Environmental Research Consultancy Department

Aircraft Noise and Health Effects – a six monthly update

CAP 2257

Published by the Civil Aviation Authority, 2021

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Beehive Ring Road,

Crawley,

West Sussex

RH6 0YR

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Contents

Chapter 1
Introduction

1.1 This report is an update on recent work and findings in the field of aircraft noise and health effects. It covers published research from March – September 2021. There were two relevant acoustics Congresses held during this period, the first being the International Commission on the Biological Effects of Noise (ICEBN) which was held as an online conference in June. The second was Internoise, held as an E-Conference in August. The report will provide an overview of the most relevant findings that were presented at these conferences, and any other recently published work on aircraft noise and health effects.

1.2 The aim of the report is to provide a succinct overview of new work relating to aviation noise and health, and such updates are published on a six-monthly basis. This report has been published to provide the public and the aviation industry with a concise and accessible update on recent noise and health developments. It should be noted that the CAA has not validated any of the analysis reported at the conferences, nor takes any view on their applicability to UK policy making. The authors would like to thank Bernard Berry (Bel acoustics) for his valued contribution to the source material.

Chapter 2
ICBEN Findings

2.1 The following research findings were presented at the ICBEN Congress, held in June 2021. They are presented in this chapter according to subject area.

Aircraft Noise and Annoyance

2.2 Charlotte Clark et al authored a paper on the revision of ISO/TS 15666: 2003 ‘Acoustics — Assessment of noise annoyance by means of social and socio-acoustic surveys’, often referred to as the noise annoyance standard. This Technical Standard (TS) was developed in 1993 by the Community response to Noise team from ICBEN, to formalise a methodology for the assessment of annoyance due to noise exposure. This includes development of questions, response scales and techniques for conducting and reporting the survey questions. The International Standards Organization (ISO) published the Technical Standard in 2003, and it has since been used internationally to measure exposure-response relationships between noise exposure and annoyance. Given the publication of this was nearly 20 years ago, this paper examines the ongoing work to update and revise the Standard and highlight any research gaps that would assist in consolidation of the methodology of noise annoyance assessment.

2.3 The ISO/TS 5-point verbal and 11-point numeric scales have allowed for comparisons of survey results globally, regardless of location or language barriers and have allowed for transparent interpretation of results. They have been suitable for face-to-face, telephone or self-completion of the questions and their resulting data have been relied on by policymakers and governments to inform policy on noise levels, annoyance and mitigation strategies.

2.4 The paper states: “The discussion presented in this paper has been undertaken by an international team convened by the United Kingdom, as a work item within ISO TC43/SC1/WG62 entitled “Revision of ISO/TS 15666 – Assessment of noise annoyance by means of social and socio-acoustic surveys”. The team was tasked with revising the Standard between 2017-2021.” The updated ISO/TS 15666:2021 was published in early summer 2021.

2.5 During a review of the literature as part of the updating process, the authors found that the questions are often adapted for use, which does not necessarily reflect what they were designed to represent. For example, use in settings outside the home, and including a “did not hear” option as a possible response, resulting in the exclusion of respondents from subsequent questions. Other adaptations included changes to how the questions were asked or presented, and not providing the checklist of reporting requirements that are included as part of the Standard. Some surveys only use one of the questions instead of the intended two, which when used together provide psychometrical robustness, and increased reliability of assessment.

2.6 The updated 2021 Standard has relaxed this requirement and allows for single use of the questions within surveys. It now includes a discussion of the advantages and disadvantages of using one question over the other and enables researchers to decide based upon their own research requirements. The Standard recommends that the 11-point numeric scale should be used if having to decide on one of the questions, as this affords the greatest options for statistical testing and comparisons with other studies.

2.7 ISO/TS 15666:2021 clarifies the assumption that the question is designed to address annoyance over the whole 24-hour period during the last 12 months or so. This refers to annoyance over the daytime, evening, and night-time periods in locations in and around the home including external areas such as the garden or balcony.

2.8 In the review of studies by the authors, it was found the reporting of the scoring for 'highly annoyed' is not always clear (for example when using a weighing to allow for comparison between the annoyance scales). The 2021 TS sets out to standardise the scoring and reporting terminology for 'highly annoyed' to allow for meaningful comparisons between studies. The following scoring and naming for the method is advised in the new Standard:

- **numerical** values 8, 9, and 10 for the 11-point numeric question – to be referred to as 'HAN';
- the top two **verbal** response categories for the 5-point verbal question (i.e., very and extremely) – to be referred to as 'HAV';
- the top two verbal response categories for the 5-point verbal question, weighted with 'extremely' counted in full, and 'very' weighted by a factor 0.4 – to be referred to as 'HAVW'.

2.9 It is reminded that the ordering of the 5-point verbal scale should remain consistent with the 2003 TS i.e. the order should be from 'not at all' to 'extremely'. In terms of future revisions of the Standard, it is advised that the following areas are examined in more detail:

- The assumption that participants are recalling their annoyance over the past 12 months or so. It is possible that respondents are actually recalling a shorter, more recent period of time over which to base their annoyance responses on.

- The assumptions that respondents are considering their home as a whole environment and integrating their annoyance experience as such. It is possible they may be focussing on the area of the home which is worst affected by noise rather than the whole home environment.
- The assumption that participants are rating their noise annoyance for the home over a 24-hour period. It is suggested that further studies comparing data on annoyance for different times of the day to the standard noise reaction questions would be helpful.

2.10 Due to the importance of non-acoustic factors, there is a consensus within the annoyance field to develop a standardised assessment survey addressing non-acoustic factors to enable easier comparisons across survey. This is currently being undertaken as part of a separate work item, led by the UK, within ISO TC43/SC1/WG62 by a different ISO Working Group.

2.11 Kuhlman et al reported on a study into how aircraft noise management can improve residents' quality of life. The EU project Aviation Noise Impact Management through Novel Approaches (ANIMA) aims to develop new methods for the reduction of aircraft noise and improve the quality of life (QoL) of residents living near to airports.

2.12 This study investigated the aspects of noise management that improve people's QoL, using implementations that already exist. Four different European Airport regions Schiphol Airport, Frankfurt Airport (consultation procedure), Marseille Airport (sound insulation), Heathrow Airport (sound insulation) were chosen to investigate the impact of different interventions, such as sound insulation schemes and a dialogue forum, on residents' QoL. In addition, focus groups and in-depth interviews were carried out at three airport locations.

2.13 Although it was intended to perform quantitative surveys at the four locations, due to Covid-19 the study design had to be adjusted. The paper focusses on the qualitative study that was conducted around Frankfurt Airport and on the re-analysis of existing quantitative data collected around Schiphol Airport. In 2018 an airspace change was proposed at Frankfurt to avoid densely populated areas, however a change in the flight path would cause an increase in noise for some residents. A consultation was held with the aim to engage local communities and allow them to share their concerns and ideas. There were four components of the consultation procedure: 1) public informative events, 2) a citizen group, 3) a group with political stakeholders, and 4) a website.

