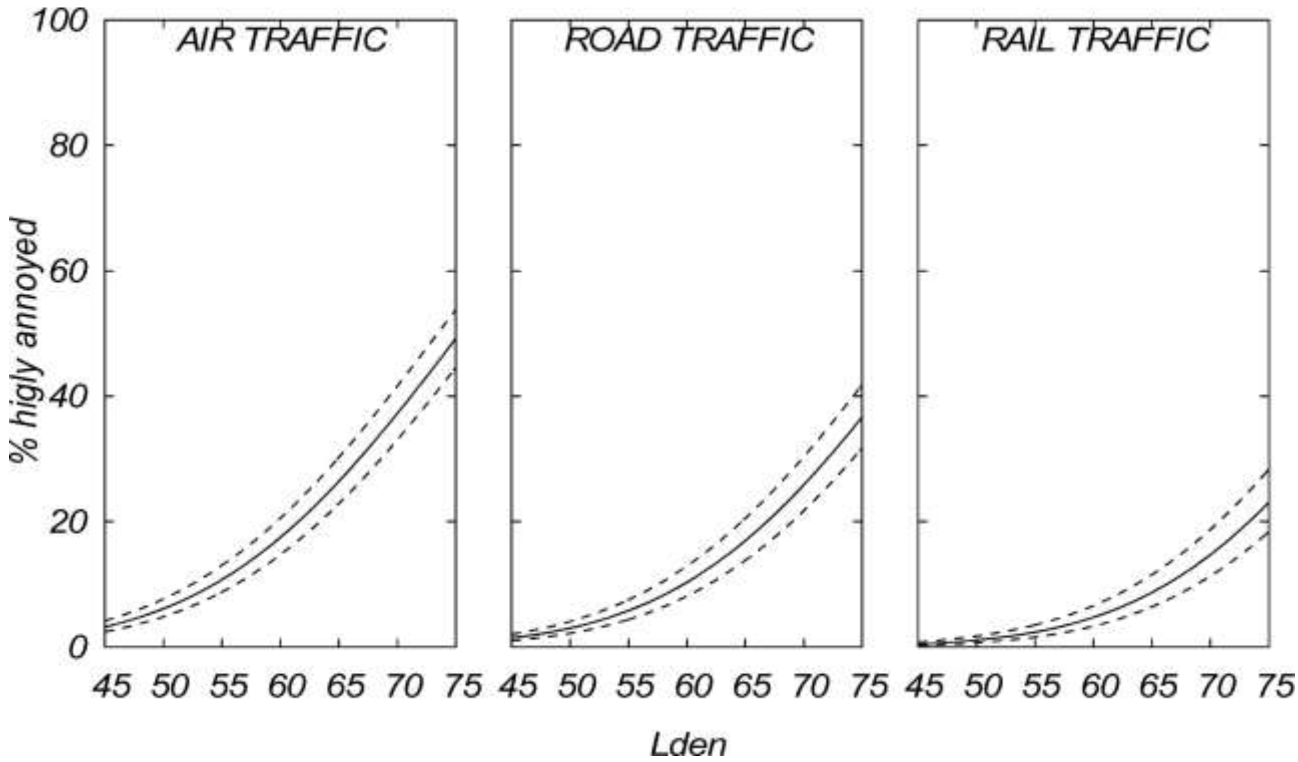

Figure 5: The percentage highly annoyed (%HA; solid lines) as a function of L_{den}, for air, road, and rail traffic noise, and the confidence interval (broken lines). Miedema (2007)

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.

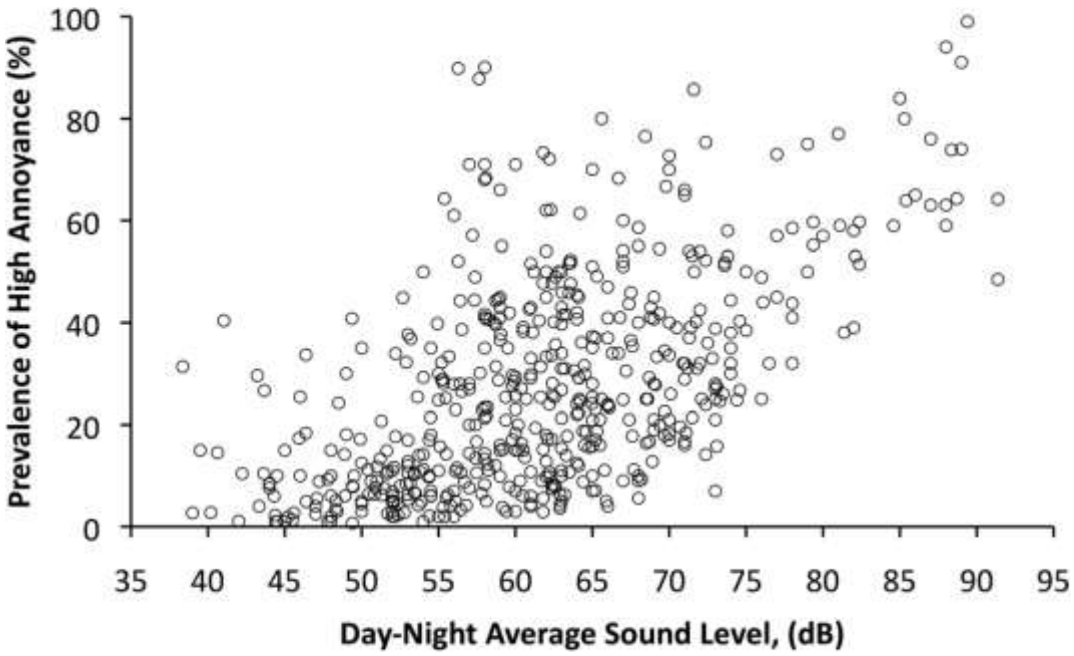

Figure 6: Illustration of variability in annoyance prevalence rates as a function of cumulative noise exposure. Each point represents an estimate of the prevalence of high annoyance at a single interviewing site.

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.

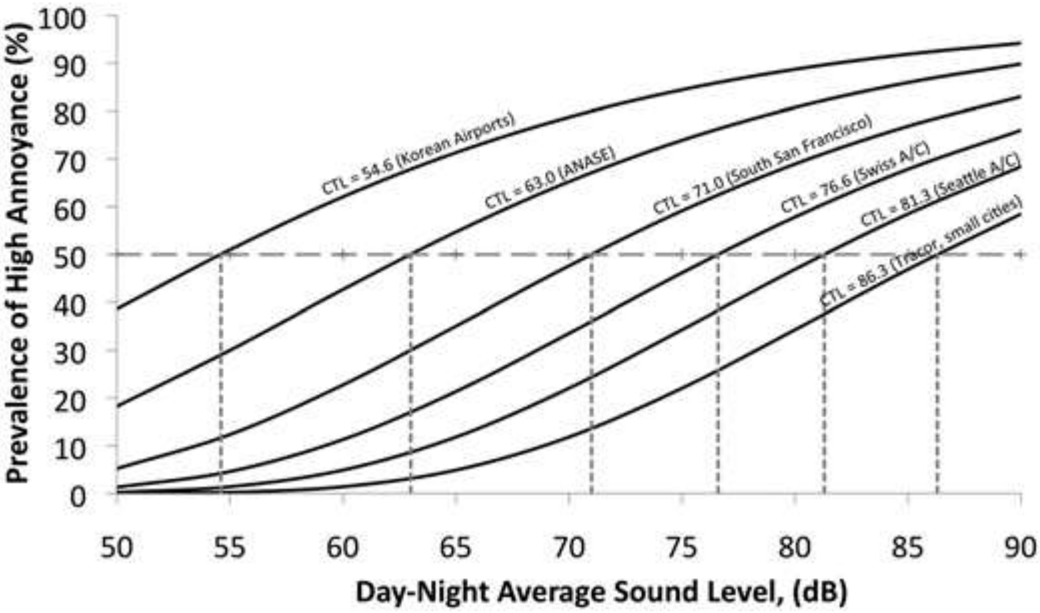

Figure 7: CTL values computed from the findings of six surveys of communities exposed to aircraft noise. Note that CTL values for the different communities shown vary over a range of 30 dB.

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.

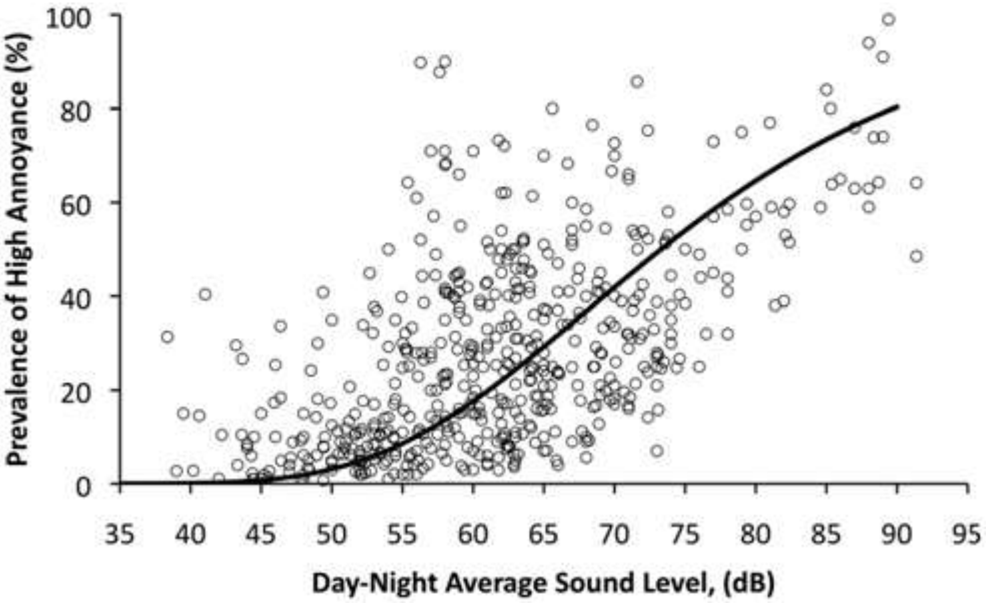

Figure 8: Fit of all aircraft annoyance data to effective loudness function for a CTL value of approximately 73 dB.

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_{eq} – 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 study[2], 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:

- Obtain new and updated evidence on attitudes to aviation noise around airports in England, including the effects of aviation noise on annoyance, wellbeing and health.
- Obtain new and updated evidence on what influences attitudes to aviation noise, and how attitudes vary, particularly how attitudes vary with LAeq, but also other non-acoustic factors that may influence attitudes, such as location and time of day, and socioeconomic group of respondents.
- Examine whether the currently used measure of annoyance, LAeq, is the appropriate measure of annoyance for measuring the impact on people living around major airports.
- Consider the appropriateness of the policy threshold for significant community annoyance from aviation noise.
- Provide baseline results that can be used for a programme of regular surveys of attitudes to aviation noise.

The findings included that $L_{Aeq,16h}$ was still deemed to be the most appropriate noise indicator to correlate with annoyance. In terms of supplementary metrics to help residents understand noise exposure, it was found that N65 was the most suitable, describing the number of aircraft noise events over 65 dB L_{Amax}.

Mean annoyance score and the likelihood of being highly annoyed were found to increase with increasing noise exposure ($L_{Aeq,16h}$). The relationship found was close to linear, though annoyance levels plateau at low exposure and do not reach zero annoyance.

Annoyance scores were found to be comparable with those found for the ANASE restricted sites, but lower than found by the full ANASE study, and higher than found by ANIS. For a given noise exposure, a lower proportion of respondents was found to be highly annoyed than compared with ANASE, the results of which were considered unreliable.

For a given noise exposure, a higher proportion of respondents was found to be highly annoyed than compared with ANIS. The same percentage of respondents said by ANIS to be highly annoyed at 57 dB $L_{Aeq,16h}$ now occurs at 54 dB. Comparing with the results, the ‘Miedema’ dose response function, predicts 12% highly annoyed at 54 dB and 16% at 57 dB.