2.14 The consultation process was assessed by ANIMA using in-depth telephone interviews for 27 residents in 2020. The aim was to: "gain a better understanding of QoL aspects that are relevant for people living near Frankfurt Airport, to shed light on residents' perception of the consultation procedure and identify a potential influence of the intervention on residents' QoL".

2.15 Some of the views of the residents included that the consultation was a token effort, it was not open-ended, and the decision to change the flight path had already been made, and for some there was a perceived lack of transparency. Only one third of the sample had taken part in the consultation process. This is a small sample size, and the ANIMA assessment only explored the qualitive aspects of the consultation process. The authors stress that further research into consultations such as these are needed for any conclusions to be made.

2.16 The study also further examined data from a survey conducted around Schiphol airport. The survey covered topics such as residential satisfaction, aircraft noise annoyance and asked about residents' concerns regarding different topics such as pollution and noise annoyance. To examine the effects of aircraft noise exposure, the following study areas were selected:

1. Inner area (>58 dB L_{den}),
2. Outer area (48 dB – 57 dB L_{den}),
3. Area outside noise contour (< 48 dB L_{den}).

2.17 The telephone survey sample consisted of 1,216 participants (>18 years of age). The response rate was approximately 14%. The following variables were assessed: age, sex, duration of residence (years: 0-5, 5-10, 10-20, 20-30, >30), residential satisfaction (5-point scale: 1 = very satisfied to 5 = very unsatisfied), sleep disturbance and noise annoyance caused by different noise sources (11-pt scale: 0 = not at all to 10 = extremely), comparison between previous and current experience of aircraft noise annoyance (3-point scale: 1 = increased, 2 = stayed the same, and 3 = decreased), expectations regarding future aircraft noise annoyance (3-pt scale: 1 = have increased, 2 = have remained the same, 3 = have decreased), how often aircraft noise disturbances occurred in the past month (4-pt scale: 1 = often to 4 = seldom or never), and worries concerning various topics (3-pt scale: 1 = a lot of worries to 3 = no worries).

2.18 Participants were also asked whether there were specific days or a time of a day when they experience the most annoyance due to aircraft noise. If participants mentioned specific days or times of a day, three follow-up questions were presented asking about this in more detail (n=749).

2.19 In summary, the findings indicated that participants experienced the highest annoyance due to aircraft noise compared to other noise sources, however, the degree of annoyance was relatively low with a mean of 4.52 (SD=3.35). The follow-up questions assessing certain days and times of a day, revealed that participants experienced aircraft noise annoyance especially on the weekend (18.6%) compared to weekdays (13.4%). For 19.5%, aircraft noise annoyance occurred especially around noon. Residential satisfaction was negatively correlated with the frequency of disturbances due to aircraft noise during the past month ($r=-0.20$, $p<0.01$), the comparison between past and current aircraft noise annoyance ($r=-0.08$, $p<0.05$), as well with future expectations concerning aircraft noise annoyance ($r=-0.10$, $p<0.01$).

2.20 Participants from the high exposure group reported a higher degree of aircraft noise annoyance, more aircraft noise-related disturbances, as well as a negative development regarding the experience of aircraft noise annoyance (i.e. a higher current noise annoyance compared to the past), and a more negative view on their future aircraft noise annoyance. This group also experienced significantly less sleep disturbances from neighbourhood and railway noise and more sleep disturbances induced by aircraft noise.

2.21 Schäffer et al presented work on the association between 'residential green' and road, railway, and aircraft noise annoyance. Residential green refers to the "greenness" of residential areas, visible vegetation, or the presence of functional green spaces such as urban parks. Previous studies have mostly looked at road noise annoyance, and it was the aim of this study to examine the effects of residential green on other transportation noise sources.

2.22 Data from the Swiss SiRENE study on annoyance due to road, railway, and aircraft noise was analysed with the addition of residential green data. The findings indicated that increasing residential green was associated with reduced road traffic and railway noise annoyance of a magnitude of ~6 dB L_{den} for road traffic noise and ~3 dB L_{den} for railway noise when comparing situations with "not much green", corresponding to the 5th percentile of the study sample distribution, to "a lot of green" corresponding to the 95th percentile. In contrast, aircraft noise annoyance was found to strongly increase with increasing residential green to an equivalent level increase of ~10 dB L_{den}. This was an unexpected result, and the authors recommend further study to try and understand this finding.

2.23 The report explains the findings further. The effects of visible vegetation from home and accessibility and/or quietness of green spaces were found to be less strong overall but showed interesting interactions with the degree of urbanisation regarding their effect on noise annoyance. For road traffic noise, visible vegetation and accessibility of green spaces seem to be particularly important in urban areas, while quiet green spaces are more effective in rural areas. For aircraft noise, in contrast, the degree of urbanisation was the most noticeable modifier in the association between quiet green or visible vegetation from home and (increased) noise annoyance, with stronger effects in urban areas.

2.24 The authors suggest that noise abatement planning should not solely rely on noise exposure, but it is of importance to protect and expand residential green areas also, particularly in densely populated areas.

Aircraft Noise and Cardiovascular Disease

2.25 Evrard et al presented an overview of the French DEBATS study on the health effects of aircraft noise. Over 1,200 participants living around Paris-Charles-de-Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac airports were interviewed in a face-to-face questionnaire study in 2013. The study comprised three methodological elements: an ecological study, a longitudinal study, and an ancillary sleep study.

2.26 The ecological study investigated aircraft noise and mortality from causes such as cardiovascular disease in general, ischemic heart disease, including myocardial infarction, and stroke, using mortality data from the French Centre on Medical Causes of Death.

2.27 The longitudinal study aimed to examine the relationship between aircraft noise and the mental and physical health of residents, including annoyance through the face-to-face interviews at residents' homes. The first dataset was collected in 2013, with follow-up studies in 2015 and 2017. The annoyance response was measured using the ICBEN five-point verbal scale. Self-rated health status was assessed, and the effects of sleep were measured using total sleep time and feelings of tiredness on waking. Salivary cortisol was collected first thing in the morning and just before bedtime and blood pressure was assessed by the interviewer. Psychological distress was assessed using the General Health Questionnaire.

2.28 The ancillary sleep study used a subset of 112 participants from the longitudinal study, and measured actimetry and heart rate. Aircraft noise levels were measured inside and outside of the bedrooms for seven days and seven nights.

2.29 The results of the ecological study indicated that an increase in aircraft noise exposure of 10 dBA was associated with an 18% higher risk of mortality for all cardiovascular diseases, 24% for ischemic heart disease, and 28% for myocardial infarction. There was no association found with stroke mortality.

2.30 After controlling for confounding factors and restricting the analysis to participants that were living at the same address for five years prior to the study, the results remained unchanged.

2.31 The longitudinal study suggested the following associations:

- A 55% increased risk of fair/poor self-rated health status in men with an increase in noise level of 10 dBA L_{den}, with no evidence of an increase in women.
- The number of Highly Annoyed (HA) is higher than that predicted by the old EU Miedema curve but lower than predicted by the new EU curve provided by the World Health Organization, in March 2020. (This is consistent with the UK SoNA 2014 findings).

- A risk of sleeping less than six hours per night increased by 60%, and a risk of feeling tired in the morning when waking up increased by 20%, with an increase in noise level of 10 dBA L_{night}.
- A disruption of the circadian rhythm of cortisol with an increase in noise level of 10 dBA L_{den} (15% decrease in the absolute hourly variation of cortisol, 16% increase in the level of cortisol at bedtime, but no significant variation at wake-up).
- A 34% increased risk of hypertension in men with an increase in noise level of 10 dBA L_{night}, with no evidence of an increase in women.
- Exposure to aircraft noise did not appear to be directly associated with psychological distress. However, aircraft noise annoyance was associated with it: compared to participants who were not highly annoyed, the risk of psychological distress was increased by 80% in participants slightly annoyed by aircraft noise, and multiplied by 4 in those who declared being highly annoyed.

2.32 The ancillary sleep study suggested the following alterations to sleep parameters:

- An increase in aircraft noise levels during sleep period in terms of integrated indicators or noise events indicators was associated with a 1.1-1.8-fold increase in the probability of sleeping less than six hours per night (short sleep); and a 1.1-1.6-fold increase in the probability of spending more than nine hours in bed (which can be interpreted as an adaptation mechanism to sleep deprivation).
- An increase in aircraft noise levels during sleep period in terms of integrated indicators was associated with a 1.1-1.3 times higher probability of sleep onset insomnia (i.e. a sleep latency greater than 30 minutes).
- An increase in aircraft noise levels during sleep period in terms of noise events indicators was associated with a probability of sleep-maintenance insomnia.
- A 10 dBA increase in the maximum L_{ASmax} noise level of an event associated with the passage of an aircraft was associated with an increase in the amplitude of the heart rate during this event (0.34 beats per minute).

2.33 The authors concluded that these findings support the hypothesis that noise is a stressor that activates the sympathetic and endocrine system. They explain that methodological differences in the assessment of highly annoyed people could be the reason why studies conducted since the 2000s found, for the same noise exposure level, higher proportions of highly annoyed people than those observed in the studies conducted before 2000.

2.34 Giorgis-Allemand et al presented the findings from the cortisol part of the longitudinal study in more detail. A total of 1,115 participants living near the three airports responded in 2013, 2015 and 2017 to detailed face-to-face interviews and two saliva samples were collected in each case, one after awakening and one before going to sleep. For each participant and follow-up, morning salivary cortisol concentration, evening salivary cortisol concentration and diurnal slope (the difference between the evening and morning concentrations divided by the time between the two samples) were estimated.

2.35 The results indicated that an increase of 10 dBA L_{den} was associated with a decrease in the diurnal slope of cortisol, higher evening cortisol levels and decreased morning levels. The authors suggest that the flattening of the diurnal cortisol rhythm across the day may indicate a disruption to the hypothalamus-pituitary-adrenal axis regulation. This confirms previous findings from the HYENA study and the 2013 DEBATS study, which also show disruption to cortisol levels with exposure to aircraft noise.

2.36 Kourieh et al presented the findings on the hypertension element to the DEBATS study in more detail. Systolic and diastolic blood pressure, and demographic and lifestyle risk factors were collected at baseline (2013) and after two and four years during face-to-face interviews. Those participants who were hypertensive in the first phase in 2013 were excluded from the subsequent analyses, and those respondents who were considered hypertensive in 2015 were excluded from the 2017 analyses. This was because the aim was to assess the incidence of hypertension, which was defined as being classed as hypertensive for the first time during the study.

2.37 The prevalence of hypertension was estimated to 35%, 36% and 38% at 2013, 2015 and 2017, respectively. A total of 80 (8%) and 47 (6%) incident cases of hypertension were identified at two and four years following the baseline, respectively. A 10 dBA L_{den} increase in aircraft noise levels was significantly associated with a higher incidence of hypertension. The association for night-time noise exposure (L_{night}) was at the borderline of statistical significance. A significantly higher incidence of hypertension was also observed with each 10 dBA increase in 24-hour noise exposure ($L_{Aeq,24h}$) and daytime noise exposure ($L_{Aeq,T}$ where T=16 hours, for the period 06:00-22:00). A statistically significant increase in systolic and diastolic BP was also found for a 10 dBA increase in aircraft noise exposure for all the four indicators.

2.38 127 incident cases of hypertension (80 in 2015 and 47 at 2017) were identified over a four-year period. The results indicated that increasing levels of aircraft noise exposure were associated with a higher incidence of hypertension, with a similar relationship found for systolic and diastolic blood pressure. The results confirm those from the cross-sectional analysis from the DEBATS baseline observations in 2013, described above, where a significant relationship was found between aircraft noise and the risk of hypertension among men.

Aircraft Noise and Sleep Disturbance

2.39 Giorgis-Allemand et al also reported findings from the sleep study part of the DEBATS longitudinal study in more detail; in particular self-reported sleep quality and aircraft noise over the four years of study duration. Time in bed was estimated from the questionnaires as the difference between the time of going to sleep and the time of getting up and characterised as short time in bed (≤6 hours) versus normal and long time in bed (>6 hours). For feeling tired after a normal night, participants answered a four-scale question that was rated as feeling tired (very or rather tired) versus feeling not tired (rather or well rested).

2.40 At baseline in 2013, 9% of the participants had a time in bed less or equal to 6 hours (respectively 8% at first follow-up and 6% at second follow-up) while 30% felt rather or very tired after a normal night (respectively 24% at first follow-up and 23% at second follow-up). A 10 dBA L_{den} increase in aircraft noise levels was associated with a short time in bed (Odds Ratio OR=3.13; 95% confidence interval CI: 2.14-4.56) and with feeling tired after a normal night (OR=1.28; 95% CI: 1.01-1.61).

2.41 Increased aircraft noise exposure was associated with a deterioration of the subjective sleep quality, characterised by a short time in bed and feeling tired after a normal night. The authors explain that these results confirm those of the cross-sectional analyses conducted at baseline in 2013, and support those found in a cross-sectional study around Schiphol airport in Amsterdam (Netherlands) that found an increased risk of tiredness when exposed to higher levels of aircraft noise.

2.42 Aasvang and Smith gave an update on sleep disturbance findings relating to a variety of sources since 2017. Studies on transportation, wind turbine, and hospital noise were included in this review. The main findings on aircraft noise and sleep disturbance were summarised. These have been described in earlier update reports. The authors discuss the future directions of noise and sleep research and explain the importance of standardisation and validation of questions on the effects of noise on sleep (in the same way the ICBEN annoyance questions are standardised), and how this helps with future research, and improves the ability to compare results between studies. They suggest encouraging the use of more standardised general sleep disturbance questions e.g. insomnia symptoms and other questions that do not ask specifically about noise as the source of sleep disturbances, as this is important for avoiding bias and for improving comparability with other risk factors for sleep disturbances.