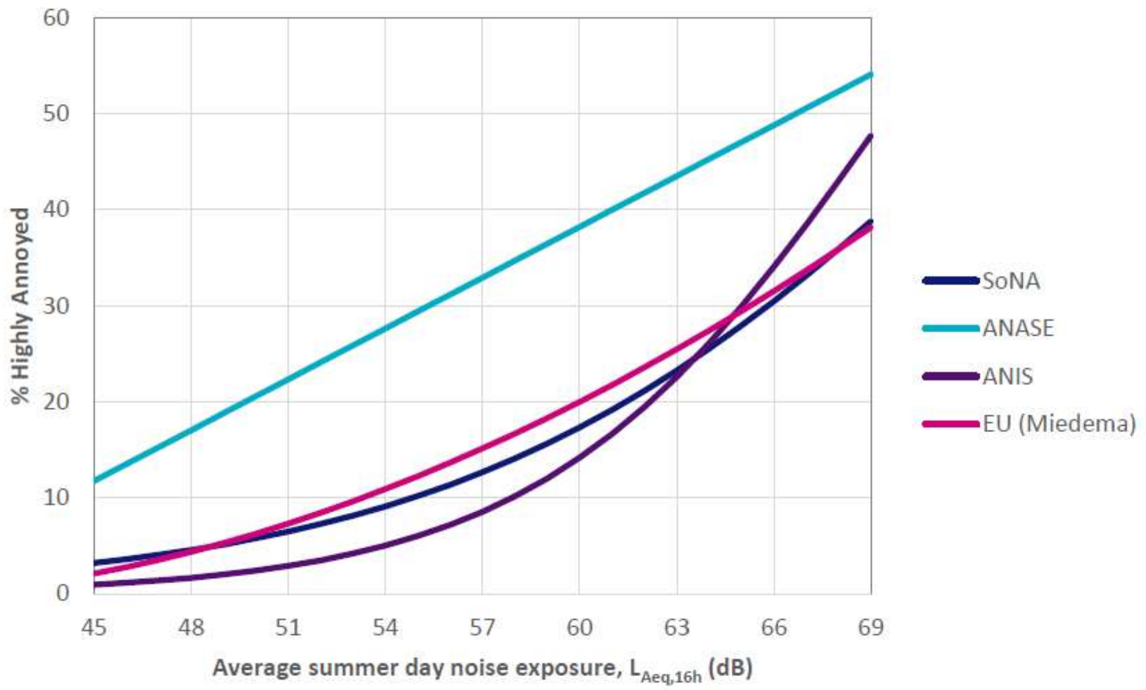

Figure 9: Comparison of % highly annoyed for SoNA, ANASE, ANIS and Miedema

It is apparent in Figure 9 that for values below 60 dB $L_{Aeq,16h}$, the SoNA 2014 results lie between ANASE and ANIS. At levels above 63 dB $L_{Aeq,16h}$ the SoNA 2014 estimates lie below ANIS. This may be due to small sample sizes at higher exposure levels for SoNA 2014 not being representative – early charts showed mean responses with relatively large uncertainties due to small sample sizes. The SoNA 2014 results are somewhat similar to the Miedema curve.

Standardisation of Questions

Data on aircraft noise-induced annoyance is obtained through surveys conducted either by post, in person face-to-face, or via telephone. Clearly face-to-face interviews are more expensive, though elicit a better response rate than postal surveys or those conducted by telephone. Postal and telephone surveys result in lower response rates of the order 15 - 20% compared to around 60% for face-to-face.

There are two standardised ISO scales that are used in social surveys on annoyance. The first is a 5-point scale that was recommended by the International Commission on the Biological Effects of Noise (ICBEN) and is shown in Figure 10 in the form presented to respondents in the SoNA study:

CAN1: So, thinking about this summer, when you were here at home, how much did each of these different types of noise from aeroplanes bother, disturb or annoy you?

		Not at all	Slightly	Moderately	Very	Extremely	Don't know
i	Overall noise of all kinds, from aeroplanes	☐	☐	☐	☐	☐	☐
ii	Noise from aeroplanes on the ground at an airport (e.g. taxiing planes, engine testing)	☐	☐	☐	☐	☐	☐
iii	Noise from aeroplanes taking off and climbing	☐	☐	☐	☐	☐	☐
iv	Noise from aeroplanes descending and landing	☐	☐	☐	☐	☐	☐
v	Noise from aeroplanes in flight	☐	☐	☐	☐	☐	☐
vi	Noise from aeroplanes during the day (7 a.m. – 11 p.m.)	☐	☐	☐	☐	☐	☐
vii	Noise from aeroplanes during the night (11 p.m. – 7 a.m.)	☐	☐	☐	☐	☐	☐

Figure 10: ISO 5 point annoyance scale as used in SoNA 2014.

The second is an 11-point scale and shown in Figure 11:

CAN34: Thinking about this summer, what number from 0 to 10 best shows how much you were bothered, disturbed or annoyed by noise from aeroplanes.

Not at all **Extremely**

0	1	2	3	4	5	6	7	8	9	10	Don't know
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 11: ISO 11 point annoyance scale, taken from SoNA 2014.

For both questions annoyance is characterised as 'being bothered, disturbed or annoyed', however throughout this document such responses are simply referred to as annoyance responses. CAN1 was presented as a matrix question, seeking views on overall annoyance from civil aircraft, but also views on noise associated with specific types of operation and specific times of day.

Such standardisation in how the questions are asked allows for direct comparisons between studies, for example between SoNA and ANASE, and also enables the responses to be transformed to mean annoyance scores for statistical analysis purposes. At the ICBEN Congress in 2017, Truls Gjestland presented a paper on the standardisation of the 5 and 11-point annoyance scales. These have now been translated into 17 further languages to enable standardisation worldwide when obtaining annoyance responses.

A report on environmental noise and health, published by the Health Protection Agency (2009) includes a section on annoyance, and the difficulties associated with analysing annoyance responses. The conclusions from this report were that generally the risk and strength of annoyance increases with the degree of sound level exposure, and such a relationship can be expressed mathematically and graphically. The report suggests that dose-response curves could be used for policy development, but they need to be studied closely due to the amount of scatter of individual responses occurring around the average response for any specific sound level. Caution should be observed due to the reasons behind such variation being not yet well understood, and that the slope of dose-response relationships may be unstable due to possible change in annoyance reactions. It was concluded that repeated surveys may still be required to establish reliable dose-response annoyance curves.

In recent years, the use of social media has become prolific and it has been suggested that this platform may be employed to gather large amounts of data in an efficient and cost effective manner in social studies. A study around Brazil’s Guarulhos airport (Silva et al, 2017) used Facebook advertisements and web-based forms to examine annoyance at various noise levels measured in DNL. 560 questionnaires were completed, and the advertisement shown to over 124,000 people, though it is impossible to know what percentage of that number actually saw the advertisement.

When compared to responses from the general population of Guarulhos regarding aircraft noise, the survey respondents’ attitude to noise was generally similar, although the survey respondents’ responses were lower for lower noise levels and higher than the general population for higher noise levels. This may be due to the recent operational changes at the airport, with an aircraft noise movement increase of 45% five years prior to the survey, making it a “high rate of change” airport. The data suggests that an increase in aircraft movements has influenced the reported annoyance of respondents.

It is important to bear in mind that with sampling techniques such as this, there is a lack of proof that the sample is representative of a noise-exposed population. In this instance, the CTL level of 65 dBA DNL suggested that the population is about 8 dB less tolerant than the average community as described by Fidell (2011). There is also a bias towards technology savvy respondents who are on Facebook, which may not be fully representative of the overall sample, and the possibility of self-selection bias, meaning that highly annoyed people will be more likely to complete the survey. The authors argue that self-selection bias is unlikely due to the low number of complaints regarding aircraft noise.

Although this method of sampling is open to certain biases, this study did not demonstrate any clear bias or distortion of results as such. The authors suggest that this method is a useful means of data collection on aircraft noise-induced annoyance in developing countries and in future to minimise bias, a postal or telephone study could be run alongside the social media method, to validate results.

Chapter 4
Recent findings

This chapter will describe and discuss a selection of the most significant findings regarding aircraft noise and annoyance since 2010. The scope of this report does not allow for a comprehensive literature review of all studies in that time period, due to the high number of annoyance studies worldwide, but instead will focus on a range of issues such as changes over time, evening and night-time studies and vulnerable groups.

The findings are grouped under the following headings:

- Changes in annoyance over time
- Psychological factors
- Night-time annoyance
- Children and vulnerable groups
- Other annoyance findings

Changes in annoyance over time

NORAH

In late 2015 some of the results of the much-awaited NORAH (NOise-Related Annoyance, cognition and Health) study were published. This was a large-scale, longitudinal German study that commenced in April 2011 and continued until 2014 and included 43 researchers from 11 institutes. In order to get more insight into the effects of transportation noise, the state-owned Environment & Community Center (ECC) of the Forum Airport and Region (FFR) commissioned the researchers to conduct a noise effects monitoring program at Frankfurt Airport before and after the opening of a fourth runway. Three Work Packages (WPs) were included in the study:

1. Annoyance and quality of life
2. Sleep and health
3. Children's cognition

Annoyance and quality of life was part of the first work package, and examined:

- Aircraft noise annoyance and health related quality of life (HQoL) before and after the opening of the fourth runway in comparison to annoyance at other airports;
- Comparison of HQoL and annoyance due to aircraft, railway and road traffic noise; effects of combined transportation noise exposure on annoyance and HQoL;

Dirk Schreckenberg, who was a lead researcher of the NORAH study, authored a paper on the effects of aircraft noise on annoyance and sleep disturbances before and after the expansion of Frankfurt airport, which were the results of Work Package 1. The study was centred on the opening of a new runway at Frankfurt Airport in 2011, along with the introduction of a new airport night curfew from 2300-0500. The study examined the impact of aircraft noise on annoyance before and after these changes by surveying residents living near the airport before the runway opening and in follow-up studies in 2012 and 2013. Over 3,500 residents participated in all three phases of the study. Surveys were conducted via telephone or optional online methods.

The operations predictions for the time after the new runway opening were that some areas would experience an increase in aircraft noise, some would experience less noise and some areas would see no significant difference in noise exposure. For each residential address, the source-specific equivalent sound level, and mean maximum sound level of aircraft, road and railway noise were calculated for the preceding 12 months of each survey study, at different times of the day.

Residents selected randomly for the study were stratified according to continuous aircraft noise level and by predicted change in aircraft noise exposure for 2020 in relation to 2007 sound levels (increase of > 2 dB $L_{Aeq, 24h}$; decrease of > 2 dB $L_{Aeq, 24h}$; no significant change i.e. a change less than or equal to ± 2 dB $L_{Aeq, 24h}$).

The surveys used the ICBEN 5-point annoyance scale and in addition to aircraft noise-induced annoyance included self-reported measurements of sleep disturbance, noise sensitivity, coping capacity/perceived control, attitudes towards aircraft, positive expectations of the change in air traffic on the economic development of the region and quality of life, and demographics such as age, gender, socioeconomic status etc.

The results suggest that the exposure-response curve for annoyance versus LAeq, 24 hour shifted following the opening of the runway, depending on changes in local sound levels. Figure 12 shows that there was a shift in % Highly Annoyed (HA) between 2011 prior to the opening of the new runway, and 2012 and 2013. This difference is especially marked for noise levels of 55 dB $L_{Aeq,24h}$ and below. The curve for 2013 lies in between those for 2011 and 2012 suggesting that there has been a settling effect of the new runway in terms of people’s attitudes and annoyance responses. In comparison to the RDF study at Frankfurt in 2005, also shown in Figure 12, there is a much larger shift in annoyance reactions for all noise levels, between these two studies.

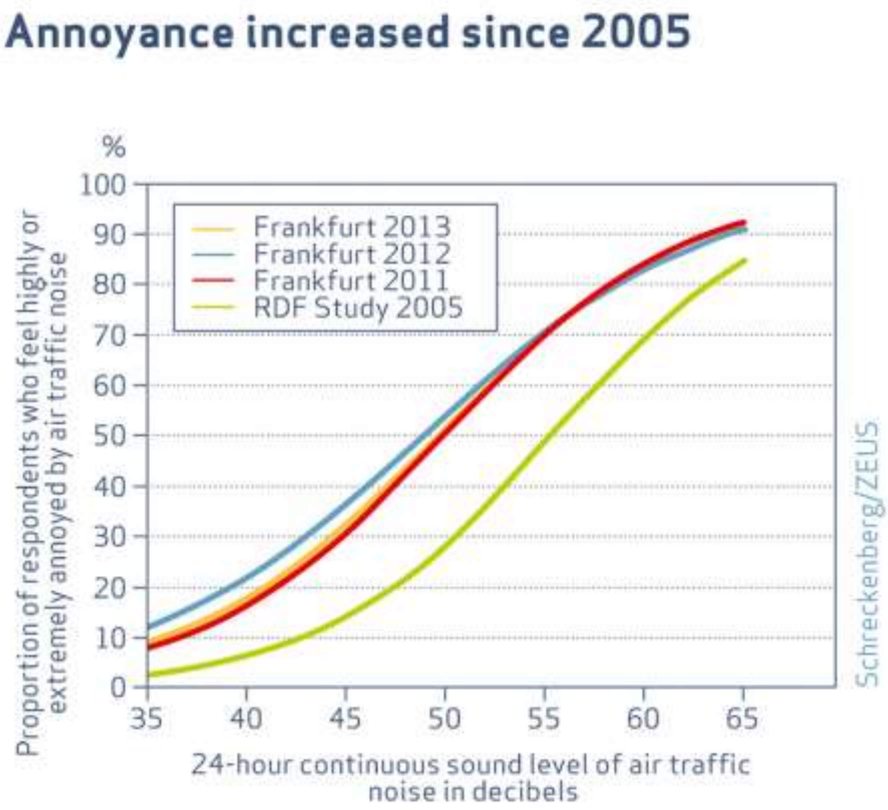

Figure 12: Percentage HA in the NORAH Study for 2011, 2012 and 2013.

For the group of participants who experienced a reduction in aircraft noise exposure, there was also a reduction in the magnitude of annoyance responses in 2012 and 2013 as seen in Figure 13. Aircraft noise annoyance in 2011 was explained by the aircraft sound level. In addition, railway sound level, survey mode, coping capability, positive expectations and judgement of air traffic as environmentally harmful were associated with aircraft noise annoyance in 2011. Participants interviewed by telephone were more annoyed than those who completed the online survey. The changes in aircraft noise annoyance in 2012 and 2013 were predicted by aircraft sound levels, coping capability, air traffic related expectations and the judgement that air traffic is dangerous.

Figure 14 shows the annoyance reactions over the three years in those residents who experienced no significant change to their aircraft noise exposure. House owners reported higher annoyance levels than tenants in this group, and sound level and noise sensitivity were also associated with annoyance levels. In this group in general the annoyance reactions increase in 2012 and then decrease again in 2013. In additions to aircraft sound levels, coping capacity and positive expectations towards the air traffic contribute to the explanation for the change in annoyance reactions.

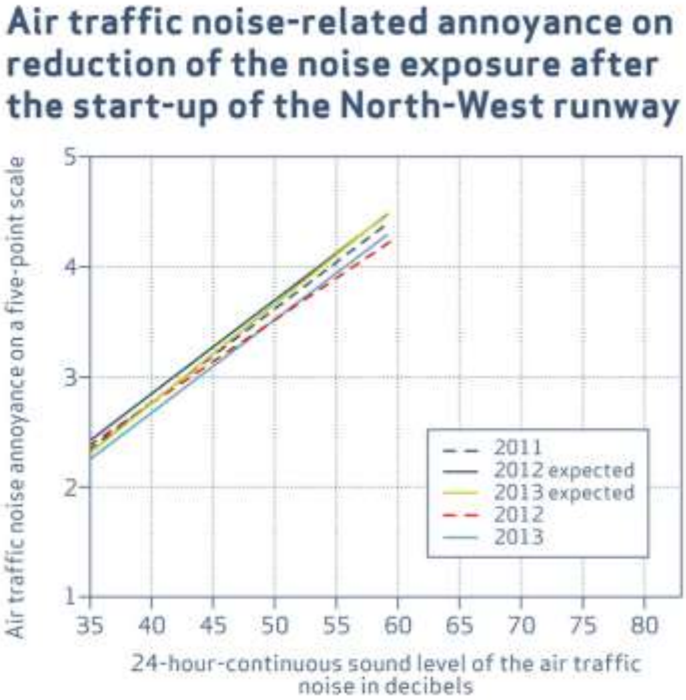

Figure 13: Annoyance reactions in the subset of the NORAH sample who experienced a reduction in aircraft noise following the opening of the new runway in 2011.

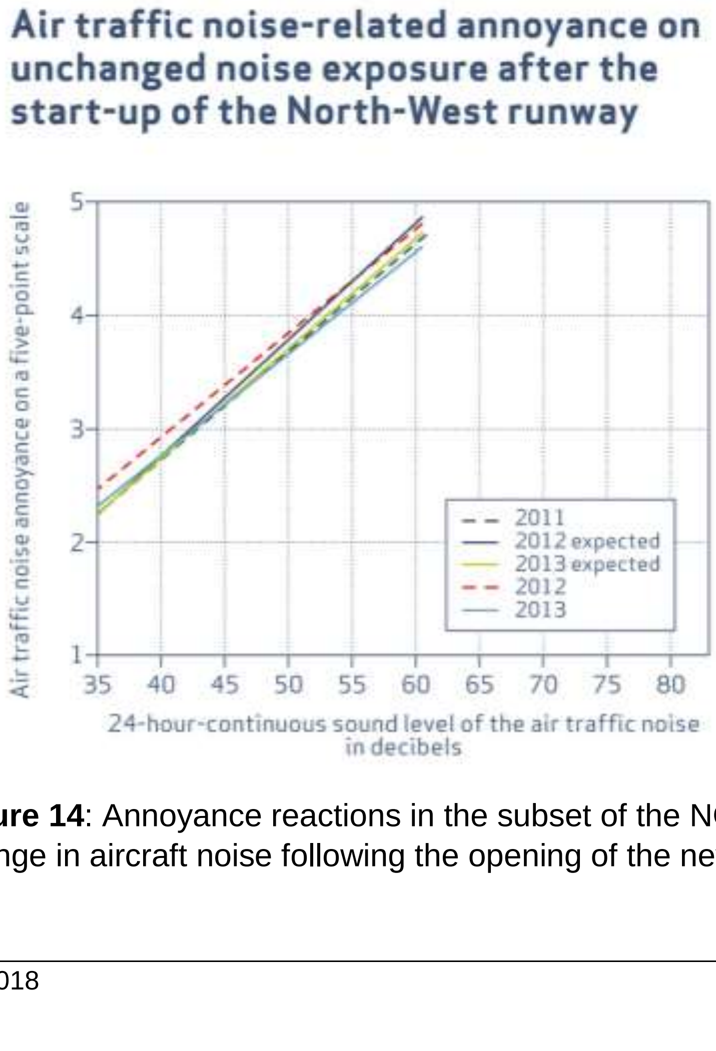

Figure 14: Annoyance reactions in the subset of the NORAH sample who experienced no change in aircraft noise following the opening of the new runway in 2011.

Figure 15 shows the change in annoyance reactions in the group who experienced an increase in aircraft noise following the opening of the runway. The change in annoyance over time is not explained by the changes in the average aircraft sound level $L_{Aeq, 24h}$. Instead, in this group annoyance changes are predicted by coping capacity, positive expectations concerning air traffic, and judgements of the airport as dangerous and environmentally harmful. In 2012 and 2013 the curve moves up and down again but is still higher than in 2011.

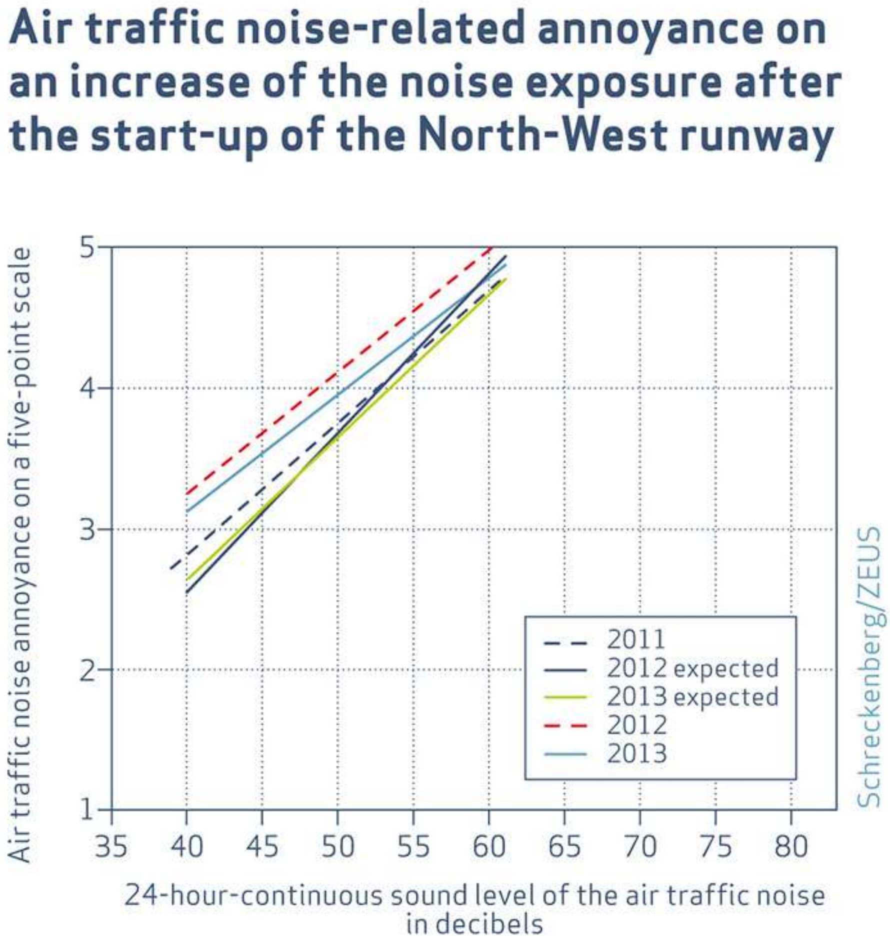

Figure 15: Annoyance reactions in the subset of the NORAH sample who experienced an increase in aircraft noise following the opening of the new runway in 2011.

It was concluded that the change effect for aircraft noise levels and annoyance responses over the three years was particularly strong:

- In lower levels of $L_{Aeq,24h}$ (below 55 dB).
- For those participants experiencing an increase in aircraft noise levels in 2012 following the opening of the new runway compared to 2011.
- In 2012 compared to 2013.

Importantly, there are several non-acoustic factors which partly explain the changes in aircraft noise reactions observed. In the group of participants experiencing an increase in aircraft noise levels, only the non-acoustic factors contributed to the change effect in aircraft noise annoyance. Those non-acoustic factors relate to coping mechanisms and attitudes, expectations and noise sensitivity. This highlights the need for the appropriate attention and controls that should be given to non-acoustic factors in aircraft annoyance studies to avoid misleading results.

Trends in annoyance over time

Janssen et al (2011) examined trends in aircraft noise annoyance and discussed the role of study and sample characteristics. Previous research has suggested annoyance levels have risen for a given aircraft noise level over the years, and it was the aim of this study to test whether there is a change over time in annoyance due to aircraft noise and if so, whether this trend may be explained in terms of study or sample characteristics.

The authors updated the previous annoyance database from Miedema and Oudshoorn (2001), with several recent cross-sectional surveys. This updated database included 34 original datasets from separate airports from 1967 to 2005. The variance of the effect estimates could be determined based on the individual data, allowing more profound statistical analysis of the trend. No extrapolation was needed for determining the effect estimates, and the problem of differences between studies in cut-off criteria for high annoyance was avoided. An adapted version of a multilevel grouped regression as described by Groothuis-Oudshoorn and Miedema (2006) was used to determine effect estimates (and their variance) of the relationship between annoyance and exposure to aircraft noise for each airport. This method allowed for correction of the effect on the exposure–response relationship of possible differences among study samples in individual characteristics. The authors then performed a meta-regression to investigate whether characteristics of the study may explain the variation in effect estimates between airports. While the main factor of interest was year of the study, the study also investigated whether other study characteristics (type of contact, type of annoyance scale applied), sample characteristics (age, number of persons in the household, use or economical dependency of the airport, insulation, noise sensitivity, fear), and acoustical characteristics of the study (number of events) may explain variability in annoyance response.

The results suggested that a significant increase in expected annoyance at a given level of aircraft noise was observed over the years. Instead of a gradual increase, annoyance appeared to show increased levels particularly from 1996 onward, although the authors explain that this could be due to the limited number of studies included in the preceding years.

It was suggested that various study characteristics can possibly explain the reason for the increased levels of annoyance based on the analysis used. The annoyance scale used, in particular the 11-point scale versus 4 or 5 point scale, was found to be an important source of variation in annoyance responses, which stressed the importance of using a standard single annoyance question. However, while the scale factor could statistically account for the year effect, a sensitivity analysis, and other previous research findings have ruled it out as a satisfactory explanation. In the SoNA 2014 study, no significant difference was found between the 5 and 11-point scales.

There were two further study characteristics that were associated with differences in annoyance, namely the type of contact, with postal surveys showing higher annoyance ratings than telephone or face-to-face surveys, and the response percentage, with higher annoyance in surveys with lower response percentages. The SoNA 2014 study specifically used face-to-face interviews in order to address these concerns. However, neither of these factors could explain the effect of the year of the study in Janssen et al. Another possible explanation for the year effect, the presumed higher rate of expansion of airports in recent years, could neither be confirmed nor ruled out due to uncertainty in attributing the change-status to an airport.

In addition, there was no evidence found for a sensitisation to noise within the population under study as reflected in self-report measures of noise sensitivity. The authors explained that a limitation of meta-regression analysis is that some of the characteristics which differ between studies can be highly correlated, making it hard to differentiate between their effects. Therefore it was suggested that caution should be taken in the interpretation of the effects, especially since several of the study characteristics discussed appear to have changed around the same time. A further limitation is that not all of the included surveys provided information on certain individual characteristics that have been shown to importantly influence annoyance, such as noise sensitivity, fear, or other attitudinal characteristics, preventing proper adjustment for these. However, the authors concluded that despite the uncertainty with regard to its explanation, it is clear from the observed trend that the applicability of the exposure–annoyance relationship for aircraft noise (Miedema and Oudshoorn, 2001) should be questioned. It is worth noting that an alternative view is that because the change over time is not consistent, it doesn't necessarily follow that a 2001 curve is actually out of date. Given the large part of the variation explained by year of the study, it does not seem justifiable to pool recent and older studies into one single relationship. While this could imply that the relationship needs to be updated on the basis of recent studies using similar methodologies, it is important to obtain further insight into the factors responsible for the change and the large variation found in the annoyance response.