2.43 The development of wearable sleep-recording devices has improved over recent years, which allows for much larger-scale data collection. The authors explain that such studies would continue to add knowledge on the pathophysiological[1] mechanisms linking chronic noise exposure with the development of disease. In addition, further research into the development of biomarkers for chronic sleep deprivation is worthwhile.

2.44 The paper explains that the noise landscape is changing with the addition of electric cars, drones, and super-sonic aircraft. These emerging noise sources will change the acoustical characteristics of environmental noise, including the introduction of sonic booms. The authors stress the need for future research including the aim to understand the impact this will have on the sleep of exposed populations.

2.45 Hauptvogel et al authored a paper investigating whether aircraft noise-induced awakenings are a more adequate indicator for better understanding of sleep disturbance and therefore night protection around airports. The rationale for this study was that usually, the metrics that are used to describe aircraft noise are based on the energy equivalent sound pressure level L_{eq}, or its derivatives L_{dn} or L_{den}, which respectively integrate a +10 dB penalty for only night noise or a penalty for both the evening noise (19:00-23:00, +5 dBA)) and the night noise (23:00-06:00, +10 dBA). The problem with these energy equivalent levels is that several noise events of moderate maximum levels can generate the same equivalent level as a single noise event with a very high maximum level, and these two scenarios could have different effects on sleep disturbance.

2.46 The authors explain that this could mean that these metrics are not adequately describing noise effects on sleep and therefore are not eligible for developing a nocturnal protection concept against aircraft noise. They argue that the because the body responds to every single noise event (audible overflight) during sleep, the resulting noise events should therefore be individually characterised by corresponding acoustical quantities (e.g. maximum level and/or SEL). They propose that the probabilities for additional awakenings due to single aircraft noise events must be summed up over the whole night in order to determine the additional noise-induced awakenings (a probability of 100% means one additional aircraft noise induced awakening). For a night noise protection concept, the number of additional aircraft-noise-induced awakenings must then be limited. The study, which was part of the ANIMA project, aimed to calculate and generate a standard exposure-response curve based on previous field studies, which can be generalised over different airports and be used for a night noise protection concept based on human sleep physiology.

[1] Definition of pathophysiology

: the physiology of abnormal states, specifically, the functional changes that accompany a particular syndrome or disease

2.47 Data from the two German DLR STRAIN and NORAH studies, both of which used polysomnography to examine noise-induced sleep disturbance, were reanalysed and a pooled model was developed. For both the NORAH and the STRAIN study, it was shown that the re-analysis with additional parameters led to statistically better results than the original published models.

2.48 As we age, sleep becomes shallower. Therefore, elderly people are generally easier to awake from noise events. Due to a lower number of elderly tested subjects, age was not incorporated into the models so far. The standard exposure-response model which was based on a pooled dataset of the STRAIN and NORAH study however, does not only consider the model which resulted from the selection process but also age as an influencing personal variable. The exposure-response curved derived from the standard model is depicted in Figure 1.

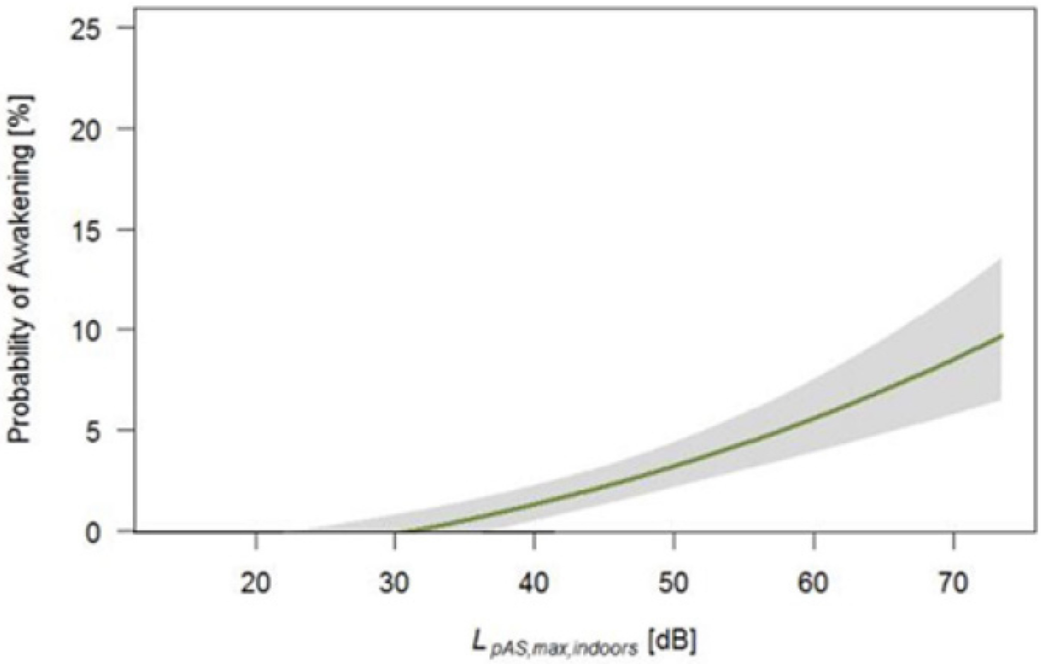

Figure 1: Probability of an awakening as a function of the maximum sound pressure level indoors of one overflight and further acoustical and non-acoustical predictors.

2.49 The authors propose to introduce a 'Virtual Community Tool', which is software using the standard exposure-response curve, that will enable calculation of additional aircraft noise induced awakenings around airports. Flight schedules, an airport database (containing ground acoustics data for all possible aircraft, on all possible flight track combinations) and a corresponding demography database and a buildings insulation quality map can be loaded onto the program. To visualise additional awakenings around the airport area, to compare the extension of critical zones defined by different metrics (e.g. L_{den} vs Awakening) or to study the effect of changes performed in the Main Window of the interface, a Results Display Window is available to users (Figure 2).