A Japanese study presented at Internoise 2016 by Nguyen from Kumamoto University looked at community response to a change in aircraft noise exposure before and after the operation of the new terminal building in Hanoi Noi Bai airport in Vietnam. Following opening of the new terminal building in December 2014, there was a 20% increase in the number of daily flights, thus changing the pattern of noise exposure in surrounding areas. Social surveys were conducted in September 2014, March 2015 and September 2015. L_{den} levels had increased from 44-66 dB during the first survey, to 45-66 dB and then 49-69 dB during the last survey, and the exposure-response increased by approximately 5% for the second survey and then very steeply for the third survey. All three curves are noticeably steeper than the EU annoyance curve, particularly for noise values above 55 dB L_{den}, indicating that residents around this airport are generally more annoyed by aircraft noise than those in Europe. Logistic regression indicated that there were significant increases in high annoyance responses between each survey. An update on this study (ICBEN 2017) reported that there were significantly higher levels of annoyance at the arrivals side of the airport for all three phases of the study, and in particular for the second survey. There were considerable gaps between exposure-response curves for general annoyance and activities interference, as well as sleep disturbances at arrival and departure sides of the airport. The excess responses at the arrivals side of the airport was possibly explained due to the corresponding level of sleep disturbance in that area, or other non-acoustical factors.

Truls Gjestland et al (2016) examined the use of noise surveys at five Norwegian airports in 2014 and 2015. The study focused on the difference between ‘high rate of change’ (HRC) and ‘low rate of change’ (LRC) airports. LRC is classified as those airports where 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 three years before and after the study. If the typical trend is disrupted significantly and permanently, the airport is classified as HRC. The Community Tolerance Level (CTL) method (see Chapter 2) was used in this study for ease of cross-study comparison and to provide a single-number parameter to describe the annoyance level in the particular community i.e. the noise level at which half of the population is highly annoyed.

In this study, Oslo Airport was classified as HRC, and the other four airports (Stavanger-Sola, Trondheim, Bodø, Tromsø) were classified as LRC. 300 participants were chosen from each airport population, and the surveys were conducted via telephone. The annoyance questions used were the two ICBEN recommended 11-point and 5-point scales.

The results indicated that residents living near the four LRC airports tolerate 7-10 dB higher noise levels than is suggested by the EU curve and had a higher CTL than the average value given by Fidell. Residents near the HRC airport were more annoyed than the average, equivalent to a shift of about 5 dB compared to the EU curve and had a lower CTL of 68 dB compared to the average of 73 dB.

The study also found a positive correlation between annoyance and the number of noise events above 55 dBA per day, with approximately 25% of the population being Highly Annoyed at 250 events per day. In contrast the UK SoNA 2014 survey found 18% and 20% Highly Annoyed for 200-399 events per day above 65 and 70 dB L_{Amax} respectively. Night-time aircraft annoyance was strongly correlated with overall noise annoyance, which suggested that night noise is not specifically problematic at the studied airports. Noise during the summer was experienced as more annoying, irrespective of seasonal differences in noise level.

The notion of HRC and LRC airports formed part of the WHO systematic review on environmental noise and annoyance from 2000-2014, which was presented by Rainer Guski from Ruhr University in Germany at the Internoise 2016 Congress. The main noise sources considered were aircraft, road traffic, railway noise and wind turbines, with the aims to assess the strength of association between exposure and long term noise annoyance, to quantify the increase of annoyance with an incremental increase in noise exposure, and to present an exposure-response relationship for each noise source.

The paper discusses the criteria used for the literature search, and definitions of annoyance. It was agreed by the WHO group that noise annoyance as seen in surveys is a complex response, comprising three elements:

1. An often repeated disturbance due to noise often combined with behavioural responses in order to minimise disturbances. (repeated disturbance of intended activities e.g. communication, watching TV, reading, sleep)
2. An attitudinal response (anger about the disturbance, and negative evaluation of the noise source)
3. A cognitive response (the realisation that one cannot do much against this unwanted situation).

This multi-faceted reaction is seen by many researchers as a stress-reaction, involving an environmental threat and individual physiological, emotional, cognitive and behavioural responses which can partly be remembered and integrated into a long-term annoyance response. The results from the aircraft noise element to this review comprised data from 15 aircraft annoyance studies which occurred between 2000 and 2014. All of the studies except one defined “highly annoyed” by the upper 27% of the response scale i.e. HA ≥ 73%.

In terms of dose-response curves, the more recent studies appear to have shifted above the Miedema/Oudshoorn curve from 2001, and closer to Janssen and Vos’ annoyance curve from 2009, especially in the 40-50 dBA L_{den} (Figure 16). This result is in line with the often reported trend that aircraft noise has increased over recent years, and aircraft noise today is higher than shown in the Miedema/Oudshoorn 2001 curve. In addition, airports that were deemed to have a HRC elicit a higher degree of annoyance than those classified as steady state or LRC for the same or comparable noise levels.

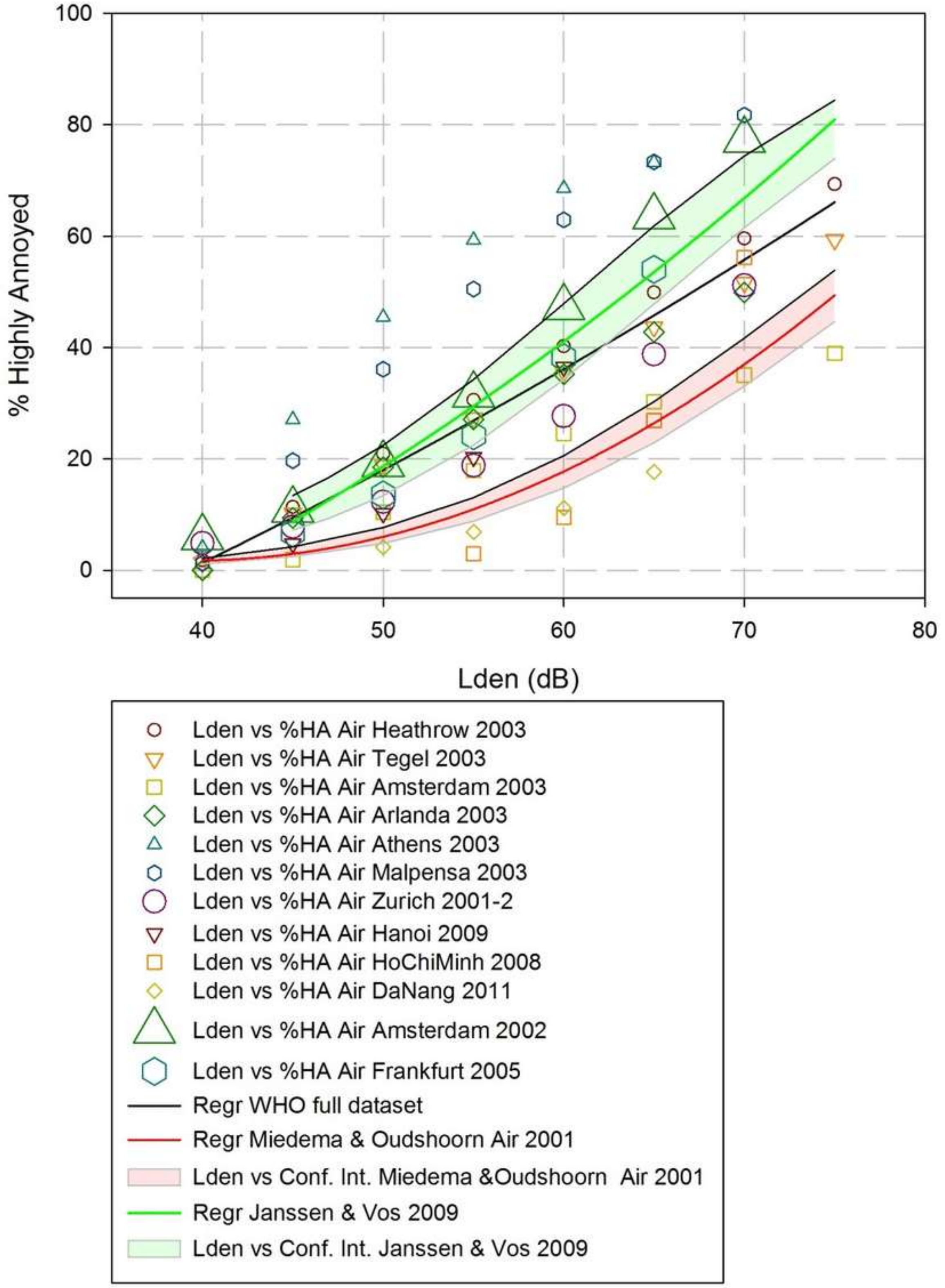

Figure 16: Scatterplot and quadratic regression of the relationship between Lden and the calculated % Highly Annoyed for 12 aircraft noise studies (black), together with exposure-response functions by Miedema & Oudshoorn (2001, red), and Janssen & Vos (2009, green). Taken from WHO (Internoise 2016).

Psychological factors

Kroesen et al (2010) investigated the direction of causality between psychological factors and aircraft noise annoyance using a structural equation modelling approach. Data was used from two surveys conducted in 2006 and 2008 using the same residents living within the 45 L_{den} contour of Schiphol airport (n=250). The model used in this study was a cross-lagged panel model, where the dependent variables at time 2 are predicted by their previous values as well as the time 1 values of the other variable of interest. The authors found surprisingly that none of the paths from the twelve subjective socio-psychological factors that were included, to aircraft noise annoyance were found to be significant. However, two effects were found to be significant in the opposite direction. The first was from 'aircraft noise annoyance' to 'concern about the negative health effects of noise', and the second was from 'aircraft noise annoyance' to 'belief that noise can be prevented.' Hence aircraft noise annoyance measured at time 1 contained information that can effectively explain changes in these two variables at time 2, while controlling for their previous values. Secondary results show that aircraft noise annoyance is very stable through time and also that changes in aircraft noise annoyance and the identified psychological factors are correlated.

The authors suggest that establishing the direction of causality between aircraft noise annoyance and possible social-psychological factors is important for noise policy. Policies specifically aimed at these factors can only be effective if the causality indeed 'flows' from such factors to aircraft noise annoyance. A second and related issue, is whether individual differences can be attributed to social or psychological variables and processes. If, for instance, personality traits appear to be dominant in the explanation of individual differences, more individually 'tailored' noise policies would be preferable. If, on the other hand, social representations are dominant in structuring noise perception and evaluation, a closer examination of the collective noise policy and the message it brings across would be more appropriate.

Evening/ night noise and lack of annoyance studies

Elmenhorst et al (2012) examined nocturnal railway noise and aircraft noise in the field with respect to sleep, psychomotor performance, and annoyance. This study was conducted using participants living alongside railway tracks around Cologne/Bonn. Previous research has suggested that railway noise is less annoying than aircraft noise in surveys, which was the reason for a so called 5 dB railway bonus regarding noise protection in many European countries. This study investigated railway noise-induced awakenings during sleep, night-time annoyance and the impact on performance the following day. Comparing these results with those from a field study on aircraft noise allowed for a ranking of traffic modes concerning physiological and psychological reactions. Thirty three participants (mean age 36.2 years (±10.3 standard deviation); 22 females) living alongside railway tracks around Cologne/Bonn (Germany) were polysomnographically investigated. These data were pooled with data from a field study on aircraft noise (61 subjects) directly comparing the effects of railway and aircraft noise in one random subject effects logistic regression model. Annoyance was rated on the ICBEN 5-point scale in the morning, regarding the previous night's railway noise in the first study, and compared with those from the aircraft noise study. Results of the regression model indicated that nocturnal aircraft noise was more annoying than nocturnal railway noise though statistically not significant. Annoyance ratings were independent from gender but increased with age.

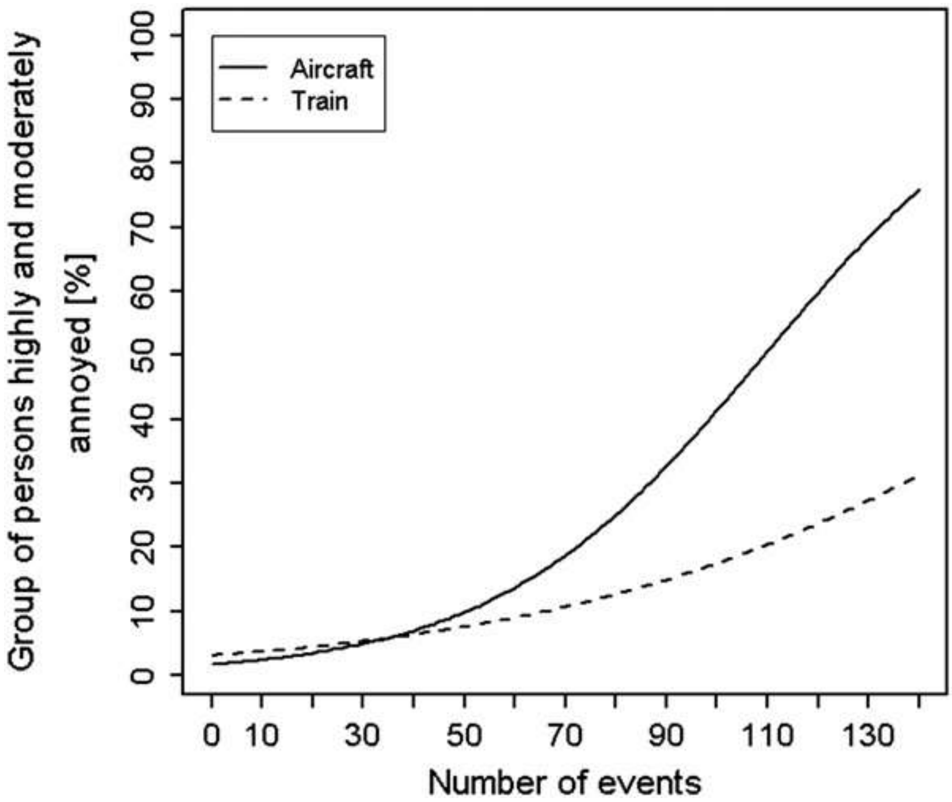

Figure 17: Comparison of railway and aircraft noise effects and annoyance against number of nocturnal events. Assumptions: age = 34 years (median), gender = male; noise levels at the sleeper's ear.

The results suggested that probability of sleep stage changes to wake/S1 from railway noise increased from 6.5% at 35 dBA to 20.5% at 80dBA L_{AFmax}. Rise time of noise events had a significant impact on awakening probability. Nocturnal railway noise led to significantly higher awakening probabilities than aircraft noise, partly explained by the different rise times, whereas the order was inversed for annoyance. Freight train noise compared to passenger train noise proved to have the most impact on awakening probability. Nocturnal railway noise had no effect on psychomotor vigilance. The authors concluded that nocturnal freight train noise exposure in Germany was associated with increased awakening probabilities exceeding those for aircraft noise and contrasting the findings of many annoyance surveys and annoyance ratings.

Maria Foraster from the Swiss Tropical and Public Health Institute from Basel investigated annoyance reactions and the risk of physical inactivity (2016). The theory behind this work was that annoyance from transportation noise, and resulting sleep disturbance may then in turn lead to a reduction or lack of physical activity. Perceived stress and unconscious stress resulting from noise can both lead to sleep deprivation. In addition, annoyance with the neighbourhood due to noise may reduce the willingness to go outside and exercise locally. The study had two aims: 1. to investigate whether there is an association between noise annoyance at home and physical activity, and 2. Is there any effect modification by gender and noise sensitivity?

3,622 participants aged 30-38 years were assessed as part of a large study cohort in Switzerland between 1991 and 2011. Annoyance was assessed on the 11-point annoyance scale. Sufficient physical activity was defined as at least 150 minutes of exercise per week. The results indicated that 60% of the study population were active, and there were fewer tendencies towards high annoyance scores in those that were physically active. Road traffic noise was responsible for the highest degree of annoyance, followed by aircraft noise and then railway noise. There was a significant association between long-term annoyance to transportation noise (on average 20 years) and being physically inactive at the end of that period.

Physical inactivity was strongest amongst those people who had reported sleep deprivation, particularly for night-time annoyance to road traffic noise. No effect modification was observed for gender or noise sensitivity, so these factors do not explain the association. Foraster concluded that noise annoyance at night may contribute to cardiovascular diseases through a decrease in physical activity, and this relationship may be stronger in those people with impaired sleep, especially due to road traffic annoyance at night. This is the first study to investigate transportation noise and physical activity with relation to cardiovascular health endpoints. Further studies are needed to confirm these results and to ascertain the pathways that may be responsible for decreased activity. In 2014 a Swedish study by Eriksson et al was published that claimed a link between aircraft noise and obesity. The study was part of the longitudinal study on hypertension (Eriksson, 2010) and aimed to investigate effects of long-term (up to 10 years) aircraft noise exposure on body mass index (BMI), waist circumference, and Type 2 diabetes in over 5,000 residents in Stockholm County. The main finding was that there was an association between aircraft noise exposure and increased waist circumference after adjustment for individual and area-level confounders. The authors found that this association appeared particularly strong among those who did not change their home address during the study period, which may be a result of lower exposure misclassification. Although this association was considered to be a physiological association, Foraster's results suggest it could be more of a behavioural outcome of lack of physical activity.

There is a lack of studies on night-time aircraft noise and annoyance; studies tend to focus on sleep disturbance which is a pre-cursor to annoyance, but an earlier study by Quehl and Basner (2006) examined the dose-response curves in laboratory and field settings for aircraft noise and annoyance responses.

Data for the study was used from questionnaire surveys with 128 subjects in a laboratory study performed at the DLR Institute of Aerospace Medicine over a period of 13 nights. One control group experienced no aircraft noise for the duration of the study, and three other experimental groups experienced varying degrees of loudness and rate of presentation of the aircraft noise. The A-weighted maximum noise levels L_{ASmax} in the noisy nights ranged from 45–80 dB, and the frequency of occurrence varied between 4 and 128 events per night.

Annoyance was measured using the ICBEN 5-point scale, 15 minutes after waking, and non-acoustic factors were assessed also using 5 point scales on areas such as noise sensitivity, adaptation to noise, attitudes to aviation and the level of annoyance at home, prior to the study. Age and gender were also measured.

The field study was conducted around Cologne/Bonn airport, using 64 participants over nine consecutive nights. The aircraft noise was recorded inside and outside of the bedroom, and numbers of events were measured as well as L_{Aeq} event. The L_{Aeq} event concerns the aircraft noise-specific, A-weighted energy equivalent noise level in the bedroom during individual sleep times, where only aircraft noise events exceeding 35 dBA were taken into account.

Dose–response curves regarding the annoying impact of nocturnal aircraft noise were calculated for the (1) maximum noise level L_{ASmax} combined with the number of aircraft noise events and for the (2) energy equivalent noise level LAeq event by means of random effects logistic regression. Logistic regression is a mathematical model used in statistics to estimate the probability of an event occurring having been given some previous data. Logistic Regression works with binary data, where either the event happens (1) or the event does not happen (0). The laboratory results were compared to the results of the field study.

In the laboratory setting there was a significant increase in the number of annoyed people relating to L_{ASmax} and the frequency of fly-overs. The percentage annoyed by aircraft noise also increased with L_{ASmax} during those nights with fewer than 16, but louder aircraft noise events. The group of annoyed subjects also significantly increased with the L_{Aeq} event; however, above 50 dBA it decreased again since fewer but louder events were presented in the underlying combinations of noise level (45–80 dBA L_{ASmax}) and number of noise events per night (4 to 128). Data from the field study confirmed the trend of the laboratory dose–response relationships. However, the dose-response curve from the laboratory study lay above the field-study curve, i.e. subjects felt more annoyed by aircraft noise in the laboratory setting than in their home environment. This was most probably caused by the increased number of awakenings in the laboratory compared to field conditions. Other studies have also found much higher responses in laboratory settings, and have suggested that habituation is a significant factor. Quehl and Basner suggest that the findings of the studies indicate that not only the energy equivalent noise level ($L_{Aeq,night}$), (as often used in European noise policy) but also the number of aircraft events are a major source of nocturnal aircraft noise-induced annoyance. This could be due to people reacting more to single event noise characteristics rather than average noise levels, and that people often complain about the frequency of flights (even though the individual events may be quieter than in previous years) and a lack of respite between them.

In terms of non-acoustic moderating factors, the results from the laboratory models showed that one factor (‘‘necessity of air traffic’’) and three personal variables (gender, age, pre-annoyance due to aircraft noise) proved to be significant. In other words, the predicted number of people annoyed by aircraft noise was significantly higher for those people who did not regard air traffic as necessary, women rather than men, older people versus younger people and those who were highly annoyed due to aircraft noise in their homes prior to the study.

Children's annoyance/vulnerable groups

Children's annoyance reactions to aircraft and road traffic noise have also been studied (van Kempen et al, 2009). Annoyance in children has rarely been studied outside of the school environment, and the aim of this work was to investigate annoyance reactions and exposure-response relationships to aircraft and road noise in both home and school. Data from the Road Traffic and Aircraft Noise Exposure and Children's cognition and Health (RANCH) study was used (RANCH study is described in detail in ERCD Report 0908) with a secondary aim to compare children's annoyance reactions with those of their parents. Both parents and children's reactions were measured using self-administered questionnaires. The study was carried out on 2,844 children, aged 9-11 from primary schools in areas surrounding Heathrow, Schiphol and Madrid-Barajas airports. Aircraft noise exposure at home and school was significantly related to severe annoyance, in both cases where the noise exposure from aircraft was higher, the proportion of severely annoyed children was higher also. At school, the percentage of severely annoyed children was predicted to increase from 5% at 50 dB $L_{Aeq,16h}$ to about 12% at 60 dB $L_{Aeq,16h}$ (Figure 18). At home these figures were 7% and 15% respectively (Figure 19). Road traffic noise at school was also significantly related to severe annoyance, with the percentage severely annoyed children predicted to increase from 4% at 50 dB $L_{Aeq,16h}$ to about 6% at 60 dB $L_{Aeq,16h}$. The authors' view was that the association between annoyance and aircraft noise is stronger in children than road noise, probably due to the intensity, variability and unpredictability of aircraft noise in comparison to road noise. Children's annoyance reactions were found to be comparable to their parent's reactions, but with children having lower response frequencies of severe annoyance than their parents at higher noise levels of 55 dB and above.

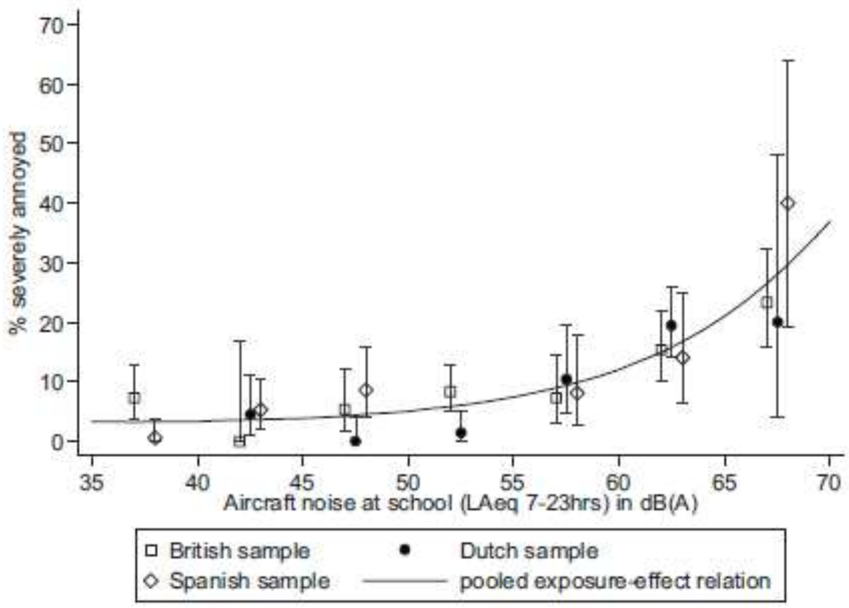

Figure 18. The country-specific percentage of severely annoyed children by 5 dB bands of aircraft noise ($L_{Aeq,16h}$) at school and the relationship between aircraft noise at school and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

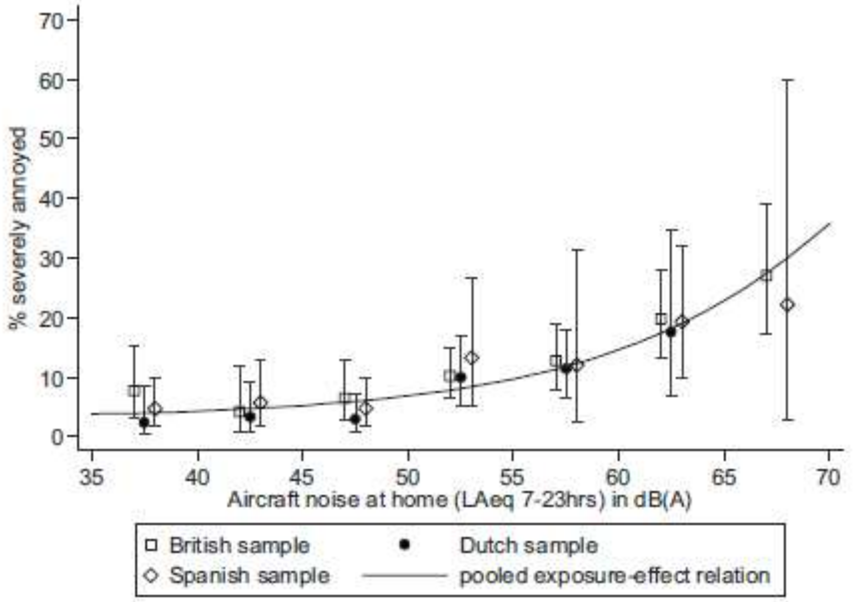

Figure 19. The country-specific percentage severely annoyed children by 5 dB bands of aircraft noise ($L_{Aeq,16h}$) at home and the relationship between aircraft noise at home and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

Another study examining annoyance reactions to aircraft noise in children (Seabi, 2013) was conducted in South Africa and also included measures of health. Known as RANCH-SA, this was one of the only studies on aircraft noise induced-annoyance in South Africa to date, and was intended to observe whether the results were comparable to those from Western Countries where there has been far more research in this area. The study was designed around the relocation of Durban Airport to an area 35 km north of the city and included children from a selected “High Noise Group” (HNG) with a range of baseline noise levels between 63.5 to 69.9 dB L_{Aeq} and “Low Noise Group” (LNG) with a range of baseline noise levels between 54.4 to 55.3 dB L_{Aeq}, for participation in three waves of the study. 732 children with a mean age of 11.1 (range = 8-14) participated at baseline measurements in Wave 1 (2009). 649 (mean age = 12.3; range = 9-15) and 174 (mean age = 13.3; range = 10-16) children were reassessed after the relocation of the airport in Wave 2 (2010) and Wave 3 (2011), respectively. Noise measurements during Waves 2 and 3 when aircraft were gone from the area, produced results at the formerly noise exposed schools of 55.2 dB L_{Aeq}. Aircraft noise levels at the quieter schools had noise levels between 50.5 to 57.9 dB L_{Aeq}.