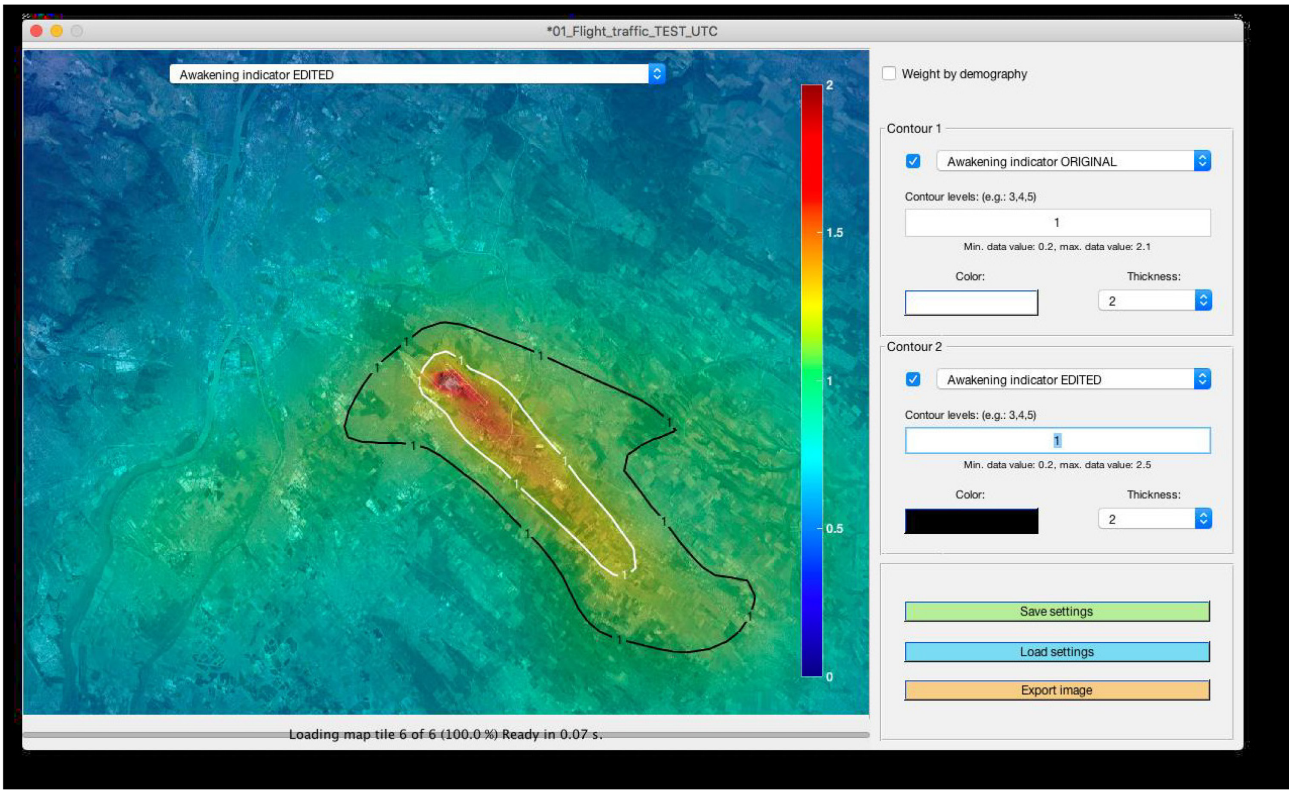

Figure 2: Results Display Window showing the increased zone boundaries of 1 additional awakening for an increase of air traffic for a hypothetic airport scenario (reproduced without permission).

2.50 The authors explain that the standard model for calculating additional aircraft noise-induced awakenings presented in the paper can be used for (1) communicating the effect of aircraft noise at night in an “easy-to-understand” metric and (2) to develop protection concepts that can prevent physiological acute-effects of aircraft noise.

Non-Acoustic Factors of Aircraft Noise

2.51 Persson Waye and van Kempen produced an overview of the non-auditory effects of noise since the last ICBEN meeting in 2017. The review focused on cardiovascular and metabolic effects, mental health, dementia, and birth outcomes.

2.52 The review process largely followed that of the WHO for their systematic reviews that formed part of the 2018 Environmental Noise Guidelines for the European Region. For mental health and dementia, meta-analyses were performed by two reviews and the most recent found that depression risk increased by 12% with an increase of 10 dB L_{den} (95% CI 1.02, 1.23) for aircraft noise. The authors suggested that the number of studies examining the relationship between noise from all sources, and mental health and dementia was very low and “better methodological quality should be strived for both with regard to outcome and exposure assessment”.

2.53 In terms of birth and reproductive outcomes there was a paucity of studies, particularly meta-analyses. The studies included in the report suggested a small increase in the risk of adverse outcomes in association with environmental noise exposure. Overall, the quality of evidence for small for gestational age babies, pre-term birth and congenital anomalies was judged to be moderate to very low or low.

2.54 For cardiovascular and metabolic outcomes, 19 reviews were included in the report. Most of the studies that were covered by these reviews reported on the impacts of road and air traffic noise exposure.

2.55 The review also included detailed descriptions of individual studies, including findings for all sources of occupational and transportation noise. In terms of the main findings from the review, the authors concluded that road traffic noise is the source that is most studied. Railway and wind turbine noise studies are still relatively scarce, but numbers are increasing.

2.56 It is suggested that there is a need for information from countries outside the European region, and for research to be conducted among younger subjects as most noise and health studies focus on the effects on adults.

2.57 The authors state that an interesting finding was that annoyance and/or noise sensitivity seemed to mediate the association between noise and mental health. They describe this as being biologically plausible as annoyance, in addition to the noise level, may reflect an individual's personal perception and reaction, and these vary between people. In addition, noise annoyance triggers negative emotions and activates stress responses in the hypothalamic-pituitary-adrenal (HPA) axis that are involved in the pathophysiology of depression. Noise sensitivity is seen as an indicator of vulnerability to noise and other stressors and has been related to as a proxy measure of anxiety. It is pointed out that this is not the case for cardiovascular and metabolic studies where no interactions between noise and annoyance or noise and noise-sensitivity were seen. An important difference is explained; it is possible that dominating pathways for how noise impacts mental health and cardiometabolic outcomes differ, with annoyance being more relevant for mental health and sleep disturbance more relevant for cardiometabolic diseases.

2.58 During the review period some studies began to investigate "new" outcomes. The authors observed that more and more studies examine outcomes such as being overweight, (central) obesity, arterial fibrillation, arrhythmia, heart failure, depression, inattention/ADHD, and dementia.

2.59 The same trend can be found with regard to early indicators of cardiovascular and/or metabolic disease. In addition to classical indicators such as blood pressure, more studies now look into other indicators that may be pre-cursors to cardiovascular disease as previously studied. For example, indicators of being overweight (e.g. change in BMI, change in waist circumference), biomarkers of cardiovascular and metabolic disease in blood, serum, saliva or urine.

2.60 Inflammatory markers and oxidative stress have also been investigated. The authors conclude that the study of new indicators are important and urgently required in order to understand the underlying mechanisms between noise and adverse health outcomes.

2.61 The authors conclude the review by stating: ‘There is a growing recognition for the need of more complex models to help us understand better how multiple and cumulative environmental exposures affect chronic disease onset, progression and outcomes at critical life stages over the life course and across generations and not in the least how we can obtain restorative living and working environments that promote resilience’.

2.62 Fenech et al presented work on the development of a new ISO Technical Specification (TS) on non-acoustic factors, with an aim to improve the interpretation of socio-acoustic surveys.

2.63 The importance of non-acoustic factors when investigating noise effects cannot be underestimated. Personal, social and situational variables are as important as acoustic features in determining the human impacts of sound. This paper described the initial stages in the development of a new ISO Technical Specification that aims to standardise the characterisation of non-acoustic factors in socio-acoustic surveys.

2.64 Non-acoustic factors are estimated to account for up to one third of the variance observed in annoyance reactions. They form an important role in both understanding the deeper reasons for annoyance, and also the opportunity for reducing the degree of health effects due to noise annoyance. These are also applicable to self-reported sleep disturbance.