Questionnaires were given to the parents and children, and used to obtain information on the children’s age, gender, and socio-economic status as well as the children’s annoyance reactions which were given on a 4-point Likert scale in seven specially adapted questions. Questions on self-reported general health and specific conditions such as headaches, stomach aches, vomiting, and difficulty sleeping were also included.

The findings revealed that the children who were exposed to chronic aircraft noise continued to experience significantly higher annoyance than their counterparts in all the waves at school, and only in Wave 1 and Wave 2 at home. This was an interesting finding as the annoyance persisted even after the relocation of the airport and subsequent decrease in noise levels. It is possible that non-acoustic factors that were not measured are accountable for this result. Aircraft noise exposure did not have adverse effects on the children's self-reported health outcomes. Taken together, these findings suggest that chronic exposure to aircraft noise may have a lasting impact on children's annoyance, but not on their subjective health rating.

It should be noted, however, that in this study there was a relatively small sample of participants in Wave 3 (less than 25% of the original Wave 1 sample) which may have influenced the results. Also, only aircraft noise was measured, and other noise sources such as road or railway noise were not included which may have led to bias.

Other annoyance findings

Military versus civil aircraft noise

Gelderblom from Norway (Internoise 2014) presented research findings on the impact of civil versus military aircraft noise on annoyance. Civil aircraft traffic tends to be spread out relatively evenly over a day, whereas military training operations can often be characterised by short periods of high activity followed by long periods of comparative silence. The study aimed to examine which acoustic properties a noise metric should depend on to be as strongly related to annoyance as possible.

Annoyance responses from airports that are operationally, and therefore acoustically, very different from another, were compared. An aircraft noise annoyance survey was conducted via telephone at two locations: near a civil airport and near a runway that is used for both military and civil air traffic. Various acoustical and operational variables were examined, together with reported annoyance and answers to questions that attempted to identify causes of annoyance.

The results indicated that at both locations, annoyance due to aircraft noise was significantly lower than predicted by the Miedema curve. The percentage highly annoyed at a certain Ldn was found to be significantly different for the different types of airports, but comparison of annoyance scores did not support this conclusion. The clearest difference between locations was an increased percentage of highly annoyed at lower levels of Ldn for the airport with mixed traffic. The authors explain that this may be due to the presence of fighter jets in this area, which are responsible for relatively high noise levels per event in areas where Ldn was low in comparison.

The results suggested that when given a choice, respondents tend to separate airport activities by the type of aircraft involved. Interestingly, the aircraft that contributes most to the Ldn was not necessarily the most annoying. An example of this is very loud events such as fighter jets are remembered as specifically annoying, even if they are relatively infrequent. The study also investigated impact of time of day, with most respondents not reporting a specific time of day that increased annoyance. In those that did, the majority specified the time period 0900-1200 for the mixed airport, and 1200-1800 for the civil aircraft airport. Descriptors of the noisiest events, like L_{Amax} and the number of loud noise events, were more strongly related to the observed annoyance than the energy-weighted units $L_{Aeq\ 24h}$, L_{dn} and L_{den}.

Novel indicators

A Swiss study, authored by Wunderli et al (2016), examined the use of a new acoustic descriptor called Intermittency Ratio (IR) , which reflects the 'eventfulness' of a noise exposure situation with the possibility of use alongside the common metrics such as L_{Aeq}. Regarding noise effects on health and wellbeing, average measures often cannot satisfactorily predict annoyance and health effects of noise, particularly sleep disturbances. It has been hypothesised that effects of noise can be better explained when also considering the variation of the level over time and the frequency distribution of event-related acoustic measures, such as for example, the maximum sound pressure level. However, it is unclear how this is best measured in a metric that is not correlated with the L_{Aeq}, but takes into account the frequency distribution of events and their emergence from background. The study looked at whether the intermittent characteristics of noise correlated with subjectively perceived intermittency of noise exposure at the homes of Swiss residents, and whether IR could actually contribute to the explanation of noise annoyance and self-reported sleep disturbance.

The preliminary results suggested that the de-correlation of the IR from L_{Aeq} in the survey sample studies worked relatively well with road traffic noise but less well with railway and aircraft noise, which is surprising given the intermittent nature of aircraft noise. IR was not strongly associated with self-reported perception of intermittency, and does not seem to increase or decrease self-reported annoyance or sleep disturbance responses. It was suggested that the situations with high IR, such as an aircraft overflights, have more and longer noise-free intervals, but also more obvious single events, which could trigger physiological responses at night. The authors suggest a possibility for future epidemiological studies on long-term health effects and sleep disturbances may be to consider the use of IR as a supplementary tool to help explain variance.

Mitigation/Intervention measures

Kroesen and Shreckenberg (2011) published analysis on a new model for general noise reaction in response to aircraft noise. In this paper a measurement model for general noise reaction (GNR) in response to aircraft noise was developed to assess the performance of aircraft noise annoyance and a direct measure of general reaction as indicators of this concept. For this purpose GNR was conceptualized as a superordinate latent construct underlying particular manifestations. This conceptualisation was empirically tested through estimation of a second-order factor model. Data from a community survey at Frankfurt Airport were used for this purpose (N = 2206). The data fit the hypothesised factor structure well and supported the conceptualisation of GNR as a superordinate construct. It was explained that noise annoyance and a direct measure of general reaction to noise capture a large part of the negative feelings and emotions in response to aircraft noise but are unable to capture all relevant variance.

The authors concluded that the results of this present study are in line with the previous findings and indicate that general measures are more valid indicators of negative reaction to (aircraft) noise than specific dimensions such as annoyance or disturbance. The developed model provides insight into the overall experience of aircraft noise. Based on the results it is apparent that this experience is multi-faceted and includes at least three, but possibly many other, dimensions. In addition, from the factor loadings on GNR it can be inferred that dimensions such as noise annoyance and activity disturbance lie at the core of GNR, while the anxiety and fear dimension operates at a more distant level.

The authors suggest several possibilities for future research, including the analysis of additional dimensions of general negative reaction, such as perceived control or the attitude towards noise source authorities to investigate whether such factors are an integral part of general reaction to aircraft noise, or whether these should be thought of as independent variables.

USA Annoyance Study

In the USA, a new Civil Aircraft noise annoyance study is underway. The aim of the study is to produce an up-to-date nationally applicable aircraft noise dose-annoyance response relationship. Given that US aircraft noise policy was first established in the 1970s, there is a need for an updated knowledge base on community noise in the US in the form of a large-scale social survey.

Twenty airports are being surveyed simultaneously over the course of one year, to capture seasonal effects and minimise the chance of bias as the names of the airports have not yet been disclosed. The selected airports meet the following criteria:

- At least 100 jet operations per day.
- At least 100 households exposed to aircraft noise of 65 dB DNL or above.
- Have at least 100 households exposed to levels between 60 dB and 65 dB DNL.

Airport characteristics that may affect how people react to aircraft noise were also taken into account such as:

- Average daily operations – a need to reflect both small and large airports.
- Percentage of night-time operations.
- Average daily temperature – warmer climates result in higher annoyance
- Fleet mix ratio.
- Population within five miles of the airport.

The sample size is approximately 10,000, with the reported annoyance related to the computer modelled noise exposure level at that respondents' location. The study will collect survey data by post and by a computer-assisted telephone interview, although the postal survey elicits a higher response rate (35% compared to 12% for phone) so the majority of data will be collected in this way. The aim is to produce a cumulative national civil airport annoyance curve from responses to the postal survey, using a logistic regression analysis.

Annoyance and mental health

Noise-induced annoyance measures are often included as part of larger studies on health endpoints, but there has been a paucity of studies examining the potential link between annoyance reactions to aircraft noise, and mental health. A German observational study (Beutel, 2016) examined the link between annoyance and depression and anxiety in a sample of over 15,000 people who were included in the cohort Gutenberg Health Study between 2007 and 2012 and in the vicinity of Frankfurt airport.

Annoyance was measured by asking “How annoyed have you been in the past years by . . .”? for six sources of noise (road traffic, aircraft, railways, industrial/construction, neighbourhood indoor and outdoor) and were separately rated “during the day” and “in your sleep”. Ratings were given on the five-point scale (“not, slightly, moderately, strongly, and extremely”).

The results suggested that mean depression (measured by the Patient Health Questionnaire) and anxiety (measured by the Generalised Anxiety scale) scores increased steadily from 3.5 to 5.1, and 0.7 to 1.1, respectively, with the degree of annoyance. A sum score of 3 and more (range 0–6) out of these two items indicates generalized anxiety with good sensitivity and specificity. In order to determine the associations between noise annoyance, depression and anxiety, a logistic regression controlling for gender, age and socioeconomic status was performed. Compared to no annoyance, the odds ratio for depression increased steadily starting from moderate (1.22; 95% CI 1.00 to 1.49) to extreme annoyance, which had a 2.12 fold (95% CI 1.71 to 2.64) likelihood of depression. Correspondingly, the likelihood of anxiety increased from moderate (1.45 fold; 95% CI 1.16 to 1.81) to extreme annoyance (2.28 fold; 95% CI 1.79 to 2.91).

The proportion of annoyance was highest from aircraft noise, with nearly 60% of the population reporting it affected them to some degree, and over 6% reporting they were extremely annoyed by it. Aircraft noise was the major source of annoyance in this study, and exceeded the other sources in terms of being strongly annoyed. Strong noise-induced annoyance was associated with a two-fold increase in incidence of depression and anxiety; however, aircraft noise could not directly be related to depression and anxiety outcomes. A major weakness of this study was that there were no objective measurements of noise and it relied solely on self-reported measures of annoyance to perceived noise levels.

Floud et al (2011) also examined the effect of aircraft noise on mental health, and reported on medication use in relation to aircraft noise of populations surrounding six European airports, as part of the HYENA study. Differences were found between countries in terms of the effect of aircraft noise on antihypertensive use. For night-time aircraft noise a 10 dB increase was associated with an odds ratio of 1.34 (95% CI 1.14 to 1.57) for the UK and 1.19 (CI 1.02 to 1.38) for the Netherlands but no significant associations were found for other countries. There was also an association between aircraft noise and anxiolytic (anti-anxiety) medication, OR 1.28 (CI 1.04 to 1.57) for daytime and OR 1.27 (CI 1.01 to 1.59) for night-time. It should be noted that these confidence intervals are considerable in variation. This could indicate an association with symptoms of anxiety. However, it could also indicate sleep disturbance because anxiolytics can be prescribed for sleep problems.

This effect was found across countries. The authors concluded that although results suggested a possible effect of aircraft noise on the use of antihypertensive medication, the effect did not hold for all countries. The data was more consistent for anxiolytics in relation to aircraft noise across countries. No associations were found between noise levels and hypnotics, antidepressants or antasthmatics.

Chapter 5
Non-acoustic factors

As can be seen from the studies in Chapter 4, investigating the effects of aircraft noise and annoyance is not entirely straightforward and the relationship is often affected by other, non-acoustic factors i.e. all those factors other than noise level which contribute to annoyance. Non-acoustic factors encompass a broad spectrum, including age, gender, socioeconomic status, attitudes to aviation, to name but a few. This chapter will explore some of the recent research that focuses on non-acoustic factors within aircraft noise-induced annoyance studies.

In 2010 Schreckenberg et al investigated the associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance. The aim of the study was to test whether noise sensitivity reflects partly general environmental sensitivity and is associated with an elevated susceptibility for the perception of mental and physical health. Annoyance due to environmental noise is influenced by several non-acoustic factors such as personal traits and attitudes toward the noise source. The study explains that previous research has shown that noise sensitivity is regarded as a moderator or mediator of noise annoyance and other effects such as subjective sleep disturbance, or impaired mental performance. Noise sensitivity has also been found to be associated with physical and mental health complaints, irrespective of noise exposure, personality traits such as introversion/extraversion, neuroticism and negative affectivity.

190 participants living around Frankfurt airport were interviewed, with the aim of assessing their residential situation, health-related quality of life, annoyance and disturbances due to noise, in particular to aircraft noise. $L_{Aeq,16h}$ was calculated for air traffic and road traffic, and ranged from 41 to 62 dB for aircraft noise, which was the predominant noise source.

The results indicated that noise sensitivity was associated with self-reported physical health but not with reported mental health. Noise sensitivity contributed to the prediction of the evaluated environmental quality in the residential area, in particular with regard to air traffic (including noise, pollution, and contaminations). Other aspects of perceived quality of the environment were not associated with noise sensitivity. Little evidence was found that suggested that noise sensitivity affects the perception of general environmental quality. The authors concluded that noise sensitivity is more specific, and therefore a reliable predictor of responses to noise rather than a predictor of the way in which people perceive the environmental quality in their residential area as a whole.

Schreckenberg also authored a paper on aircraft noise annoyance (2012) and residents' acceptance and use of sound proof windows and ventilation systems. Residents of Raunheim, which is a town 8km west of Frankfurt, are exposed to high levels of aircraft noise (>60 to 70 $L_{Aeq,16h}$ for easterly operations) and are included in the night protection zone and therefore the noise protection plan implemented by the airport. A telephone survey was conducted on 765 residents, covering annoyance, sleep disturbance and perceived room climate. The results indicated that sleeping with usually closed windows and active ventilators in bedrooms is associated with negative perception of indoor climate, increased aircraft noise annoyance and self-reported sleep disturbance. Schreckenberg suggested as a result, that insulation measures cannot replace operational measures to reduce aircraft noise, such as night flight limitations, optimized take-offs and landing procedures.

Van den Berg et al authored a paper (2012) on the relationship between worry and annoyance with respect to aircraft noise.

Health surveys are carried out periodically in The Netherlands by regional or local Public Health Services. Every four years the GGD (Municipal Health Service) Amsterdam sends questionnaires to a representative part of the population of Amsterdam and, separately, five other municipalities in its work area. In the most recent survey in those five municipalities a number of questions addressed the local environment and its perceived effects. One of the important issues is the effect of Amsterdam Schiphol Airport in terms of noise, air pollution and safety. 70% of the respondents stated that they lived close to the airport. Previous research from Miedema and Vos has suggested that fear is correlated to annoyance, and the aim of this study was to investigate the relationship between worry and aircraft-induced annoyance. The survey results showed a strong correlation between worry about safety or health because of the airport or passing aircraft and annoyance (from noise and odour) of aircraft. 11% of those not worried about living close to a route were highly annoyed by the sound and 1% by the odour of aircraft. For those that are highly worried these percentages are 74% and 23%. This is not a new insight: fear or worry has long been known to be an important determinant of annoyance. Men and young adults (19-34 years) were significantly less annoyed. In relation to self-reported health (symptoms), respondents with anxiety/depression complaints and those with bad health were significantly more worried. A correlation between worry from living in a busy street and noise and odour annoyance from road traffic was also found. Here less people were involved, but of those living in a busy street, approximately the same proportion was worried.

These findings concur with those from Miedema and Vos: fear or a perception of risk is an important factor in relation to noise annoyance. It is interesting that this also appears to be true for odour annoyance.

Noise from air routes and, to a lesser degree, from road traffic, causes most annoyance when compared to noise from the airport and odour from aircraft and road traffic. However, the increase in annoyance score is comparable: when the worry score increases from 4 to 8, the average annoyance score in all relations increases with two to three score points. Worry about health and safety risks is apparently related to both signals coming from the source of worry and though noise creates more annoyance, the signals have approximately the same differential effect on noise as well as odour annoyance.

Charlotte Clark from Queen Mary University of London (2014) authored a paper on the factors associated with noise sensitivity in the UK. The study used data from the 2012 National Noise Attitude Survey (NNAS 2012), and examined whether certain sub-groups of the UK population are more or less sensitive to noise. NNAS 2012 had 2,747 respondents that answered questions relating to attitudes towards environmental noise. Data relating to a range of socio-demographic, dwelling, and geographic factors was also collected. Respondents rated how sensitive they were to noise on a seven-point scale ranging from ‘not at all sensitive’ to ‘very sensitive’.

Overall, noise sensitivity was more strongly associated with socio-demographic factors than with dwelling or geographic factors. Age; gender, homeownership, children, employment status, social class, and interviewer rating of hearing problems were associated with noise sensitivity after adjustment for dwelling and geographic factors. The analyses suggest that certain sub-groups of the population may be more or less noise sensitive compared with the UK population as a whole.

Considered individually, several socio-demographic factors were significantly associated with noise sensitivity: age; gender, homeownership, children, employment status, working at home, shift work, social class, and interviewer rating of hearing problems. These factors remained associated with noise sensitivity scores, after taking other statistically significant socio-demographic, dwelling, and geographic factors into account.

The analysis also revealed that older respondents (aged mid-forties and upwards) had higher noise sensitivity scores, whilst younger respondents (aged 16-24 years) had lower noise sensitivity scores. There was also a significant gender difference in noise sensitivity, with males having lower noise sensitivity scores and females having higher noise sensitivity scores. These findings suggested that within the population, younger respondents and male respondents may be less sensitive to environmental noise exposure than older respondents and female respondents.

Interestingly, those respondents who had a mortgage on their property were found to report themselves as more noise sensitive than those people who owned their home outright. Respondents who had children less than 17 years of age living in the household had significantly lower noise sensitivity scores and respondents without children under 17 years of age in the household had significantly higher noise sensitivity scores. These findings might be explained by higher internal noise exposure within houses with children less than 17 years of age, associated with activities within the home and more residents, making respondents less sensitive to noise.

Respondents who were working full-time or who were retired had significantly lower noise sensitivity scores. This may reflect the fact that respondents who work full-time probably spend less time at home compared to the general population. It is unclear why retired respondents might be less noise sensitive. The authors suggested that it may be due to changes in the auditory system due to aging, but is more likely to be explained by other attitudes and behaviour, as the association between retirement and noise sensitivity remained after taking hearing problems into account.

There was a social gradient in noise sensitivity, with noise sensitivity being higher in respondents with a head of household with a high social class (A) and lower in respondents where the head of household had a lower social class (C2 or D). Future research could examine what other individual or situational factors might explain this social gradient. The results also suggest that hearing ability might be related to noise sensitivity:

respondents without hearing problems had significantly higher noise sensitivity and respondents with hearing problems had significantly lower noise sensitivity scores.

Bauer (2014) authored a paper on findings from the COSMA study. One aim of the EU-project COSMA (Community Oriented Solutions to Minimize aircraft noise Annoyance) was to identify commonalities of the most important non-acoustic factors contributing to aircraft noise annoyance around three different important European airports (London Heathrow, Cologne/Bonn, Stockholm Arlanda) and therewith prepare further studies aiming at updating and more differentiating the current EU dose response relationship. Therefore around 1,200 residents were interviewed by telephone, and 50 residents at each airport were supervised for four consecutive days including continuous sound pressure level recordings and hourly annoyance ratings. The results show that working on other, mostly non-acoustic, influential factors possibly carry a higher potential to reduce aircraft noise annoyance in the medium term than acoustic factors are able to do due to long-term technical implementation times. This is consistent with the findings of the SoNA 2014 study.

In the COSMA study the following influences increased long-term annoyance around the study airports:

- annoyance at night or in early/late hours of the day
- disturbed mental work or relaxation
- noise felt as a health hazard
- coping measures necessary
- personal noise sensitivity

The following influences reduced long-term annoyance around the study airports:

- feeling fairly treated by airport authorities
- belief in getting used to aircraft noise in the future
- belief that the airport is economically important
- satisfaction with noise insulation
- satisfaction with residential area

Bauer explains that in the case of Cologne/Bonn airport, when these non-acoustical variables were included more than 55% of the variance for noise annoyance ratings was accounted for, and thus they are important factors that need to be included when attempting to determine aircraft noise-related annoyance. Increased communication and transparency between airports and residents is clearly an important step in helping to address attitudes towards aircraft noise, and could be assisted by external mediation experts that have a thorough knowledge of noise and associated factors.

The paper discusses the ranking of importance of these non-acoustical factors, and the possibility that they may differ from airport to airport. The COSMA study airports indicate that there are some that presumably matter at every airport. Based on these results, the author recommends that future studies at selected cluster airports should start concentrating on understanding the underlying effects of annoyance reactions at night or in early/late hours of the day, residents' attitude towards possible health effects and examinations about their satisfaction with the installed noise insulation. Is it, for example, important to guarantee for day and night in at least one room each of the airport residents' homes that they always can retire from aircraft noise if they wish to?

These are interesting findings, as although there may be a geographical and cultural bias when assessing aircraft noise-induced annoyance in the UK, these factors are all relevant and should probably be considered in future design of questionnaires and field studies.

Babisch et al (2013) examined whether noise annoyance is a modifier of the association between noise level and cardiovascular health. Effect modification is a biological phenomenon in which the exposure has a different impact in different circumstances. Different models were used to either, include the noise level and noise annoyance variables separately, simultaneously, or together with an interaction term referring to the same noise source for the noise level and the noise annoyance for hypertension data obtained during the HYENA study.

The results suggested that the noise level (objective exposure) as well as the noise annoyance (subjective exposure) may serve as explanatory variables for the assessment of cardiovascular diseases due to chronic noise exposure. There was some indication from the HYENA study that the noise level might have a stronger predictive meaning for the relationship between noise exposure and hypertension than the reported noise annoyance. However, no general conclusion can be drawn as to whether one of the two exposures (noise level and noise annoyance) is a "better" predictor of cardiovascular risk than the other.

Regarding effect modification, the results of the HYENA study support the findings from a Swedish cohort study showing that subjects that are more annoyed by aircraft noise are at a higher risk of hypertension with increasing exposure to aircraft noise (level).

At the 2017 ICBEN Congress, an emerging theme was to attempt to separate out the non-acoustic factors that contribute to the annoyance response. Schreckenberg et al authored a paper on the development of a Multiple Item Annoyance Scale (MIAS). The aim was to incorporate the different dimensions to the annoyance response in terms of a multiple item annoyance scale. Data from the NORAH Work Package 1 was used, which looked at annoyance and quality of life across four airports. Factor analysis[5] was used to separate out those variables which are responsible for the most variance within the annoyance response. For this study, different models were examined, with the best one being the one that included the two factors, Factor 1 (F1): 'Experience of aircraft-related Disturbances' and Factor 2 (F2) 'Lack of coping ability', and correlated error terms. The second best

[5] A statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. The values of observed data are expressed as functions of a number of possible causes in order to find which are the most important.

model was this one with the addition of the ICBEN annoyance item. Table1 shows the 21 variables included in the measurement of aircraft noise-induced annoyance.

Experience of aircraft noise-related disturbances	**Affective evaluation, attitudes**	**Perception of loss in control, lack in coping capacity**
In the last 12 months aircraft noise has disturbed … I-1. during communication, when using the phone at home I-2. when listening to the radio and watching TV I-3. when reading and concentrating I-4. when having visitors at home I-5. when staying and/or recovering outdoors I-6. when falling asleep I-7. during the night I-8. when awakening (1) not at all, (2) slightly, (3) moderately, (4) very, (5) extremely	I-9. ICBEN 5-point aircraft noise annoyance Expectations concerning impact of air traffic on residential quality of life: *Response scale: agree (1) not, (2) a little bit, (3) moderately, (4) rather, (5) very* I-10. The air traffic leads to fall in value of residence and properties I-11. The air traffic spoils residents' outdoor stay in the garden, on the terrace or on the balcony. Attributes of air traffic: *Response scale: agree (1) not, (2) a little bit, (3) moderately, (4) rather, (5) very* Air traffic is … I-12. useful I-13. dangerous for me I-14. comfortable for users I-15. environmental harmful	Perceived capability to cope with noise: *Response scale: agree (1) not, (2) a little bit, (3) moderately, (4) rather, (5) very* I-16. I know that I can protect myself quite well against noise. I-17. If it is too loud outside, I simply close the windows, and then I am no longer disturbed. I-18. Sometimes, I really feel at the mercy of the noise. I-19. If it is very loud, I just mentally switch off. I-20. I do not hear the noise anymore. I-21. I have accepted the fact that the noise is here.

Table 1: Initial list of 21 items for the assessment of aircraft noise annoyance

The statistical tests indicated a good model fit for both models (MIAS with two factors and MIAS with two factors plus the ICBEN scale) at each airport studied, indicating adequate construct validity beyond the initial Frankfurt sample.

Correlations of the MIAS, ICBEN 5-point scale, F1 and F2 separately with indicators of aircraft noise exposure, and non-acoustic factors showed that the MIAS and ICBEN scale produced very similar correlation results, with the ICBEN scale being slightly higher in most cases. In terms of the aircraft noise exposure indicators ($L_{Aeq,06\text{-}22h}$, $L_{Aeq,22\text{-}06h}$, $L_{Aeq,24h}$ and L_{den}), the highest correlation coefficients were seen for F1 ‘disturbances’ and the lowest were for F2 ‘lack of coping capability’. The ICBEN indicator correlates slightly higher than MIAS for the aircraft sound level indicators, and MIAS is slightly higher correlated than ICBEN with the non-acoustic factors including degrees of sleep disturbance, trust in authorities, noise sensitivity, views that air traffic is useful/dangerous/environmentally harmful etc.

The results indicated that F1 ‘disturbances’ correlated higher with sleep, with the judgement that air traffic is dangerous, and with physical health related quality of life than F2. The F2 ‘coping ability’ correlated higher with other judgements and expectations concerning the impact of air traffic, mental HQol and noise sensitivity than F1.

Schreckenberg recommended that F1 and F2 should be calculated before summarising these scores together with the ICBEN annoyance item to MIAS. Statistically, a higher order factor of annoyance consisting of F1 and F2 would already be a reliable and valid parsimonious[6] construct. However to continue the internationally standardised assessment of noise annoyance, the inclusion of the single annoyance item suggested by ICBEN is still recommended by the authors. In addition, the ICBEN 5-point scale was found to be an assessment of noise annoyance with good criterion validity, and the correlations with acoustical and non-acoustical factors are of expected size and quite similar to those of MIAS.