2.65 Unlike for annoyance, there is currently no standardised methodology for measuring non-acoustic factors, to allow for meaningful cross-study comparisons, consistency and reliability across studies, or for enabling the consolidation of data. On behalf of the British Standards Institute (BSI), the authors were tasked with drafting an outline scope for a new International Technical Specification (ISO/TS) on non-acoustic factors.

2.66 There is considerable inconsistency across the field in terms of defining non-acoustic factors. The authors concluded that any physical acoustic quantities should not be included as non-acoustic factors. The initial proposed definition is:

> *‘All factors other than the objective, measured or modelled acoustic parameters which influence the process of perceiving, experiencing and/or understanding an acoustic environment in context, without being part of the causal chain of this process.’*

2.67 The authors explain that it is anticipated that the TS will have a specific focus on those non-acoustic factors that will help researchers understand the effects of noise and soundscape assessment in relation to health and quality of life. Therefore, the scope of this TS would cover the collection, analysis and interpretation of non-acoustic factors in all environments, both indoor and outdoor, in any context. Examples of these are given as:

- ‘Socio-acoustic surveys investigating noise annoyance and self-reported sleep disturbance at home. “Home” includes both the indoor space and any external amenity space that forms part of the dwelling (such as balconies, gardens and any shared private amenity space).
- Soundscape assessments of general living and recreational environments, including indoor and outdoor urban, suburban, peri-urban and rural areas.
- Work settings’.

2.68 The development of the new TS is still in the initial stages, but it is explained that there are two types of content that may comprise the TS once developed. These are normative and informative content, where:

Normative content could include:

- a list of non-acoustic factors that should be included as a minimum in socio-acoustic surveys;
- if consensus can be achieved, exact wording / survey instruments to measure specific non-acoustic factors;
- if consensus can be achieved, methods for data analysis and interpretation.

Informative content could include:

- additional non-acoustic factors that may be included, depending on survey/study objective;
- examples of wording to measure non-acoustic factors (when consensus cannot be reached on a single method);
- examples of methods for data analysis and interpretation.

2.69 There will also need to be agreement on the number and types of categories of non-acoustic factors. The authors include a suggested example using three categories as defined by Riedel: personal, tangible, and psychosocial. These are explained in Table 1.

Category of non-acoustic factor	**Illustrative Examples**
Personal: *strongly linked to an individual, show stability over time and situation, vary between individuals.*	Noise sensitivity; Coping capacity; Perceived control; Perceived fear.
Tangible: *properties of the specific environment.*	Access to green space; Quiet façade; Location of inhabited space(s); Visual modifiers.
Psychosocial: *shared between individuals of a community.*	Perceived fairness; Perceived community benefit/disbenefit; Attitude towards noise authorities.

Table 1: Example categories of non-acoustic factors

Chapter 3

Other Research

3.1 This chapter includes some of the most relevant findings presented at the Internoise congress, as well as other recently published journal papers relating to aircraft noise and associated health impacts.

Mental health

3.2 The first paper is authored by Gong et al and is a systematic review of the association between noise annoyance and mental health outcomes, presented at Internoise 2021. The authors conducted a meta-analysis of 12 studies between 2000 and 2021 on noise annoyance in relation to depression, anxiety, and subjective mental well-being, regardless of noise source.

3.3 The authors describe the complex relationship between noise and mental health, including the mediating effect of noise annoyance, which remains an under researched area. In this systematic review, they analysed the evidence on the relationship between a high level of noise annoyance and mental health outcomes. The main aim of the review was to examine the pooled association between high noise annoyance, and depression and anxiety. The authors also looked at annoyance and subjective mental health.

3.4 The average sample size of the 12 included studies was 6,867 (1,244 to 19,294). The participants were representative of the general population (N=6), the male population (N=1), the general population living near airports (N=1) and the general population living in multistorey houses (N=4). All studies were from European countries. A meta-analysis was performed for subsets of the studies, and pooled estimates were obtained for the associations between high annoyance, depression, anxiety, and subjective mental well-being.

3.5 Broadly speaking, the findings indicated that a high level of noise annoyance was associated with mental health outcomes in the meta analyses but with high degrees of variability. Noise annoyance was significantly associated with depressive symptoms as assessed by self-reported diagnosis or screening tool, but not with the likelihood of taking antidepressants. There was a significant pooled relationship between high noise annoyance and general anxiety disorder which was also significant in the subgroup analysis. The authors also found an association between high levels of noise annoyance and subjective mental well-being, but with high variability.

3.6 The study combined all estimates of high noise annoyance regardless of the source of the noise. The noise sources included in the meta analyses varied considerably, including traffic, commercial, and neighbourhood noise etc, but the subgroup analysis by outcome assessment had a low level of heterogeneity (variability) across studies. The authors suggest that this may mean that the actual source of noise may be a less significant cause of heterogeneity in the association between noise annoyance and mental health outcomes. Limitations to this study include a small sample size due to the small number of studies that have examined this relationship to now, and it is suggested that more research is required in order to investigate this relationship further, and for public protection.

FAA Neighbourhood Environmental Survey (NES)

3.7 A series of papers on the U.S. Federal Aviation Administration (FAA) national study on aircraft noise and annoyance, known as the Neighbourhood Environmental Survey (NES) were presented. These included an overview of the study design and methodology (Jodts et al), the noise methodology (Czech et al), which included a detailed explanation of the sampling procedure for the study, and the survey motivation and results (Doyle et al). The aim of the study was to produce an updated and nationally representative civil aircraft exposure-response curve for the relationship between annoyance and aircraft noise exposure around U.S. airport communities. The study was described in detail in the previous Noise and Health CAP report 2113.

3.8 Doyle et al provided an overview of the history of trends in aircraft noise exposure and the ways in which the FAA has worked to reduce community aircraft noise exposure through the phased transition to quieter aircraft. It is explained that since the 1970s the number of people exposed to aircraft noise levels of 65 dB DNL or above in the U.S. has dramatically reduced from over seven million to just over 400,000 today, despite the numbers of commercial aircraft having increased from approximately 200 million in 1975 to approximately 935 million in 2019. However, concerns regarding aircraft noise have increased, possibly due to the number of movements having increased despite the average noise level being reduced.

3.9 The paper describes the work currently being undertaken by the FAA to examine the health effects of aircraft noise. It is working with researchers from Boston University to leverage existing national longitudinal health cohorts wherein statistically large numbers of people provide data about their health on a periodic basis over the course of many years. The team is expanding the list of factors to include aircraft noise exposure so that it can be placed in context with other factors that could increase the risk of cardiovascular disease.

3.10 The FAA is also working with the University of Pennsylvania School of Medicine to conduct a national sleep study that will quantify the impact of aircraft noise exposure on sleep. The study will collect nationwide information on the probability of being awoken by aircraft noise exposure. Approximately 25,000 respondents will be contacted through a mail survey, which will then be used to determine the eligibility of respondents for a detailed field study with around 400 volunteers. The volunteers in the detailed field study will use equipment provided by the research team to collect both noise and electrocardiography data in their homes while they sleep.