The advantages of using a MIAS include:

- It helps to understand the interrelations between different noise effects and therefore might be more effective in the assessment of the impact of noise-related interventions.
- Using multiple items to assess annoyance means response bias is reduced and different causes of different components of annoyance are more explicit.

The limitations to this study include:

- The questionnaires were not specifically developed for the purpose of the study; this was an ad hoc analysis of pre-existing data from the NORAH study.
- No emotion-related item concerning aircraft noise was assessed – the ICBEN item was used as its own proxy for affective reaction.
- The ICBEN 11-point scale was not used, and it is not certain how this would fit in to the factorial structure of MIAS.
- This study was aircraft-noise specific. Whether it could also be generalised to other noise sources has not been tested.
- The items referring to F2 were non-source specific and should be related to the specific noise source of interest.

Marquis-Favre and Gille (2017) authored a paper at ICBEN 2017 on how to test noise annoyance models based on psychoacoustic indices using socio-acoustic survey data. The models used were proposed by Gille et al and were based on noise sensitivity and psychoacoustic indices for aircraft noise studied in laboratory conditions. The psychoacoustic indices account for annoying auditory sensations such as sensations due to tonal components and amplitude fluctuations present in aircraft flyover noise.

This paper describes a methodology that is proposed in order to estimate values of psychoacoustic indices. The methodology is assessed using data collected during a French socio-acoustic survey carried out in 2012. The database is constituted of noise annoyance and noise sensitivity responses as well as Lden values for each respondent.

A methodology proposed to estimate the psychoacoustic index values at respondents' dwellings is presented. Then, the methodology is assessed comparing in situ measured

[6] A model that accomplishes a desired level of explanation or prediction with as few predictor variables as possible.

annoyance and annoyance predicted from model using the estimated psychoacoustic index values.

The results suggested that a model based on psychoacoustic index and noise sensitivity enabled better prediction of measured noise annoyance responses than the L_{den} index alone did. Results also highlighted that the methodology proposed to approximate psychoacoustic index values for each survey respondent allowed further enhancement of models for a better prediction of noise annoyance felt by inhabitants. More work in this area is required to eliminate approximations and gain more accurate results, but it is possible that consideration of psychoacoustic factors will enable in situ annoyance responses to be better understood and therefore predicted in future.

Also at the ICBEN 2017 Congress, Dirk Shreckenberg presented work on attitudes towards authorities and aircraft noise annoyance, with sensitivity analyses on the relationship between non-acoustical factors and annoyance.

The study used survey data from the three waves of the NORAH study, in 2011 prior to the opening of the new runway at Frankfurt airport ,in 2012 and 2013 (one and two years after the runway opening, respectively). In order to clarify the potential of non-acoustical factors to reduce annoyance, sensitivity analyses of attitudinal and annoyance data from the NORAH study were carried out. Considerable differences in exposure-response curves for aircraft noise annoyance were found depending on 'trust in authorities', ‘perceived procedural fairness’ and 'expectations regarding the air traffic's impacts'. The aim of this study was to explore the causal direction of noise annoyance and ‘trust in authorities’ as an indicator of people’s attitudes towards authorities.

Within the questionnaire, aircraft noise annoyance was measured on the ICBEN 5-point scale, “trust in authorities” was measured as an indicator of attitudes towards the aviation community and authorities, residents' belief about authorities' efforts for reducing the aircraft noise annoyance in communities around the airport was measured using a 5-point scale (endeavours (1) not at all – (5) very). The perceived fairness of the decision process regarding the air traffic operations and noise management at Frankfurt Airport was assessed only in the first survey wave (2011). A summarised mean score of 'perceived procedural fairness' was calculated from responses on a 5-point scale (agree (1) not – (5) very) to the following four items: (1) I think that aircraft noise is distributed fairly amongst all residents; (2) When decisions concerning aircraft noise are being made, I have opportunities to express my views to the relevant people; (3) I have the chance to appeal decisions that I consider to be wrong; (4) Decisions concerning aircraft noise are explained and justified to me in detail. The variable 'Positive expectations concerning the impact of air traffic on the regional development and the residential life' was assessed by a mean score of the following items on a 5-point scale (agree (1) not – (5) very): (1) The airport improves the regional development; (2) The air traffic leads to fall in value of residence and properties; (3) The air traffic brings new jobs to the region; (4) The air traffic spoils residents' outdoor stay in the garden, on the terrace or on the balcony.

Figures 20- 22 display the percentage of people highly annoyed by aircraft noise (%HA) in 2013 by $L_{Aeq,24h}$, and by discrete values of attitudes assessed previously such as trust in authorities, perceived procedural fairness and positive expectations of the impact of air traffic.

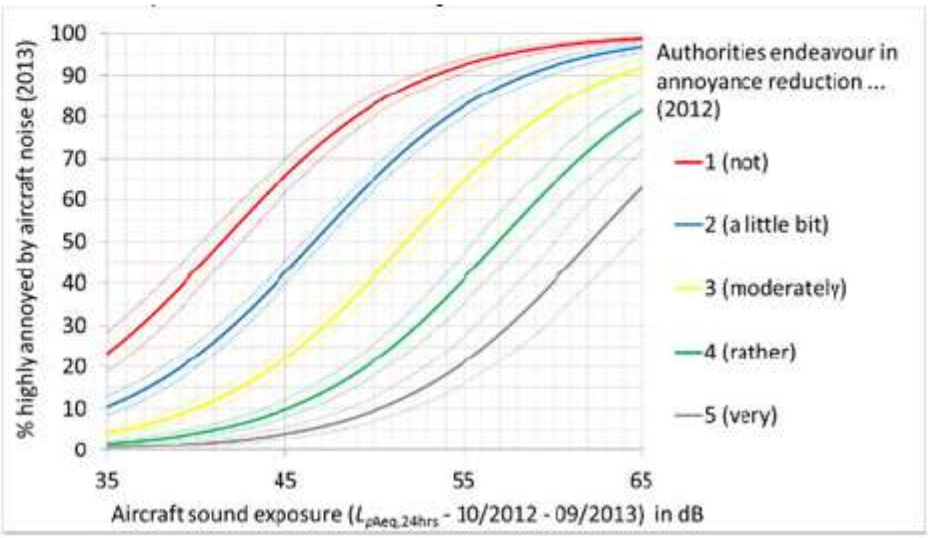

Figure 20: Percentage Highly Annoyed by Aircraft Noise and 'Trust in Authorities' (2012)

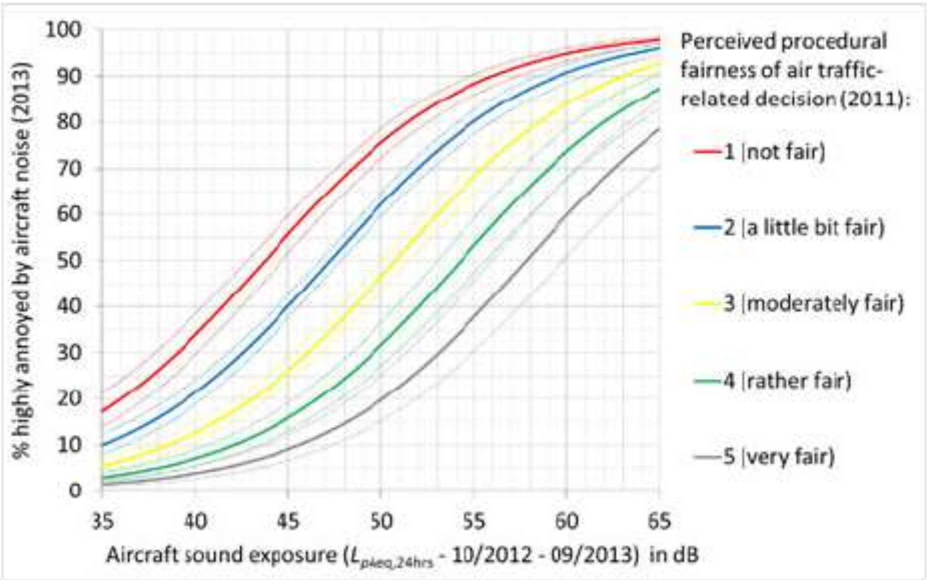

Figure 21: Percentage Highly Annoyed by Aircraft Noise and 'Perceived Procedural Fairness of decisions relating to air traffic and noise management' (2011)

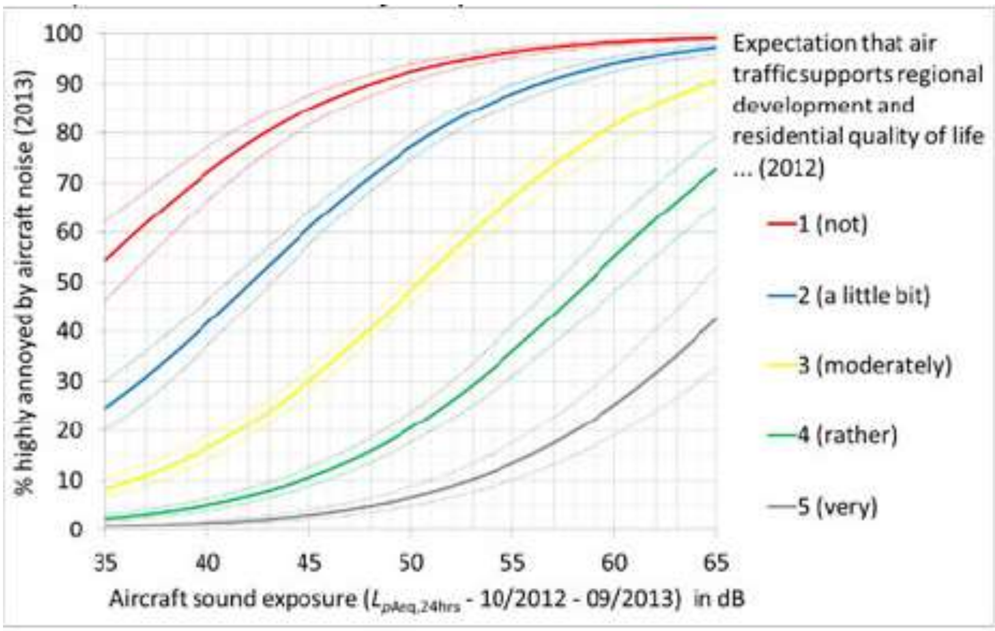

Figure 22: Percentage Highly Annoyed by Aircraft Noise and expectations of air traffic on regional development and residential quality of life. (2012)

Taking the example of 'trust in authorities', different hypothesised causal directions between annoyance and attitudes ('trust in authorities' contributes to the prediction of annoyance and vice versa) were analysed using longitudinal data of the NORAH study. The relationship between trust and annoyance seems to be reciprocal with changing strength of one of the two causal directions depending on whether there is a change in noise exposure (e.g. airport expansion) or not. The relationships are complex in nature and it is suggested by the authors that in future noise abatement projects the attitudes related to the source or to authorities should be considered in addition to the acoustical and operational measures. The impact of such a noise management on exposed people should then be evaluated in intervention studies in order to get a better understanding of noise effects and of how to minimise noise effects.

Non-acoustic factors are an important consideration when undertaking research on aircraft noise-induced annoyance, and indeed other sources of environmental noise. There is an emerging drive to separate out the relative contribution of non-acoustic factors to the annoyance response and address the importance of understanding the complexities of the relationships between such factors and annoyance.

Chapter 6

Summary and Conclusions

This report has provided an overview of the background to, methodologies surrounding and recent research into aircraft noise-induced annoyance. Several themes have emerged in the literature, and can be summarised as:

- Briefly, there has been a change in annoyance responses; people are more highly annoyed now by aircraft noise than 30 years ago, but it is important to take into account confounding factors.
- With regard to annoyance changing over time, there remain questions around whether this is due to survey methods and/or non-acoustic factors rather than a shift in attitudes towards aircraft noise.
- The NORAH Study has utilised a natural opportunity for the exploration of annoyance responses following the opening of a new runway, and implementation of a night curfew, and found that annoyance responses were particularly strong for lower noise levels (below 55 dB $L_{Aeq,24h}$); for those people experiencing an increase in noise levels in the year following the opening of the runway, and for the first year after opening compared to the following year, which saw a decrease in annoyance and levelling-out effect.
- The examination of ‘high rate of change’ (HRC) and ‘low rate of change’ (LRC) airports revealed that residents around LRC airports are able to tolerate 7-10 dB higher noise levels than the suggested EU curve, and in terms of Community Tolerance Level (CTL). Those people living around HRC airports exhibit a lower Community Tolerance Level (CTL) level, and were more annoyed by approximately 5 dB on the EU curve.
- There is the potential for longitudinal studies in order to obtain a clear timeline of attitudes over time in the UK. This could be possible with repetition of the SoNA Study.
- Several attempts are being made at trying to explain the variance within the annoyance response, using modelling to calculate the weight of non-acoustic factors. This is important work, and should lead to improved methodologies for annoyance studies, and a greater insight into the annoyance response characteristics.
- A question remains around annoyance at night. It is very difficult to separate the sleep disturbance response from the annoyance response at night and it could be questioned as to whether this even matters to some extent?
- It is recommended that the inclusion of questions on trust in authorities and perceived fairness in air traffic related decisions should be included in future surveys, given the importance of these aspects to the annoyance response.

Chapter 7
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