3.11 The results of the NES suggested that substantially higher percentages of people were highly annoyed over the entire range of aircraft noise levels (from 50 to 75 dB DNL), when compared to the earlier Schultz curve. The FAA is now engaging with aviation community stakeholders to collect their feedback on the entire noise research program, including the findings from the NES. The FAA will then be initiating an evidence-based noise policy review.

Covid-19 Lockdowns

3.12 Results from two studies conducted during lockdown in different countries were presented. The first was in Vietnam, focussed around Tan Son Nhat International Airport (TSN). A survey on community responses to aircraft noise around TSN was conducted in August 2019, and two further surveys in June and September 2020, three and six months after the airport stopped operating all international flights in March 2020.

3.13 Twelve residential areas were selected, ten sites under the landing and take-off paths of the aircraft, two at the north of the airport. The ICBEN 11-point annoyance scale was used to assess annoyance due to aircraft noise, and sleep disturbance was measured by a mixture of questions relating to sleep and the Insomnia Symptom Questionnaire (ISQ). The total number of flights per day during the first, second, and third surveys were 728, 413, and 299, respectively. The range of noise levels estimated for the 12 sites around TSN decreased from 45-81 dB in 2019 to 41-76 dB in June 2020 and 41-73 dB in September 2020.

3.14 The results indicated that annoyance and insomnia were not reduced in line with the reduction of aircraft movements, but significantly increased in the survey conducted three months after the change and then returned closer to the results before the change. The authors explain that Brown and van Kamp defined an "excess response" as the state whereby the response to an increase or decrease in noise exposure results in a respective increase or decrease in the response as compared to the response in the steady-state condition; the opposite is known as "under response." It was observed that the noise reduction at TSN airport did not cause excess response, rather an "under response" that occurred with the decrease in aircraft noise exposure around TSN shortly after the change; but this increased at the third study three months later. This finding also supports the hypothesis that change effects are usually strong shortly after the step change but become less significant over time.

3.15 The results indicate that the exposure-response relationship in the third survey is lower than in the second survey. However, it stays higher than the first survey regardless of the continuous decrease of noise exposure during the pandemic.

The authors suggest that further investigation is needed to examine whether the community response in around TSN airport returns to the same as the pre-pandemic change, or whether it will remain at higher levels of annoyance.

3.16 Paunović reported the results of a pilot study on annoyance from community and neighbourhood noise during the Covid-19 lockdown in Serbia. Survey data was collected from 187 respondents online using Google Forms, between January and March 2021.

3.17 The results indicated that during the lockdown, participants perceived less noise from the major community sources, such as road traffic, air traffic, and construction work on the streets. It was observed that they perceived more noise from their neighbours, such as noise from electrical appliances and elevators inside the buildings, as well as noise from humans (music, voices, steps) and animals. In addition, respondents more often perceived “new” community sounds, such as birds, church bells, and emergency vehicles. They found the sirens of emergency vehicles and noise from their neighbours most annoying at that time. The authors conclude that the study highlights the need for the improvement of acoustic environments for all those working or studying at home under various circumstances.

Cardiovascular function

3.18 Schmidt et al published a study in the European Society of Cardiology on the impact of aircraft noise on vascular and cardiac function in relation to noise event number during a randomised trial.

3.19 The rationale for this study was that little is known about whether the commonly used average sound pressure level metrics, particularly L_{eq}, is an adequate representation of the increased risk for cardiovascular disease in response to noise, or whether other aspects of noise are equally or even more important. The authors cite the example of Quehl et al who found that in the NORAH and STRAIN dataset, sound pressure reduction of night-time aircraft noise does not necessarily lead to reduced annoyance, since annoyance correlated with the number of noise events. It has been suggested that intermittent noise exhibiting similar L_{eq} but with higher event rates may be more annoying and thus may affect cardiovascular health more adversely. The aim of this study was to investigate the differential effects of noise exposure scenarios consisting of equal average sound pressure levels but different numbers of noise events and peak sound pressure levels on vascular and myocardial function and associated annoyance.

3.20 The study included 70 participants with established cardiovascular disease or increased cardiovascular risk, who were exposed to two aircraft noise scenarios and one control scenario within their own homes. Polygraphic recordings, echocardiography, and flow-mediated dilation (FMD), which is a marker of vascular function, were determined for three study nights. The noise patterns consisted of 60 (Noise60) and 120 (Noise120) noise events, respectively, but with comparable L_{eq}, corresponding to a mean value of 45 dB.

3.21 The results indicated that sleep quality was rated worse after noise nights than after the control night. On a visual analogue scale with higher values indicating worse sleep, there was a significant increase ($p<0.001$) from 3.96 ± 2.29 (Control) to 6.65 ± 2.45 (Noise60) and 6.75 ± 2.36 (Noise 120). For FMD, the authors found a statistically significant difference between noise scenarios ($p<0.001$). FMD in the control night was 10.02 ± 3.75%, in the night with the Noise60 scenario FMD was 7.27 ± 3.21% and the Noise120 scenario resulted in an FMD of 7.21 ± 3.58%, suggesting a worsening of vascular function with increased noise. Post hoc tests showed a significant difference between the control night and both noise patterns, but no significant difference between the two noise patterns.

3.22 The authors conclude that the results confirm that L_{eq} can be used to estimate the impact of noise on exposed individuals in terms of vascular function and night-time annoyance levels. There was no difference in noise health effects, regardless whether repetitive noise events were either louder (Noise60) or more frequent (Noise120), although there was a certain dose–response relationship for number of noise events and cardiac dysfunction (E/E0 ratio – a non-invasive estimate of left atrial filling pressure to predict cardiac events). Sleep quality and FMD were significantly different between control nights without noise and both noise scenarios, but no differences could be found between the two noise scenarios. They conclude that it therefore seems that average sound pressure levels such as L_{eq} do adequately describe noise effects (during the night) in a setting were individual noise events only differ in terms of loudness and number.

Noise Abatement: Phenomena Study

3.23 The Phenomena study - Potential Health Benefits of Noise Abatement Measures in the European Union was concluded in March 2021. This was a study performed for the European Commission Directorate-General for Environment by a consortium consisting of VVA, TNO, Anotec Engineering, Tecnalia, and Autonomous University of Barcelona.

3.24 The objective of the study was to support the European Commission in defining noise abatement measures capable of delivering a 20–50 percent reduction of the health burden due to environmental noise from roads, railways, and aircraft and to assess how relevant noise-related legislation could enhance the implementation of measures, while considering the constraints and specificities of each transport mode. The project collected and analysed data from geographic areas as set by the European Noise Directive (END), for:

- roads and railways inside agglomerations of more than 100,000 inhabitants;

- major roads with more than 3 million vehicles a year;
- major railway lines with more than 30,000 trains a year; and
- major airports with more than 50,000 movements a year.

3.25 The study looked at long-term noise exposure levels above 53 dB L_{den} for roads, above 54 dB L_{den} for railways, and above 45 dB L_{den} for airports. These are the exposure levels given by WHO’s 2018 Environmental Noise Guidelines for the European Region. The study consisted of analysing a wide range of literature sources and assessing a balanced selection of member state noise abatement practices.

3.26 Overall, the study found that within the given time frame up to 2030, more than 20 percent reduction in health burden would be feasible, and this is possible only by using combined noise abatement solutions, which are driven and supported by revised and strengthened EU environmental policies, including the END, noise source directives (limits for vehicle noise emission), the European Green Deal, and other legislative measures with a strong environmental impact. It is suggested that increased emphasis should be put on the consultative participation of those national and local authorities that identify, select, and implement noise abatement measures.

3.27 As part of the study, noise abatement techniques were reviewed for the effectiveness and potential for noise reduction. For aircraft noise the main noise abatement solutions include (a) improved flight profiles, (b) precision area navigation, (c) night curfews, (d) phaseout of noisier aircraft, (e) accelerated fleet renewal, (f) sound insulation, (g) buffer zones, (h) stakeholder engagement, and (i) reception limits.

3.28 The analysis found that an effective and EU-wide reduction of noise emission, which would result in a decrease of at least 20 percent of associated health burden within the next 10 years, cannot be reached by individual scenarios but rather by a set of combined and complementary abatement measures. Figure 3 illustrates the policy options available for aircraft noise. Recommended new EU actions are shown in red.

3.29 The recommended generic policy options included the following:

- Standardisation, streamlining, and mandatory evaluation of Noise Action Plans
- Extend the scope of the END to urban planning, infrastructure planning, and land use
- Introduction of EU noise reception limits at dwellings
- Improve coherence between noise prediction models and vehicle type tests

- Include noise requirements in public procurement procedures for vehicles and transport infrastructure
- Enhance EU financial incentives and increase noise charges.

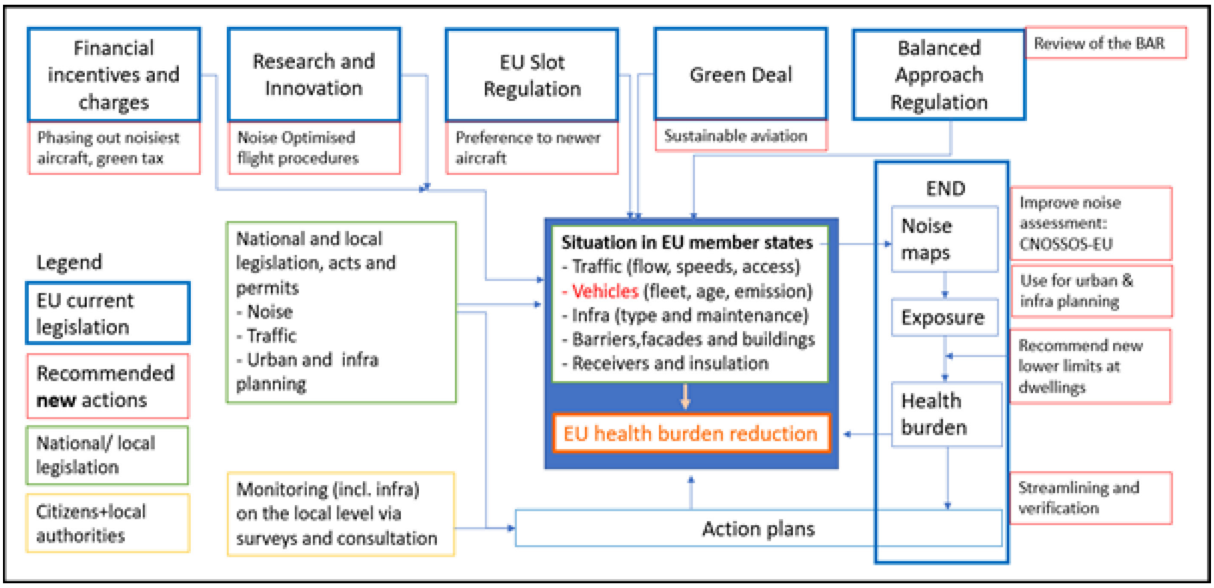

Figure 3: Policy options for aircraft noise: EU and national, local, citizen-based, and recommended new EU actions (in red).

Children's learning

3.30 Clark et al published a meta-analysis of the association between aircraft noise at school on children's reading comprehension and psychological health. The data from three studies carried out in 106 schools near London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports (the Schools Environment and Health Study, the West London Schools Study, and the RANCH study), using the Strengths and Difficulties Questionnaire, were analysed. The authors reported that a 1 dB increase in aircraft noise exposure at school was associated with a −0.007 (95%CI −0.012 to −0.001) decrease in reading score and a 4% increase in odds of scoring well below or below average on the reading test.

3.31 The analyses also found that a 1 dB increase in aircraft noise exposure at school was associated with a 0.017 (95% CI 0.007 to –0.028) increase in hyperactivity score. No effects were observed for emotional symptoms, conduct problems or Total Difficulties Score.

Cardiovascular Mortality

3.32 Barceló et al published a paper investigating the risk of cardiovascular mortality, stroke and coronary heart mortality associated with aircraft noise in São Paulo, Brazil.

3.33 The rationale for the study was that there have been relatively few studies from low and middle-income countries. This study investigated the association between day-night average (L_{dn}) aircraft noise and the risk of death from cardiovascular disease (CVD), stroke and coronary heart disease (CHD) around São Paulo‘s Congonhas airport, during 2011–2016. The study covered an area that included 3.5 million residents living near the airport, and around 1.5 million of these were exposed to aircraft noise levels above 50 dB L_{dn}. Of these, 4% lived in areas exposed to > 65 dB L_{dn}. Data on deaths among the population aged over 20 years old occurring between 2011 and 2016 in the study area were obtained and deaths due to CVD, stroke and CHD were analysed, and covariates such as socioeconomic development, ethnicism, smoking, and noise and air pollution from road traffic, were controlled for.

3.34 The results revealed that areas exposed to the highest levels of noise (>65 dB) showed a relative risk (RR) for CVD and CHD of 1.06 (95% CI: 0.94; 1.20) and 1.11 (95% CI: 0.96; 1.27), respectively, compared to those exposed to reference noise levels (≤50 dB). The RR for stroke ranged between 1.05 (95% CI: 0.95;1.16) and 0.91 (95% CI: 0.78;1.11) for all the noise levels assessed. The authors found a statistically significant positive trend for CVD and CHD mortality risk with increasing levels of noise (p=0.043 and p=0.005, respectively). There was no significant linear trend for stroke. Risk estimates were generally higher after excluding road traffic density, which suggested that air and noise pollution from road traffic are potentially important confounders.

Chapter 4
Summary

4.1 This report has provided a summary of some of the main findings in the past six months (March 2021 – September 2021) with regards to aircraft noise and health effects. The report has focussed on research findings presented at ICBEN and Internoise 2021. Summary reports such as these are published on a six-monthly basis and continue to include all health outcomes in relation to aircraft noise exposure. The next update report will contain any relevant findings from the Euronoise Congress being held as an E-Congress in October 2021.

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